Università degli Studi di Napoli Federico II

Scuola di Dottorato in Ingegneria Industriale

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XXII Ciclo

**Titolo della Tesi**

# ENERGY PERFORMANCE OF BUILDINGS: LOW ENERGY HEATING AND COOLING IN EUROPEAN CLIMATES

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School of Doctorate in Industrial Engineering

Research Doctorate Program in Mechanical System Engineering

XXII Cycle

**Title**

ENERGY PERFORMANCE OF BUILDINGS:
LOW ENERGY HEATING AND COOLING IN EUROPEAN CLIMATES

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ENERGY PERFORMANCE OF BUILDINGS:
LOW ENERGY HEATING AND COOLING IN EUROPEAN CLIMATES

CHAPTER 3: THE ENERGY EFFICIENCY OF ITALIAN DWELLINGS: ENERGY PERFORMANCE EVALUATION AND LIGHT COST IMPROVEMENTS



CHAPTER 4: PASSIVE SOLUTIONS FOR OFFICE BUILDING SUMMER COOLING IN SEVERAL EUROPEAN CLIMATES: COMPARISON OF VARIOUS STRATEGIES AND POSSIBLE COUPLINGS

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Tesi di dottorato

**Energy Performance of Buildings:**
**low energy heating and cooling in European climates**

ABSTRACT


*"L'invenzione non può che essere il frutto di un'armoniosa fusione tra personale intuizione ed impersonale, realistica, ed inviolabile scienza". Pierluigi Nervi.*

L'emanazione della Direttiva Europea 2002/91/CE (*Energy Performance of Buildings Directive - EPBD*) ha rivitalizzato e dato nuovo impulso alle tematiche proprie dell'efficienza energetica in edilizia, obbligando, in un contesto internazionale vivacizzato dalle problematiche ambientali e legate all'approvvigionamento energetico, gli Stati membri dell'Unione verso nuovi e comuni traguardi da raggiungere relativamente alla riduzione improrogabile della domanda di energia nel settore edilizio.

L'obiettivo dell'attività di ricerca riportata in questa Tesi è consistito nello studio di misure di efficienza energetica in diversi ambiti del settore civile, con particolare riferimento all'edilizia residenziale, al settore terziario ed alle architetture adibite a musei. Gli studi di efficienza energetica hanno valutato sia gli aspetti metodologici e procedurali alla luce dei nuovi orientamenti legislativi e normativi scaturiti dalla EPBD, sia le potenzialità di miglioramento delle prestazioni di involucri edilizi ed impianti, per quanto concerne gli usi energetici dovuti ai bisogni di riscaldamento, ventilazione e climatizzazione degli edifici.

Partendo da un quadro conoscitivo delle caratteristiche tipologiche del parco immobiliare europeo, e dalle criticità del caso italiano, la ricerca riportata è stata quindi focalizzata su due aspetti principali: il primo, prettamente metodologico, ha investigato procedure di calcolo per la valutazione dell'efficienza energetica, mediante analisi della rispondenza delle nuove metodologie elaborate dal CEN (European Committee for Standardization) rispetto alle prestazioni reali; il secondo, mediante studi ed esperienze in campo, ha analizzato criticità, potenziali di miglioramento e soluzioni tecnologiche migliorative, con attenzione sia all'involucro edilizio che agli impianti tecnologici, corredando le analisi con valutazione della fattibilità tecnica ed economica degli interventi.

Le ragioni della scelta delle tipologie edilizie rispetto cui condurre gli studi (*residenze, uffici, musei*) risiedono nelle diverse condizioni costruttive, tecnologiche ed operative, che rendono estremamente interessanti, per quanto riguarda l'efficienza energetica, tali destinazioni d'uso: l'*edilizia abitativa*, irrinunciabile categoria di studio, per l'impatto quantitativo del parco

residenziale italiano, per le prestazioni energetiche mediocri, per la variabilità nelle caratteristiche termofisiche ed impiantistiche; l'*edilizia per uffici*, caratterizzata da peculiarità, relativamente all'involucro edilizio ed agli impianti, e da altre condizioni al contorno (indici di affollamento elevati, ampia presenza di superfici vetrate, carichi endogeni rilevanti) che rendono critiche le condizioni, soprattutto estive, all'interno degli ambienti, con fabbisogni energetici per il raffrescamento non sostenibili; l'*edilizia museale*, che rappresenta il luogo in cui contenuti e significati di efficienza energetica si scontrano con le condizioni operative più difficili, essendo tali architetture caratterizzate da condizioni microclimatiche richieste molto restrittive (tra cui il bilanciamento necessario del carico latente, il controllo assoluto delle escursioni temporali e spaziali di temperatura ed umidità, il funzionamento continuo degli impianti).

Le principali ricerche condotte ed i principali risultati conseguiti e riportati nella Tesi sono di seguito brevemente descritti.

*Edilizia residenziale e termofisica dell'involucro edilizio: valutazione critica dell'impatto delle nuove disposizioni legislative ed interventi per la riqualificazione energetica a basso impatto.* Le analisi sono centrate sulla valutazione tecnica delle nuove norme e leggi ad oggi in vigore, sia per quanto concerne l'efficacia delle nuove disposizioni e prescrizioni, sia relativamente alla valutazione della adeguatezza delle metodologie di calcolo semplificate previste dai comitati normatori internazionali e nazionali. I principali argomenti trattati dallo studio concernono le nuove disposizioni relative al contenimento del fabbisogno energetico in regime estivo, i valori limite previsti dal legislatore, l'efficacia della prescritta alta capacità termica delle strutture, la non attenzione alle tecniche per scaricare la massa termica e l'omissione di indicazioni, anche solo qualitative, sui trattamenti superficiali esterni (*determinanti per governare gli scambi termici radiativi che interessano l'involucro edilizio*), al fine di ridurre le richieste energetiche per riscaldamento e raffrescamento, così come i cenni a tecniche di free-cooling e la possibilità di far coesistere diverse tecnologie per la conversione energetica da fonti rinnovabili. Gli studi sono effettuati sia mediante applicazione delle procedure di calcolo previste dal CEN sia mediante gli strumenti dell'analisi energetica dinamica.

I principali risultati ottenuti evidenziano una non completa efficacia dei limiti imposti dal legislatore per quanto concerne il fabbisogno energetico degli edifici in regime estivo, essendo imposti valori massimi a tale fabbisogno differenziati solo sulla base dei gradi giorno invernali e non sulle criticità reali del clima estivo, senza inoltre considerazione del rapporto di forma S/V (superficie disperdente/volume raffrescato) proprio dell'edificio, che, in estate, incide fortemente sulle prestazioni energetiche. Un criterio alternativo, corredato da validazione numerica, è stato proposto per la valutazione del fabbisogno limite, mediante applicazione di procedure tali da contemplare sia l'esposizione delle diverse superfici disperdenti degli edifici, sia il rigore delle condizioni climatiche estive (temperature esterne e radiazione solare).

Altri studi condotti hanno investigato l'efficacia delle nuove misure volte al contenimento del fabbisogno energetico e del surriscaldamento degli ambienti in regime estivo, mostrando solo una parziale efficacia delle prescrizioni che impongono masse termiche elevate e/o trasmittanze termiche periodiche basse, per i componenti opachi degli edifici localizzati in località caratterizzate da elevata radiazione solare estiva. Infatti, tali misure, idonee alla riduzione dei picchi e allo sfasamento temporale del carico ambiente, globalmente non consentono riduzione del fabbisogno energetico in raffrescamento. Pertanto, lo studio si è concentrato su misure integrative tali da migliorare le attuali prescrizioni. In particolare, si è valutata l'efficacia di soluzioni quali interventi sulle caratteristiche radiative delle finiture esterne dei componenti dell'involucro e tecniche per scaricare la massa, con particolare riferimento alla ventilazione notturna. Gli studi dimostrano che l'attivazione della massa consente sia riduzione del fabbisogno stagionale di raffrescamento sia miglioramento delle condizioni di comfort in edifici non climatizzati.

Altri studi hanno riguardato le possibilità di riqualificazione dell'edilizia esistente, sottolineando le criticità del parco immobiliare italiano; in particolare, le analisi sono state centrate su possibili interventi di riqualificazione a basso costo. Le facciate degli edifici, con il tempo, sono interessate da fenomeni di degrado e pertanto divengono soggette a periodici rifacimenti. A tale proposito, sono state ricercate soluzioni tali da consentire, a parità di trasmittanza (*e quindi agendo solo sulle caratteristiche radiative delle superfici esposte alla radiazione solare*), le migliori prestazioni energetiche annuali. Gli studi hanno portato all'elaborazione di un indice, costruito considerando irradiazione solare estiva e gradi-giorno invernali, idoneo ad orientare la scelta, in funzione dello specifico clima, verso il trattamento superficiale esterno più opportuno. Rispetto alle medesime tipologie abitative, è stato valutato anche il potenziale in raffrescamento della ventilazione notturna, sia naturale che meccanica.

Ulteriori studi hanno riguardato altri aspetti di novità del nuovo panorama legislativo e normativo, concentrandosi in particolare sul ruolo delle superfici vetrate per quanto riguarda il bilancio energetico invernale di un edificio, e le possibilità di integrazione contemporanea sia di energia termica che elettrica da fonti rinnovabili nell'edilizia abitativa. Dagli studi è emerso che, con riferimento al primo aspetto, la possibilità offerta dal legislatore di omettere il calcolo dell'$EP_i$ (indice di prestazione energetica riferito alla stagione invernale), in presenza di un ridotto rapporto superficie vetrata/superficie utile, svilisce il ruolo di una buona progettazione, essendo le vetrate, qualora ben concepite, non elemento di debolezza dell'involucro. Per quanto riguarda l'obbligatoria adozione di fonti rinnovabili, la nuova edilizia intensiva rende impossibile il rispetto di tutte le prescrizioni, non presentando superfici libere in misura tale da offrire spazio sufficiente. L'unica soluzione, pertanto, consiste nella completa integrazione architettonica.

*Passive cooling nell'edilizia per uffici. Efficacia delle nuove prescrizioni e analisi del potenziale di risparmio ottenibile mediante tecniche passive.* Il settore terziario presenta richieste energetiche specifiche, per quanto concerne gli usi energetici obbligati (riscaldamento, illuminazione e, soprattutto, climatizzazione), non sostenibili. L'usuale presenza di ampie vetrate, gli alti carichi endogeni dovuti alla presenza di potenze elettriche installate e gli elevati livelli di occupazione rendono particolarmente onerosa la domanda di energia soprattutto in regime estivo. Le peculiarità dell'edilizia per uffici rendono necessarie soluzioni e approcci progettuali diversi da quelli adottati per l'edilizia residenziale. Pertanto, una parte considerevole degli studi condotti durante il triennio di dottorato (*in collaborazione anche con l'istituto FBTA dell'Università di Karlsurhe*) è stata indirizzata, con riferimento a diverse situazioni climatiche, alla valutazione del potenziale di varie tecniche per il raffrescamento passivo.

Il passive cooling, se ben concepito, rappresenta un modo per ridurre, con contenuti costi economici ed ambientali, i fabbisogni energetici per la climatizzazione estiva. Le tecniche di passive cooling analizzate sono l'isolamento mobile di tetti o pareti (*per favorire, nelle ore diurne, protezione dalla radiazione solare e, di notte, il raffrescamento delle strutture per irraggiamento*), l'utilizzo di scambiatori interrati per il raffrescamento dell'aria di ventilazione, la ventilazione meccanica controllata notturna. Ad una prima analisi, volta ad identificare (con riferimento a specifiche zone termiche degli edifici e per diverse regioni climatiche) le migliori soluzioni adottabili, è seguito un secondo studio orientato all'ottimizzazione delle prestazioni energetiche dell'edificio mediante accoppiamento delle migliori tecniche individuate. Nei climi dell'Europa mediterranea, le diverse strategie di passive cooling hanno mostrato potenziali importanti di riduzione del carico termico, significativamente ridotto ma non annullato. Nei climi dell'Europa centrale e settentrionale, invece, il raffrescamento passivo ha consentito condizioni di comfort termico (*senza impianto attivo di climatizzazione*) soddisfacenti, secondo i criteri di benessere adattativo in edifici non climatizzati.

Tra le soluzioni per il raffrescamento passivo, ulteriore approfondimento ha riguardato gli scambiatori interrati terra aria, questa volta rispetto a diversi climi italiani. Mediante simulazioni energetiche dinamiche sono state variate le principali caratteristiche di tali scambiatori, con analisi parametriche relative alle tipologie di terreno, ai parametri costruttivi, al tipo di moto dell'aria, alle strategie di ventilazione meccanica adottate, al tipo di controllo. L'energia richiesta dai ventilatori è nodo "chiave" della progettazione, richiedendo un accurato dimensionamento del sistema al fine di ottenere il massimo scambio termico controllando le perdite di carico. I risultati migliori, in termini di recupero geotermico, sono ottenuti in presenza di terra umida; il materiale che costituisce il tubo (calcestruzzo, metallo o PVC), invece, non determina significative variazioni sulle prestazioni ottenibili. Per quanto concerne la lunghezza dei tubi, oltre i 50 metri, i benefici ottenibili, in termini di recupero termico, non giustificano i maggiori costi dell'impianto e la maggiore potenza elettrica assorbita dai ventilatori. La profondità di posa in opera del tubo, al contrario, è molto influente (*ma bisogna valutare i costi dei movimenti di terra*); velocità basse dell'aria sono migliori, perché, a parità di portata, si riducono le perdite di carico e aumenta la superficie di scambio; in estate, incrementare le portate determina un aumento del potenziale di raffrescamento, mentre in inverno conviene ridurre al minimo necessario la ventilazione. Nonostante COP molto elevati del sistema, le analisi economiche denunciano la necessità di una rigorosa progettazione, al fine di ridurre i costi iniziali, soprattutto quelli legati a movimenti di terra e costo dei canali interrati.

*Edilizia museale: prestazioni energetiche e termoigrometriche di soluzioni impiantistiche innovative.* In ambiente museale, l'efficienza energetica deve essere necessariamente abbinata ad un rigorosissimo controllo microclimatico: la stabilità spaziale e temporale dei valori assunti dai parametri microclimatici è necessaria innanzitutto per la conservazione delle opere custodite ed, in secondo luogo, per il comfort termoigrometrico degli occupanti. Negli studi condotti, l'integrazione di analisi energetiche dinamiche e di analisi di fluidodinamica computazionale ha reso possibile previsioni accurate in merito all'efficacia di numerose soluzioni impiantistiche, consentendo di conoscere la capacità di controllo microclimatico da parte degli impianti di climatizzazione, la loro prestazione in termini di richiesta energetica, i fenomeni che investono l'ambiente confinato, evidenziando campi di moto e velocità dell'aria, distribuzioni di temperatura ed umidità. Gli studi condotti hanno considerato molteplici tipologiche sale espositive, poste in diverse condizioni climatiche. La necessità di ridurre il tempo di ripristino delle condizioni di progetto, al variare impulsivo dei carichi, ha spinto verso lo studio di impianti di climatizzazione a tutt'aria, dotati di componenti innovativi. Il recupero di calore totale dall'aria esausta, mediante scambiatori entalpici, si è dimostrato molto efficace in ogni regione climatica italiana, non solo sotto il profilo dei costi, ma anche per quanto concerne la limitazione dei transitori termici ed igrometrici. La deumidificazione per adsorbimento, mediante modulo essiccante costituito da ruota, recuperatore sensibile e raffreddatore evaporativo sull'aria di rigenerazione, è risultata estremamente funzionale in presenza di elevati carichi latenti estivi, con una notevole riduzione dei costi di esercizio ed un migliore controllo del grado igrometrico. Laddove le esigenze di contenimento dei costi operativi risultano essere prioritarie rispetto alla stabilità delle condizioni microclimatiche, una buona soluzione è rappresentata dagli impianti a portata d'aria esterna variabile o da quelli dotati di sistemi economizzatori a controllo entalpico (*free-cooling*) che però, a fronte di utili risparmi, causano un lieve peggioramento delle prestazioni dell'impianto in termini di controllo.

Per quanto riguarda la diffusione dell'aria in ambiente, analisi CFD sono state effettuate per evidenziare le migliori soluzioni adottabili in tipiche sale museali. I terminali che garantiscono prestazioni mediamente migliori sono i diffusori ad alta induzione (elicoidali a soffitto), nettamente superiori agli altri per quanto concerne il controllo dell'umidità relativa; buone risultano anche le prestazioni ottenibili tramite l'utilizzo di diffusori lineari a soffitto disposti in fasce perimetrali (attraverso cui si ha una capillare diffusione dell'aria climatizzata nelle diverse zone della sala espositiva), e quelle ottenibili ben progettando, in numero e posizione, gli ugelli a lunga gittata in sale espositive caratterizzate da elevate altezze interne. Meno efficaci risultano i diffusori circolari a soffitto e le bocchette a parete, indipendentemente da numero e collocazione.

Durante il periodo trascorso presso l'Università di Karlsruhe, le analisi teoriche sviluppate in Italia sono state accompagnate dallo studio dei progetti, dei monitoraggi, nonché con sopralluoghi tecnici al Museo Ritter di Waldenbuch (Stoccarda). Lo studio di tale architettura, all'avanguardia per quanto concerne termofisica dell'involucro, installazioni tecnologiche ed utilizzo di energie rinnovabili, ha dato nuovi spunti alla ricerca condotta in Italia, stimolando nuovi studi orientati all'ottimizzazione di interrelazione e comunicazione tra diversi impianti e dispositivi energetici.

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*In sintesi, la scelta delle diverse destinazioni rispetto cui condurre gli studi ha consentito di concentrare l'attenzione su problematiche diverse tra loro ma tipiche del costruito italiano, dove, oltre alle naturali funzioni residenziali e del terziario, il patrimonio storico-museale assume impatti qualitativi e quantitativi considerevoli.*

*Ancora, tali differenti ambiti di analisi hanno affrontato i tre principali nodi attraverso cui passa l'efficienza energetica in architettura: l'involucro edilizio (studi sulla termofisica), contestualizzazione e sfruttamento delle risorse ambientali (passive cooling), adozione di idonee tecnologie per il controllo microclimatico (efficienza degli impianti di climatizzazione).*

## PREFACE: STRUCTURE, METHODOLOGY AND PURPOSES OF THE RESEARCH

The emanation of the European Directive 2002/91/EC (*Energy Performance of Buildings Directive - EPBD),* during the 2002, gave new impulses to the topic of the energy efficiency regarding the building sector. In particular, the EU member States have been oriented towards new and common sustainability concepts, within an international context revitalized by the world questions related to energy supply and climatic changes.

The EPBD, that had to be implemented by the end of 2006 in all the national legislations of the member States, is focused on few main topics:

1. identification of a common methodology for calculating the integrated energy performance of buildings;
2. individuation of minimum standards on the energy performance of new buildings and existing ones that are subject to major renovation;
3. study of methodologies for the energy certification of new and existing buildings and, for public buildings, evident display of this certification and other relevant information.
4. prescription of regular inspections of boilers and centralized air-conditioning systems in buildings and, in addition, an assessment of heating installations in which the boilers are more than 15 years old.

These points, connected to the thermal behaviour of a building and to the technological systems and plants here installed, establish the guide-lines for the EPBD transposition into the various national legislations. Today (*Autumn 2009*), the building sector still requires the greater part of the overall energy consumption throughout the European Union, demanding approximately the 40% of the global energy requests, and absorbing more sources than the energy consumptions demanded by the industry and the transport sectors.

Although different measures for the improvement of the energy quality of the buildings have been established already beginning from the half of 70's (*as a result of the energy crisis related to Kippur war*), and these were modernized several times until the 2002, the energy demand of the building sector (above all tertiary and residential uses) remains very high. This because, mainly until the Directive 2002/91/EC, all the legislative dispositions, in the various EU member countries, consisted in prescriptions related only to the new constructions, not considering, therefore, the energy demands of the existing buildings. The attention to the energy performances of the existing buildings, on the other hand, just represents one of the higher interesting points of the new European indications, above all considering the very reduced building turn-over rate, that varies, according to the different ratios of urban density all around the Europe, between the 1% and 3% annually. Thus, new energy legislations, even if quite restrictive and rigorous, would have no significant effects in the short and medium periods, if referred only to the new architectures.

Well knowing these aspects, the European Commission and Parliament established, in the EPBD, a prominent role assumed by the energy renovation of the existing buildings, so that the single national transpositions have to receipt mandatory prescriptions regarding the energy refurbishments of the existing buildings, when interested by large renovations or enlargements.

Moreover, the energy refurbishments, when not mandatory, however have to be promoted, by means of legislative acts and funding programs containing various financial supports (*e.g. tax deductions or economical loans*).

Today, the European building stock is represented by about 35’000’000 square meters of built surface, and the greater part of this (*more than the 80%)* has been realized before the 1975 (*when the first and low effective prescriptions regarding the building energy question were emanated*). Furthermore, less than the 18% of the European building stock has been realized after the 1990.

These data explain the high-energy consumption of the European architectures. Around the 60% of the European buildings are residential ones, meanly characterized by an annual energy request of 1.65 toe/dwelling, and it means an energy request equal to around 190 kWh/m$^2$ year in terms of primary energy.

Despite favourable climatic conditions, the Italian dwellings require energy demands very similar to these mean values, with a primary energy need around 180 kWh/m$^2$ year. Still today, despite a significant diffusion of split-systems for the indoor temperature control during the summer, the higher energy use characterizing the Italian building stock is represented by the indoor environment heating in wintertime, with an energy demand of about the 70% of the total request. Thus, immediately the scarce results and applications of the previous energy laws can be evaluated, and this depends by several reasons, among which the low national attention and culture towards the energy and environmental building sustainability.

The Italian situation can be easily described by means of the following data: meanly the Italian buildings, realized during the last 40 years, are characterized by around 5 cm of thermal insulation layers inside the building envelope. This thickness is around 15 cm in the central Europe countries and higher than 25 with reference to the Scandinavian nations. This explains, in spite of a favourable climate, the enormous winter thermal dispersions of an Italian flat.

The winter energy performances of the Italian real estate clarify a poor energy quality with reference to both the building envelope thermal insulation and the heating system efficiencies. As regards the summer season, the energy performances are, at the same way, quite unsatisfactory, determining high environmental indoor overheating and not sustainable energy consumption for the space cooling with reference to the buildings provided with air-conditioning systems. In particular, as consequence of the large diffusion of low-cost technologies, during the last 10 years around 20 millions of air-conditioners have been installed into the 27’000’000 of Italian dwellings, determining criticalities related to the seasonal energy requests, the urban heat island and the peak demand of electric energy during the summer.

In fact, starting by the 2005, the electric energy peak demand, in summertime, is constantly higher than the winter value, with a demanded peak power in July higher than 56’000 MW (*winter peaks around 53’000 MW*). The used electric energy is converted from fossil fuels (68%), renewable sources (17%) or imported (15%). These data underline that the main energy sources are, still today, the traditional fuels.

Also considering the whole Italian energy need, the situation is quite critical, being this nation strongly dependent by the foreign energy supply (*around 85% of the whole energy need*): 82% with reference to solid fuels, 86% for the natural gas need, 93% as regards the oil.

Moreover, the great foreign dependence determines a loss of the Italian competitiveness, due to the higher cost of the energy (*that influences the costs of the Italian industry and manufactures*) and also induces risks related to the often-faltering provisions.

About this last point, the frequent diplomatic crises between Russia and Ukraine submit the whole Europe and, first of all, the Italy, to serious risk regarding the provisions of natural gas. The great development and the high request of oil in China, India, Russia and Middle East (*that require around the 85% of the increase of the demand*) determined a further cause of risk for the European provisions. Furthermore, the perennial political instability in Middle East, the precarious extraction in the delta of the Niger, the Iraqi conflict and the Iranian tensions, as well as the worldwide economical crisis of the last months, do very unstable the oil prices, so that it fluctuated very strongly during the last ten years.

Even if the above reported description is quite brief, it emerges clearly the frailty of the Italian situation, so that a necessary change of culture, as regards the energy efficiency, today cannot be postponed. In particular, as regards the building sector, not only new and restrictive laws are necessary but, above all, their application has to be strongly controlled. About this, the present problems of the Italian building stock do not depend by the absence, in the past, of legislative instruments apt to guarantee fair energy performances; contrariwise, the main reason consists in the lacked application of these prescriptions during the last 30 years.

Since the 1976, in Italy, the building envelope thermal insulation is mandatory; anyway, still today, it is very common and quite typical finding residential buildings, under construction, without any layer of insulating materials.

After the emanation of the European Directive 2002/91, the European Commission has formally assigned to the CEN (European Committee for Standardization) the elaboration of a technical standard set, in order to render homogenous, in all the member countries of the Union, methodologies, parameters of study and procedures of calculation related to the building energy audits. This full package (*approximately 40 standards, presently quite complete and published*) results rather complete. As regards the international situation, currently the EPBD transposition into the several national legislations is characterized by different levels of applications. With reference to the present 27 member States, even if it was mandatory a full transposition within the 2006, today only few countries have fully received the European guidelines (*e.g. Netherland, Austria and Germany*), while many others are still during the initial national adjustment phase (*Greece and Cyprus*).

In Italy, the EPBD transposition started during the 2005 (*Legislative Decree 192/2005*). Despite this, a complete transfer and application of the European guidelines have been quite ready only during the 2009 summer, with the emanation of the Presidential Decree 59/2009 and the National Guidelines for the Building Energy Certification (Ministerial Decree 26.06.2009). The main innovations, introduced into the new Italian legislative frame, concern the winter energy performances, the domestic warm water production, the energy request for the summer environmental cooling and the mandatory use of renewable energy sources in buildings.

As regards the “winter” verifications, the new Italian legal frame strongly changed the prescriptions contained in the Law 10/91. In particular, the main indicator, with reference to the energy performance related to the winter space heating, consists in the evaluation of the annual primary energy consumption necessary to guarantee the heating of a unitary floor surface or a unitary indoor volume (*EPi index*). The EPi has to result lower than a limit value calculated considering the specific climatic conditions (*correcting the admitted limit values depending on the winter degrees-day of the building location)* and interpolating the values also considering the building *surface-to-volume* ratio). The verification of the EPi index is mandatory for the new constructions and for the significant renovations, while different prescriptions involve other types of minor renovations (*e.g. evaluation of the building envelope thermal transmittances or calculation of the energy efficiency ratio of the heating systems*).

On the other hand, with reference to the summer performances, the Italian national frame is not yet well-defined, lacking technical standards apt to the evaluation of the cooling system energy efficiency ratios, so that the present limitations regard only the thermal (cooling) needs of the building, considering an indoor thermal level of 26 °C.

Other prescriptions, with reference to the summer energy needs, concern the thermal mass and the periodic thermal transmittance of the building envelope opaque structures, the mandatory use of windows shadings, the maximum values of the transparent surface solar transmission factor, a rational use of natural ventilation. Globally, the set of prescriptions is quite complicated, lacking a harmonic approach and well-defined measures and indicators that have to be verified.

Also the National Guidelines for the Building Energy Certification provide clear methodologies to classify the building performances, adopting a graduate scale ranging from A+ (*optimal energy characteristics*) to G (*very poor performances*), only with reference to the winter heating energy need and to the domestic hot water production. On the other hand, as regards the summer energy performances, the criteria are much less understandable and unambiguous, being based on several alternative indicators, such as the thermal cooling need of the building ($EP_{e,invol}$), the attenuation factor of the thermal wave ($f_a$), or on the time lag of the peak cooling load (S).

Other prescriptions, enacted during the last four years, regard the mandatory installation of systems for the energy conversion by renewable sources. In particular, the new legislative measures impose the installation of solar system for the domestic hot water production (*sized in order to achieve, at least, an integration of the 50% with respect to the overall need*) and for the electric conversion by means of photovoltaic plants (*establishing a mandatory installation at least equal to 1 $kW_p$/flat*).

Presently, despite 5 legal acts have been emanated during the last four years (*i.e. the Legislative Decrees 192/2005, 311/2006, 115/2008, the Presidential Decree 59/2009 and the Ministerial Decree 26.06.2009*), the Italian National frame about a full transposition of the EPBD is not yet fully operating. In particular, the main lacks regard several other energy uses, among which the primary energy need for the summer cooling and the artificial lighting requests.

Starting by the above described frame, regarding the present European and Italian contexts, both as regards the EPBD transposition and the present conditions of the building stock, this Thesis has been focused on two main aspects. The first one, decidedly methodological, analysed methods and calculation procedures for the building energy audit. The second one, by means of studies and direct experiences, evaluated peculiarities, criticalities, possible energy effective actions, innovative technological solutions in order to improve the building energy performances, with reference to both the building envelope thermal physical behaviours and parameters, and as regards the installed active energy systems.

The studies regarded both the new architectures and the existing ones, being centred on tree different kinds of buildings: dwellings, offices and museums.

The reason of such choice derives from the very different and interesting peculiarities characterizing each one of the above-cited applications.

The first one, the residential buildings, represents the main topic for all the technicians involved in the energy efficiency sector, above all because of the great quantitative impact (*in Italy, with reference to an overall real estate constituted by around 60'000'000 buildings, more than 27'000'000 are dwellings, according to the National Territory Agency*). Moreover, the distribution of the dwellings on the territory, the ages of construction, the high variability in the geometrical, constructive and thermal-physical properties, as well as the different installed heating systems do very significant the study about this kind of building use, being very variable the achievable level of energy efficiency.

On the other hand, the specific boundary conditions of the office buildings (*high crowding, significant heat gains, elevated installed electric devices, high presence of glazed surfaces*) make very critical, above all in summertime, the indoor temperatures and the energy requests, respectively with reference to naturally ventilated and full air-conditioned buildings. Thus, also a specific research regarding the tertiary sector has been considered interesting.

Finally, the buildings dedicated to the storage and to the fruition of the cultural Heritage. As regards this last application, Museum, Libraries and Archives, probably, are the places where all the critical aspects regarding the building energy efficiency are verified. First of all, the running of the heating, ventilating and cooling systems is quite critical, being necessary a continuous work (*24h/day with reference to the whole year*). Then, the strict control necessary for the artwork conservations, as regards the indoor thermal level (*without the seasonal variations admitted, for example, for other building typologies*), and a strict management of the relative humidity make the museum air-conditioning the hardest challenge, under the energy consumption point of view, for all the involved designers.

In particular, the rigours control of the latent loads, above all in summertime, requires energy needs very elevated, principally when the dehumidification is obtained cooling the external air below the dew point. This very common air handling requires a summer post-heating process, that represents an irrational energy use. Furthermore, also the kind of solutions adoptable for the museums are often quite limited, being frequently a lot of limitations determined by the artistic or historical values of the building hosting the exhibition spaces. About this, several researches testify that the greatest share of the Italian Museums is located in ancient architectures, so that the same buildings are cultural Goods that should be preserved.

In this Thesis, considering a legislative and procedural frame greatly changed during the last few years, the understanding of methodologies, calculation procedures and the validation of the imposed criteria has been considered necessary, requiring a deep study oriented to the verification of the goodness of the new calculation tools. About this, the evaluation of errors and approximations deriving from the adoption of simplified calculation methods represented the first step of the research. This aspect has been considered very significant; in fact, starting by the 2006, the building energy efficiency interested, considering the whole Europe, an enormous number of researches, constructors and designers, so that the identification of simple methodologies became necessary in order to determine an easy application of the new regulations. Of course, simple methodologies mean also significant approximations, so that, in this context, the gap between the procedures identified by standards and legal acts, compared to the real building energy performances, has been investigated. From this notation two different considerations derives: on one hand, it would not be useful the definition of too complex methodologies, that cannot be correctly applied by a number of professionals so large. Therefore, the development of simple methodologies and easy energy evaluation procedures is necessary in order to diffuse, as much as possible, a new culture of energy efficiency. From the other hand, the reliability of the simplified calculation methodologies must be satisfactory, being the real effectiveness of the legislative instruments (*enacted for the improvement of the energy use*) strongly related to reliable modelling and correct interpretations. Wrong methods of analysis would give false output. The notation, also banal, is not so obvious. For example, the present Italian legislation imposes that the energy performances reported by the building energy certificates should be evaluated considering a continuous (*24h/day*) use of the heating systems during the winter. This boundary condition, obviously only conventional, is quite false, even if, considering the purposes of an energy certificate, can be acceptable, being the energy certificate useful to compare the performance of different buildings (*calculated under the same boundary conditions*). Therefore, the perennial use of the heating systems is only an assigned boundary condition, not so dangerous because this is the same for all the buildings. On the other hand, the recent legislative instruments establish that the energy certifiers should suggest also improving actions, and, if based on an energy audit based on a continuous temperature control, these become very unreal, in particular determining payback periods, for possible improving solutions, much shorter than the real ones.

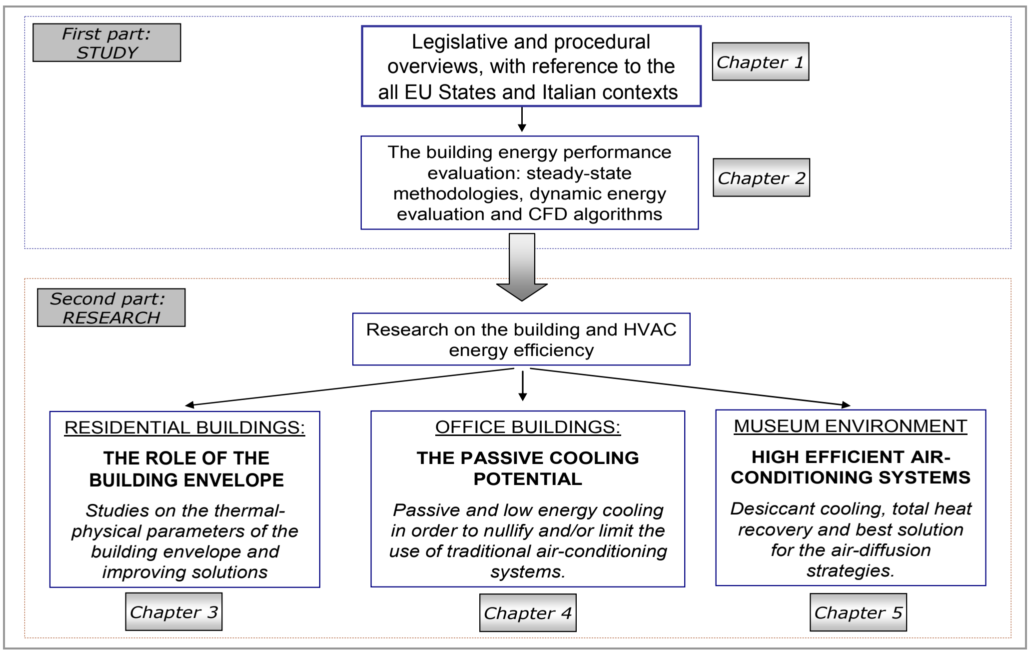
Among the EN standards developed by the CEN, the EN 1379/2008 "*Energy performance of buildings - Calculation of energy use for space heating and cooling*" has been deeply analysed, being the main technical document useful to evaluate the building energy performances. At the same way, the Italian UNI TS 11300 "*Energy performance of buildings"* Part 1 *"Evaluation of energy need for space heating and cooling*" and part 2 "*Evaluation of primary energy need and of the system efficiencies for space heating and domestic hot water production*" have been described and commented. In the same section of the study, the more complex calculation methods, based on dynamic energy simulators and computational fluid-dynamic tools, have been also presented and examined.

In the second part of the Thesis, several studies, with reference to the building typologies before cited (*dwellings, offices and museums*) have been carried out adopting complex numerical investigation methods, in order to identify the critical aspects of these applications and to suggest possible technical improvements.

The dynamic energy simulations BEPS induced reliable diagnoses of the building energy performances, both with reference to the building envelope and to the heating, ventilating and air-conditioning system efficiencies. In particular, these energy analyses, based on hourly climatic data, determined the evaluation of the annual thermal energy need of the building and the energy consumptions due to the active system inefficiencies, dynamically evaluating also the microclimatic conditions inside the indoor environment. About the behaviours and boundary conditions of the buildings, these have been accurately modelled, properly considering each parameter influencing the overall energy balance (*e.g. indoor crowding, endogenous loads and solar gains*). The studies investigated the incidence of both the building envelope (*composition of the structures, thermal insulation quality, thermal capacity and dynamic thermal-physical parameters*) and the installed HVAC systems (*radiators, fan-coil or constant air volume systems*), making possible comparisons among different technologies and solutions. The numerous obtained indications concurred to identify solutions apt to improve the energy performances.

When necessary, also another kind of numerical investigation has been carried out, in order to provide more reliable predictions. In fact, the calculation of temperature and relative humidity, such as obtained with the dynamic energy simulation, is based on the hypothesis of perfect mixing ventilation. This approach can be accepted where the thermal-hygrometric spatial excursions are not so relevant, for example in buildings characterized by usual inner heights (*dwellings and offices*). On the other hand, whereas the indoor spaces are characterized by high indoor dimensions (*e.g.. exhibition rooms or libraries*), the significant spatial thermal and hygrometric gradients require also another numerical analysis, by means of CFD studies, in order to understand and define the real thermal, hygrometric and kinetic fields interesting the indoor environment. For example, with reference to the museum applications, the spatial lack of uniformity of the microclimatic conditions should be strongly contained, in order to avoid degradation processes of the artworks. Therefore, as regards this kind of building use, also systematic CFD studies have been carried out, in order to evaluate the indoor microclimatic parameter value distributions.

In the following pages, all the studies have been reported in detail, while, in the last section of the paper, the main inferred conclusions have been summarized.




*Layout of the Thesis*

# Chapter 1:

# Energy Efficiency in the building sector: European and Italian overviews

## 1.1 ENERGY PERFORMANCES OF THE EUROPEAN BUILDING STOCK

### 1.1.1 INTRODUCTION

With reference to the European Union until the 2004, and so considering the so-called EU-15 (*Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, United Kingdom*), the building sector requires around the 40% of the total energy consumption. In particular, the residential sector demands around the 26% of the overall energy uses, and the service buildings the remaining 14%.

The 70% of the total building stock consists in residential architectures and the big part of these is represented by single-family houses (≈ 60%). The remaining 30% is represented by non-residential buildings (such as office buildings, shopping centers, industrial parks, churches, or hotels) and, about these, the 75% presents a surface higher than 1000 $m^2$. In figure 1.1.1, the composition of the European building Stock is represented[1] and, in Table I.1, it is characterized also depending on the construction period.

Although several energy savings measures have been enacted starting by the 1970's energy crisis, today the building sector remains the main responsible of the overall European energy consumptions and, above all, this is the sector that shows the higher potential as regards the energy use improvements.

Presently, the gap between the greenhouse gas emissions and the energy consumption, compared to the targets of the Kyoto protocol, is large, requiring strong actions toward a sustainable development of all the European Community member States. This becomes necessary in order to reduce drastically the energy demands and the related environmental pollution without determining loss of competitiveness and, at the same time, improving the air quality, limiting phenomena such as the urban heat islands, assuring also security as regards the energy supply.

During the 2002, the European Parliament and Commission enacted the European Directive on Energy Performance of Buildings (EPBD), 2002/91/EC [1], aimed to purpose Guidelines to be receipt into the member States, in order to spread new energy efficiency trends as regards the building sector. Together with analogues measures enacted to provide a long-term climate protection, the EPBD purposes, as in the following described, a new concept of building energy efficiency, establishing, for the first time in the European energy efficiency tradition, a great attention also toward the building energy oriented refurbishments.

Today the EU-15 States present around 20'000 millions of $m^2$ of living surface, characterized by a very low turnover rate. Until the EPBD, the energy efficiency prescriptions of the single States, as regards the building sector, have been focused on energy efficiency

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[1] *According to Ecofys III, the following order has been considered: cold climates: Finland and Sweden; moderate climates: Austria, Germany, Belgium, Ireland, Denmark, Luxemburg, France, Netherlands, UK; warm climates: Greece, Italy, Portugal, Spain. The classification has been realized adopting the following criteria: mean national value < 1800 degrees-day → warm; > 1800 and < 3000 degrees-day → moderate; >3000 → cold.*

precautions mandatory only for new constructions. Considering a change rate variable between 1 – 3%, it becomes quite clear that useful improvements cannot be achieved without a strong action on the existing building energy refurbishment.

The necessity of a new development model, based on energy and environmental sustainability by means of effective actions on the building related energy uses, is underlined by several authoritative studies. Petersdorff *et al.* [2] evaluate how much the application of the measures, included in the EPBD, can induce significant environmental advantages. For example, about the $CO_{2\text{-EQUIVALENT}}$ emissions, appling energy efficient concepts to new buildings and to the refurbishments of large architectures, around 34 Mt/year starting by 2010 can be saved, while, extending the energy efficiency measures to the whole building stock, the achievable benefits consist in emission reductions two times higher.

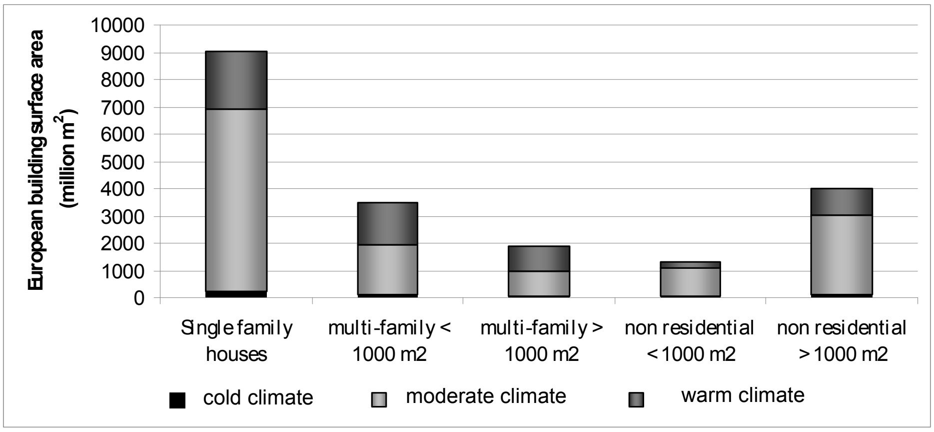


*Figure 1.1.1 – Division, for use and dimensions, of the EU-15 building stock (millions of m²).*

Table I.1: characterization of the European building stock

| | Building age | Total | Single family house | Apartment house <1000m² | Apartment house >1000m² | Small non-residential buildings <1000m² | Non-residential buildings >1000m² |
|---|---|---|---|---|---|---|---|
| | Year | [Million m²] | [Million m²] | [Million m²] | [Million m²] | [Million m²] | [Million m²] |
| Cold | < 1975 | 534 | 220 | 109 | 59 | 55 | 92 |
| climatic | 1975-1990 | 154 | 63 | 31 | 17 | 16 | 27 |
| zone | 1991-2002 | 120 | 31 | 26 | 14 | 18 | 30 |
| Moderate | < 1975 | 9,145 | 4,607 | 1,242 | 669 | 780 | 1,848 |
| climatic | 1975-1990 | 2,551 | 1,290 | 348 | 187 | 216 | 511 |
| zone | 1991-2002 | 1,708 | 670 | 181 | 97 | 226 | 535 |
| Warm | < 1975 | 3,116 | 1,197 | 769 | 414 | 319 | 416 |
| climatic | 1975-1990 | 1,945 | 748 | 480 | 259 | 199 | 259 |
| zone | 1991-2002 | 1,175 | 399 | 256 | 138 | 166 | 216 |

At the same time, the energy efficiency actions should become cost-effectiveness, in order to promote the energy improvements even when not mandatory. In this direction, as it will be shown in the followings of this study, many European Governments promoted, in the last years, funding programs (*e.g. financing support and fiscal benefits*) in order to spread the energy oriented retrofits.

As regards the energy efficiency in the building sector, three main actions are necessary:

- reduction of the useless energy losses, due to not apt thermal insulation levels and irrational use of active energy appliances;
- spread of renewable energy sources as regards the civil buildings;
- adoption of best practices and high efficient technologies with reference to the use of fossil fuels.

Moreover, a climate protection, by means of well-designed passive techniques, as regards the reduction of the heat losses through the building envelope or the solar protection in summertime, represents a pre-requisite for an energy sustainable building activity, with reference to both the existing buildings and the new constructions.

The European Performance of Building Directive EPBD imposes four main Guidelines that have to be integrated in the national energy legislations:

- development of a standardized calculation method in order to provide the calculation of the overall building energy performances;
- definition of minimum values of energy efficiency performances, based on this common calculation methodology;
- mandatory adoption of the energy certificate for new and existing buildings, in order to spread a building energy efficiency culture;
- definition of mandatory, regular and programmed inspections for heating systems and large energy active appliances (*e.g. the environmental air-conditioners*).

A full application of the EPBD prescriptions and targets, with reference to new and large buildings, requires significant economical investments, around 10 billions Euros starting by the 2006 [2]; the cited date represents the deadline of the mandatory transposition of the European Directive into the single national legislation.

Appling the EPBD measures also to the existing building renovations would require approximately an annual cost around 25 billions Euros. Anyway, it is quite accepted that the energy savings achievable would make profitable these investments, determining, globally, net annual cost reductions for the national economic systems, in terms of energy savings, pollution containments and social health and security.

Comparing annual costs and savings achievable adopting the EPBD energy reduction measures for large buildings (*so converting the investments into annual capital expenditures),* the induced net economic saving would be around 4 billions euro starting by 2010 (figure 1.1.2). This value could result two times higher (*8 billions euro*), if the EPBD application would be extended to all the new dwellings. In the Ecofys [2] computation, the economies of scale, deriving from an extended culture of efficiency building technologies, are considered too.

Furthermore, other benefits would regard the employment sector, being estimated around 30'000 – 50'000 new job possibilities, in the building energy efficiency sector, considering the whole European market.

In figure 1.1.1, the European building composition has been represented. Even if the greater specific energy consumptions are related to commercial buildings and to the non-residential sector, it is quite evident that, because of the large amount of small building represented by the single-family houses, the role played by the domestic energy efficiency represents a key aspect of the problem. Therefore, although the large family houses and, above all, the institutional buildings have a fundamental demonstration role, an effective energy policy cannot neglect the single family dwellings.

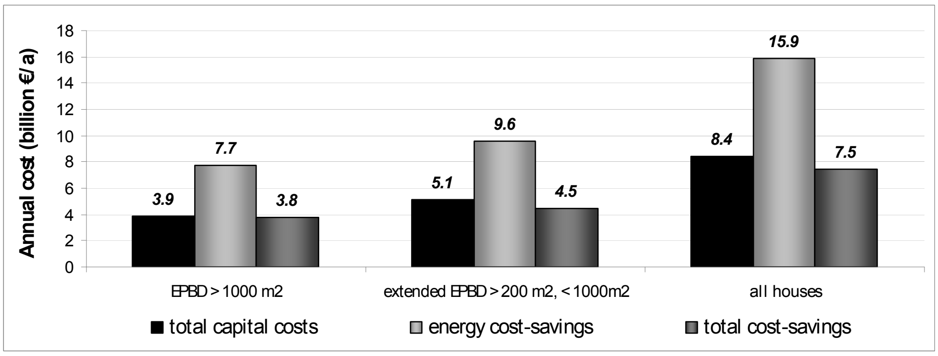


*Figure 1.1.2 – Cost Analysis (2010) of EPBD Directive effects – new buildings*

Starting by the Kyoto protocol (1997), the EU member States established a reduction, as regards the greenhouse gas emissions, around 8% in the period 2008-2012 compared to the 1990 levels. Moreover, targets that are even more ambitious have been subscribed during the 2002 at the Sixth Environmental Action Program (6-EAP) [3], when the European States established a stabilization of emission at levels that will not cause dangerous variations of the earth's climate.

In the last recent years, the European Parliament and Council enacted the Directive 2003/87/EC, "*establishing a scheme for greenhouse gas emission allowance trading within the Community and amending Council Directive 96/61/EC*". This Directive, presently, limits the balances only as regards the $CO_{2\text{-EQUIVALENT}}$ emissions, introducing a system of exchange and regulation of greenhouse gas pollutions (i.e. the European Union Greenhouse Gas Emission Trading System, briefly EU ETS) in European Union countries. In particular, starting by the January 2005, the managements of the industry-involved sectors have to record and report their emissions to the National Responsible; about this, the European Commission has issued Guidelines that set out the methods of calculation, coefficients and principles of monitoring and reporting. The European Directive 2003/87 establishes a balance between cap and trade of emissions; in a first period, only the $CO_{2\text{-EQUIVALENT}}$ emission have been considered, while, in a second phase, all six greenhouse gases must be recorded, matching the Directive purposes to the Kyoto targets. The attention of the 2003/87/EC is focused on the on big industrial emitters, imposing a compliance system based on penalties and credits. The European institutions provided Guidelines for the third part verifications. As regards the calculation of greenhouse gases, such as established by the subscription of the Kyoto Protocol, the ISO established a working group for the emanation of specific standards.

Regularly, the EEA (*European Environment Agency*) publishes technical reports on the application of the Emissions Trading Directive by Member States.

In the same direction toward a low polluting European future, on 23 January 2008 the European Commission presented a set of proposals to fight the climate changes and to propose a future development, up to 2020 and beyond, for the member countries, based on low-impact concepts. The so-called 20-20-20 target considers the overall energy uses and the polluting emissions, proposing, within 2020:

- 20 percent reduction in GHG - greenhouse gas - emissions compared to the 1990 levels;
- 20 percent reduction in the overall energy demand, improving the energy efficiency in several sectors;
- 20 percent increase as regards adoption and use of renewable energy sources.

The 20-20-20 package involves many aspects of energy uses and polluting emissions, citing also the extraction and cultivation of fuels (and their processing), as well as transportation, distribution and combustion.

At 2005, in Europe, the renewable energy production covered only the 7% of the total energy consumptions of the member countries.

In order to obtain these proposals, each country will contribute according to its development level, ranging from -20% (rich States) and + 20% (in-developing Ones).

The increment in the use of renewable energy sources, necessary to contrast the negative effects induced by an intensive use of traditional combustion fuels, is strongly promoted also in order to limit the European energy dependence on foreign sources of energy.

This aspect, today, it is not secondary. In January 2009, a new diplomatic crisis between Russia and Ukraine, about the gas transportation through the Kiev land, caused a consistent reduction and, sometimes, a global cut-off in the gas furniture of 18 European Countries.

At the end of the last year, in the December 2008, the European Parliament and Council approved the final version of the “Climate-Energy Package”. The ambitious target would transform the Europe into a low-carbon continent, promoting the energy security, supply, efficiency and reduction of environmental impacts. Thus, at the United Nations Climate Change Conference 2009, that will be hosted in Copenhagen on December 2009, the European countries will propose their example to rest of the world, giving an important message towards the direction of an overall energy and environmental sustainability.

In the prefaces, the EBBD accounts that “*the residential and tertiary sector, the major part of which is buildings, accounts for more than 40 % of final energy consumption in the Community and is expanding, a trend which is bound to increase its energy consumption and hence also its carbon dioxide emissions*”. Therefore, achieving only a 30% in the reduction of the building energy requests, more than half of the 20-20-20 target can be easy obtained.

Of course, considering only new efficient constructions, even if interested by very restrictive conditions as regards the energy efficiency for the space heating, cooling, ventilation and lighting, this target cannot be achieved. In fact, meanly in Europe, the annual new building construction quantity represents only a 1% compared to the whole EU building stock, while significant renovations regard about the 1.8% of the existing buildings. This means that, to reach the 30% target, it is necessary to promote and make cost-effectiveness both the energy refurbishments (even when not mandatory) and the high-energy efficiency for the new buildings.

With reference to the energy uses for the space heating, cooling and ventilation (*i.e. the topics addressed in this Thesis*), the present mandatory energy performances could be also better than the minimum imposed ones. Presently, the international and national legislations establish minimum energy performances based on the $U_{VALUES}$ of building envelope, heating and cooling systems minimum efficiency values, EP indexes (*intended as the amount of annual primary energy required for the space heating and cooling*). In this direction, several European States developed funding programs to promote, through tax deductions and/or economic incentives, the energy re-qualifications of the building envelopes, the substitution of ineffective plant and systems, the installation of renewable energy sources to produce part of the building demanded energy.

Furthermore, the economically "untouchable" benefits have to be considered too, such the improved life quality and the better comfort conditions induced by a climate apt building. Of course, a low-energy building stock contributes also in reducing the energy dependence of the European countries, inducing higher security as regards the energy supply.

As above-mentioned, the EPBD Directive, at the article 4, imposes that "*Member States shall bring into force the laws, regulations and administrative provisions necessary to comply with this Directive at the latest on 4 January 2006*"; in the next paragraphs, the present application of the EPBD in the single national legislation will be analyzed.

As above-mentioned, the energy effective refurbishments play a great role toward a sustainable European development. Of course, an extended application of the EPBD prescriptions would be much more onerous with respect to an application referred only to the new constructions. Imaging a global refurbishment of the whole existing European stock, it will requires over 2000 billions Euros.

The Ecofys's [2] studies show that, as regards the existing buildings, converting the investments in annual capital expenditure, the energy efficiency measures determine energy savings that do not compensate, economically, the required costs (*i.e. the annual capital costs would result higher than the energy cost-savings*). Actually, in the evaluation analyses, not only the economic savings achievable recurring to energy efficiency actions should be considered, but also the avoided annualized mitigation cost per ton of $CO_{2\text{-EQUIVALENT}}$ emission. In other words, national programs funding energy efficiency actions can be justified also as institutional measured to fight climatic changes and to reach the international subscribed targets.

Besides the economic consideration, the environmental benefits achievable and the reduced energy uses, also other factors influence the decision making relatively to the implementation of energy-efficiency measures, such as the higher comfort through better room climates and the increased values of the properties.

Often, the divergent interests regarding the rented apartments, where energy effective retrofit actions can be not convenient for the owners, represent one of the main barriers as regards the energy-saving refurbishment actions. Therefore, international programs, National Governments, local institutions should play an active role in order to overcome the economical obstacles, supporting financially the energy renovations, facilitating the bank financial support and providing incentives for investors in energy refurbishment projects.

Several forms of public incentives are possible. For example, today, in the European States, best practices as regards both new buildings and existing architecture energy retrofits are funded:

- financing directly the works by means of capital investments;
- lowering the Value Added Tax for ;

- providing tax deductions as regards the invested money;
- admitting higher volumetric sizes and building density rates;
- admitting the increase of the rent rates for energy renovated dwellings;
- providing incentives through reduced interest rates on loans;
- conveniently financing the converted energy as regards the investments in renewable energy sources.

In figure 1.1.3, the present $CO_{2\text{-EQUIVALENT}}$ emissions and the possible savings obtainable applying the EPBD recommendations are reported. Compared to the 2002 emissions, a full application of the EPBD (and so providing apt insulation level) could halve the emitted pollution, passing from 725 Mt/a to 398 Mt/a (*327 Mt/a the overall potential saving*).

A gradual application of the EPBD, instead, could provide the emission savings reported in figure 1.1.4. Also in this last graph the high weight and influences of the residential sector is quite evident. In fact, considering the small houses, these represent a great part of the whole European building stock, so that an effective development strategy cannot offset the energy renovations of the existing dwelling stock, at the present moment characterized by energy performances quite unsatisfactory, as it will be shown in the next paragraph.

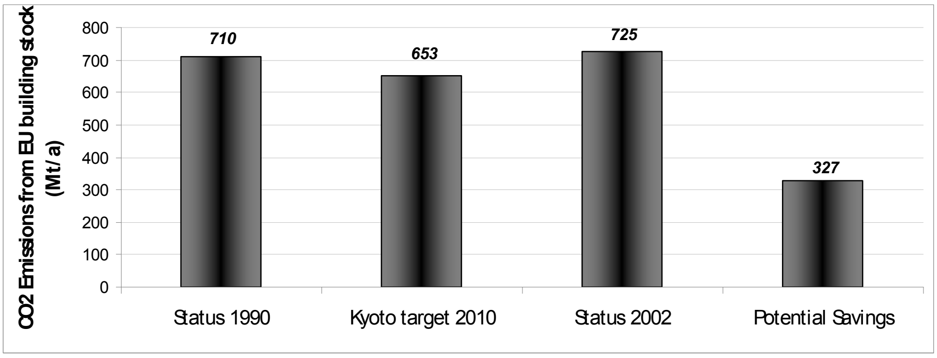


*Figure 1.1.3 – EU-15 $CO_{2\text{-EQUIVALENT}}$ emissions : present values and technical potential savings*

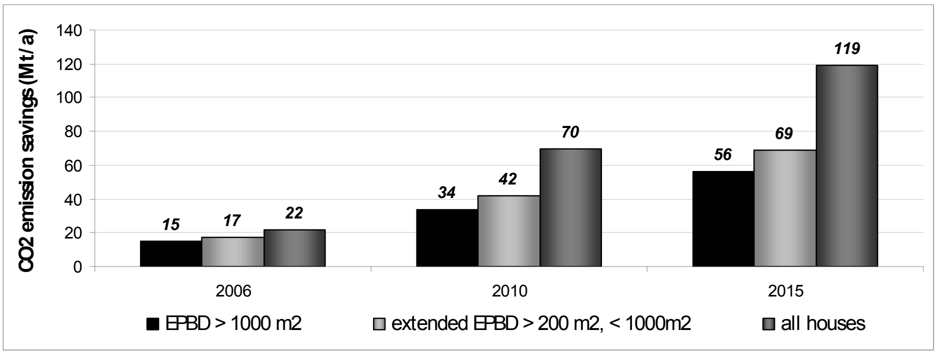


*Figure 1.1.4 – $CO_{2\text{-EQUIVALENT}}$ emission savings*

With reference to the above-reported graphs and estimations, the emissions have been evaluated considering the present energy uses, so that the heating systems represent the main responsible of the elevated pollution emissions. In fact, until now, the role played by the summer air-conditioning is not exhaustively considered. On the other hand, the large diffusion of single-house equipments (split-systems), during the last years, today imposes, in the southern Europe countries, energy effective actions in order to reduce also the use of the active cooling.

In the followings, above all in the description of the Italian building stock and related energy uses, the role of the summer air-conditioning will be exhaustively explained.

### 1.1.2 EUROPEAN RESIDENTIAL BUILDINGS

With reference to the residential buildings, the main energy use is related to the space heating that requires, today, around 68% of the total energy demand [4]. Until the 1990, this energy use represented about 72% of the total energy consumption, so that a significant reduction, in percentage, has been recently determined, due to the better performances of building envelopes and heating systems verified in the last years. Actually, also new energy uses, e.g. the summer air-conditioning, contribute to reduce the share of the space heating.

In figure 1.1.5, the energy incidence of the domestic hot water production for hygienic use is reported [4]; meanly, this energy request represents around 14% of the whole end energy demand. The same percentage, in terms of primary energy, is required by the electric uses related to the space lighting and other installed equipments.

Globally, the residential sector has been interested by a brief reduction of the total energy demand, with a decrease, referred to the 2004, of about -3% compared to the same values of the 1990.

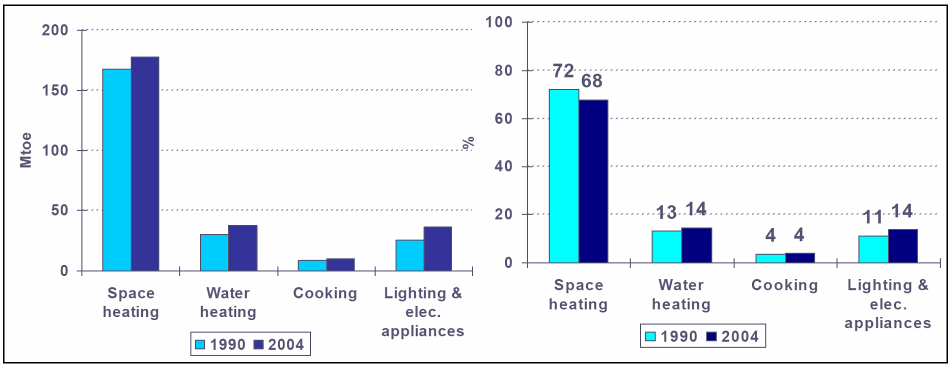


*Figure 1.1.5 – EU-15 end energy uses, in tons of equivalent oil and in percentage [4]*

In figure 1.1.6, with reference to a typological dwellings and considering each European country, the total annual energy demand has been diagrammed, such as the increasing-decreasing trend of these.

In particular, establishing 1 toe = 11628 $kWh_{PRIMARY}$, = 5347.59 $kWh_{ELECTRIC}$ (*i.e.* $1\ kWh_{ELECTRIC} = 0.187 * 10^{-3}\ toe \rightarrow \eta_{CONVERSION\text{-}PLANT} = 0.46$ *[5]*) and with a reference to a mean apartment size equal to 100 $m^2$, it can be noted that:

- the average EU-15 dwelling requires around 192 $kWh/m^2a$, in terms of primary energy, as regards the overall energy use;
- despite quite moderate climatic conditions, the Italian building stock presents primary energy demand (180 $kWh/m^2a$) close to the European mean value. The same energy demand characterizes the Danish dwellings while the Finnish ones have lower specific energy requirements (155 $kWh/m^2a$);

- the energy demand increase is very accentuated in Greece and Spain, because of a large spread, in the last years, of air-conditioning systems.
- Netherlands, Denmark, Norway and Sweden have been interested by a high-energy demand decrease, due to new effective regulations regarding the thermal insulation of the buildings and due to the purpose of no active cooling in summertime.

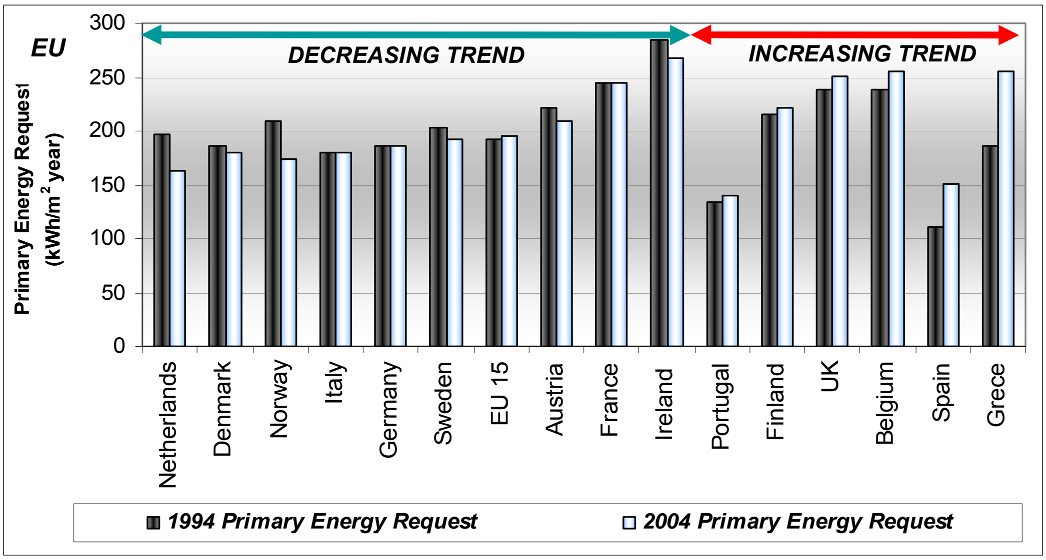


*Figure 1.1.6 – EU-15 primary energy demands: decreasing and increasing trends*

As shown in figure 1.1.6, despite a spread of energy efficiency measures, provided by the European Community and by the single countries, the overall building energy demand not always presents a significant reduction. This happens because, even if new regulations impose the adoption of energy efficiency actions (*as regards the building envelope, the heating/cooling systems, the water-heating boiler and heaters, lighting devices and other energy appliances*) the increase of the environmental comfort determined a higher control of the environmental conditions. In other words, the use of active energy equipments has been interested by a large diffusion, above all in the countries interested by higher development trends, due to the accentuated economic expansions characterizing the last period [6].

SPACE HEATING. The large part of the overall energy demand is represented by the winter heating need, which represents, as above cited, around 70% of the annual energy demand.

Of course, analyzing the single countries, the incidence of the winter heating energy demand is strongly variable depending on the specific climatic conditions. As regards the southern European countries, the winter heating energy demand represents around 40% of the total energy needs (*Greece and Portugal*), while in the North Europe, its impact results much higher (*e.g., in Germany and Netherlands, the incidence is around the 75% of the building global energy request*).

Although quite restrictive legal measures have been enacted all around the EU countries, the space heating energy demand has not been significantly reduced in the last years, with a decrease, respect to the 2004, very contained (around 6%) compared to the 1990 levels. This result can be explained only considering the occurrence of two opposite events:

1. on one hand, the increased comfort quality and the spread of larger dwellings and single family homes;
2. on the other hand, new energy efficient standards both with reference to the building shell behaviors and heating systems efficiency [4].

Globally, compared to the early 1990s, today the mean annual decrease, with reference to the space heating energy requirement, is around the 0.5%.

Moreover, the energy performances characterizing the southern-Europe countries are quite unsatisfactory, above with reference to the energy demanded in wintertime for the space heating. In particular, despite climate conditions quite moderate, the construction quality in Italy and Spain is unsatisfactory, while, on the other hand, in Sweden, Norway and Germany the results, as regards the winter thermal losses and related energy requests, are very appreciable.

These results are quite clear in figure 1.1.7, where, considering the EU-15 countries and the thermal energy request in wintertime for the space heating of the typological household of the building stock, the heating demands have been normalized with respect to the degrees-day of the specific location.

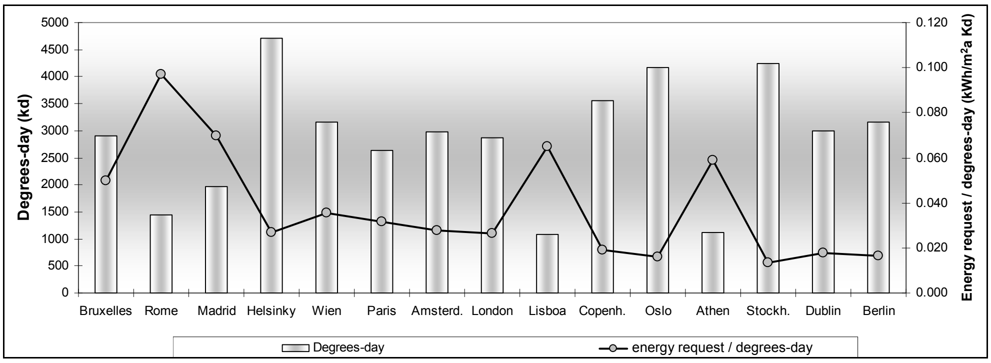


*Figure 1.1.7 – EU-15 capital cities: degree-days and climatically normalized winter energy requests*

It is quite clear that the worst performances are referred to the southern Europe countries, where, despite a warm winter climate, the energy consumption in wintertime is elevated. On the other hand, the north-Europe Nations, in particular Sweden, Norway, Denmark, Ireland and Germany, show building features that induce moderate winter losses.

These results are quite coherent with those reported in figures 1.1.8 and 1.1.9 [7], where the levels of adopted thermal insulation materials have been reported: also in this case, Spain, Italy and Greece show a constructive tradition much lower, qualitatively, compared to the other countries; on the other hand, the northern Europe countries are characterized by the best practices.

During the 2002, the European Institution enacted the EPBD, Energy Performance of Building Directive 2002/91/CE, which had to be receipt in the national legislations within the 2006. The document, in the following paragraph fully described, should harmonize standards, measures and prescriptions related to the building energy efficiency in the EU member states, in order to promote a new culture of rational use of energy in the building sector.

In the last years, quite all the European States began to harmonize the national codes to the new European principles, establishing space heating reduction, compared to the previously admitted values, ranging from -30 ÷ 35 % (*i.e. Ireland, Denmark and Germany*) to – 7 ÷ 10 (*i.e.*

*Spain and Portugal*). As regards the new Italian regulations, the energy demand for space heating is reduced, compared to the value admitted by the previous laws, meanly around - 15 ÷ 20%. In the paragraph 1.3.2, a full prospect of the singular national legislations is reported.

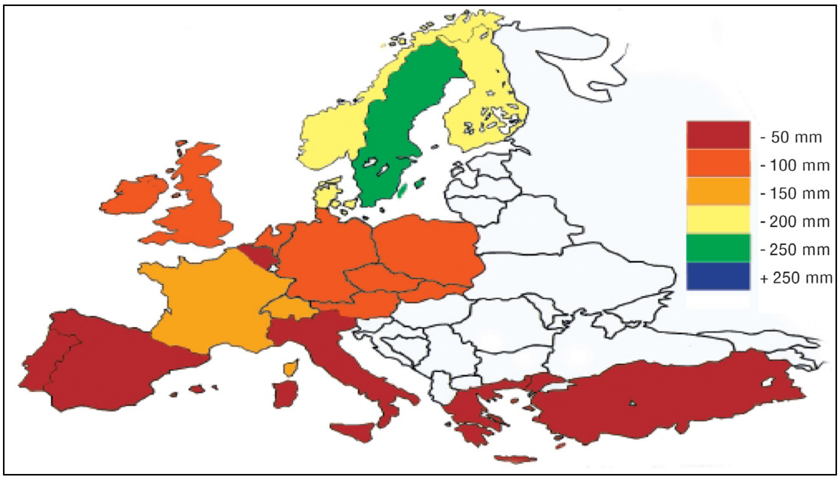


*Figure 1.1.8 – European countries: millimeters of thermal insulation inside the residential building vertical walls [7]*

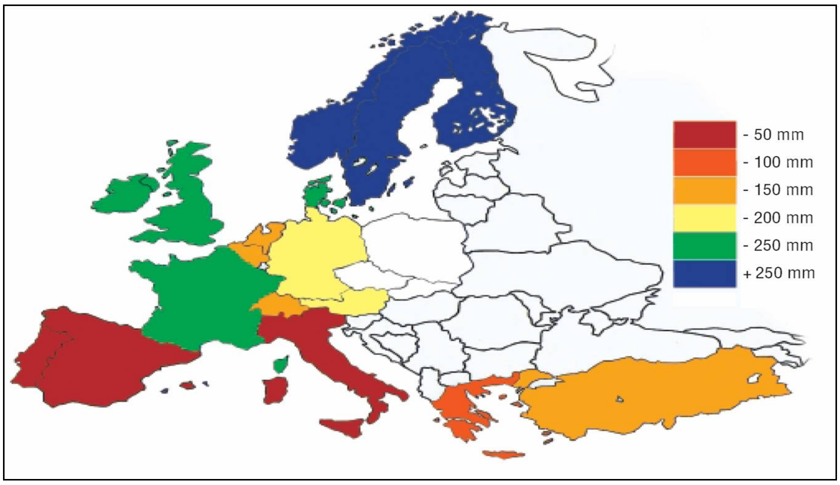


*Figure 1.1.9 – European countries: millimeters of thermal insulation inside the residential building roofs [7]*

Even if in Europe, according to the present legislation, the new buildings should require, starting by the 2005, energy amount for the winter heating meanly reduced around 25% compared to the 1990 values, presently, the building stock is still characterized by low energy performances. Therefore, the attention to the re-qualifications represents a key aspect of the question, being the existing building the part numerically more influent and less energetically efficient. In this direction, the EPBD imposes, for the first time in Europe, energy efficiency measures mandatory also as regards the building renovations, considering the quite low turnover rate interesting the building sector.

According to the specific codes approved in the European States after the EPBD emanation, at the present moment the heating energy demand in wintertime is reduced around 60% compared to the dwellings built before the oil crisis happened during the 1973-74. In particular, the Kippur war represents the historical moment that determined the first energy regulations as regards the building sector energy uses.

Considering the building activity, quite low in Europe (*only an 18% of the European building stock has been built after the 1990*), it becomes clear that a useful energy rationalization in the building sector can be obtained only acting on the existing building energy oriented retrofits.

Actually, even if the thermal insulation levels and the minimum energy efficiency ratios of the heating systems, such as imposed by the new rules, reduce drastically the thermal transmittances of the building shell and the energy losses due to technical plant inefficiencies, other factors limit the benefits achievable in terms of energy savings.

In particular, as shown in the studies of Eichhammer and Schleich [8], higher indoor temperatures, longer heating period and increase in the number of the heated rooms in each apartment caused a drastic containment of the benefits obtained increasing the thermal insulation level and rising the heating system efficiency.

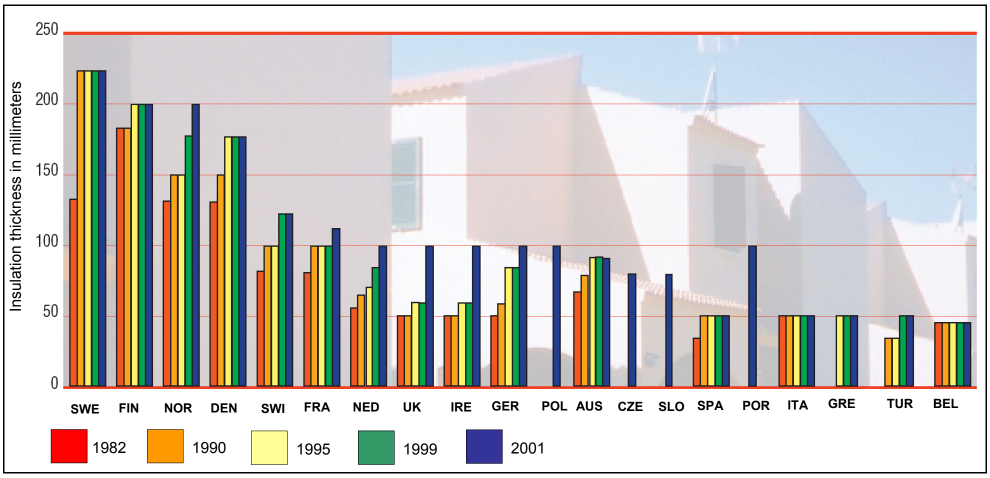


*Figure 1.1.10 – European countries: vertical wall thermal insulation [7]*

For example, in Germany, the savings achievable applying the new prescriptions are meanly quantified around 70% compared to the mean performances of the building stock, while, because of the factors above described, practically the actual energy reduction can be quantified around 35%; analogues researches show similar trend also in several other European nations.

Furthermore, the larger dwellings increased the winter energy demand in the last years. In particular, the mean single-family apartment in EU-15 countries is today 91 $m^2$, and thus 6 $m^2$ higher than the dwellings built until 1990. Therefore, even if the specific energy request per $m^2$ is interested by a reduction because of the new more restrictive regulation, the total dwelling energy demand is raised. The same effect has been caused by the diffusion of the central heating systems, which determined an increase of the heated rooms and a higher heating number of hours per day.

The central heating is meanly more efficient compared to the singular room/apartment heating systems, also inducing better comfort conditions and energy savings. Thus, considering a multi-family house, central system requires energy amount lower than the sum of single apartment heating systems. This has been briefly explained to clarify that the spread of central heating systems caused higher energy costs because the heated room and the mean room temperatures are increased (*and not because this kind of system represents a lower efficient solution*). Thus, summarizing, the above described lifestyle factors determined a reduction of the energy savings achievable applying the new regulations promoted in European States by the EBPD.

ELECTRIC ENERGY DEMAND. Electrical appliance and artificial lighting require, meanly in the EU-15 countries, an electric energy requests around 2700 kWh/dwelling (figure 1.1.11). Analyzing the requests in the singular states, the deviation compared to the mean value is not accentuated, with the higher requests referred to the Scandinavian States and the lower ones characterizing Germany and Austria; this results is quite important, considering that in large part of the central-Europe the electric energy is adopted also for the cooking-related uses.

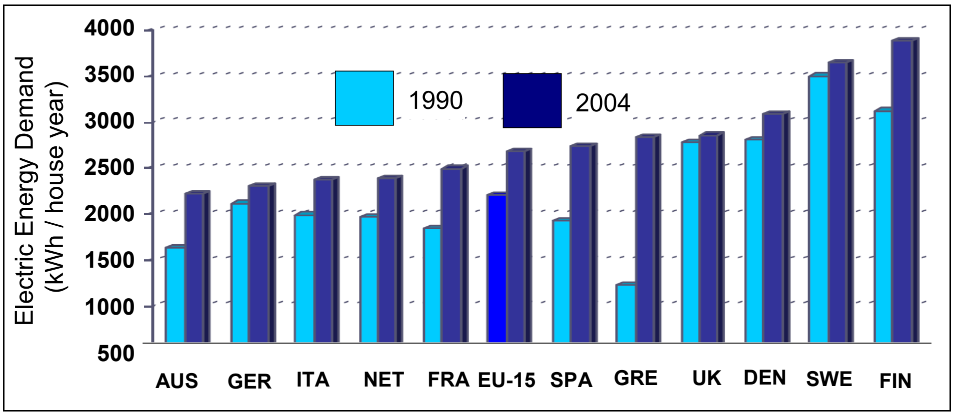


*Figure 1.1.11 – European countries: electric energy demands in dwellings [4]*

The spread of new appliances and domestic active equipments is partially connected to the development trends of some European States; the higher increments in the installation are referred to the Southern Europe countries, in particular Greece and Spain.

Furthermore, the increased required comfort level in households determined a growth of the demanded energy across the all-European countries. The spread of air-conditioners (*for the summer cooling in residential buildings*) caused in the last years and in the whole Europe (*particularly in the States of the Mediterranean area*), a significant growth of the electric energy demanded in summertime.

The mean growth, considering the whole EU-15 States, is around 1.5% per year, with the lower increment in UK, Sweden and Germany and the higher ones referred to Greece and Spain (fig. 1.1.12).

Analyzing the uses responsible of the electric energy consumptions, in figure 1.1.13 the household electricity consumptions are represented, underlining the incidence of each macro-kind of household appliance.

In the category large appliances, are included: refrigerators, freezers, washing machines, dishwashers and dryers. As regards these devices, several European Directives imposed mandatory energy efficiency standards, above all as regards the cold appliances, so that, despite a generalized increase of the total energy consumption due to the spread of these equipments, the specific energy demand of each of these is interested by a decrease.

In particular, the EU labeling scheme, the international agreements and prescriptions on minimum standards for energy efficiency and the efficiency progress contributed to contain the required energy growth due to the large diffusion of various active electric energy systems.

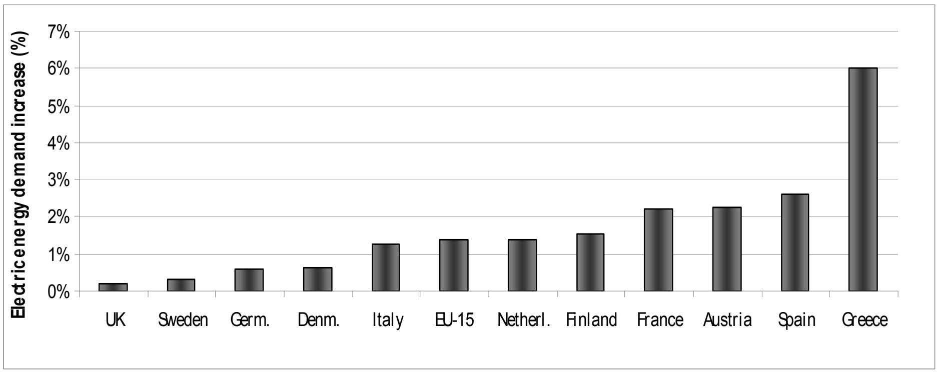


*Figure 1.1.12 –Electric energy demand increase (1990 – 2004)*

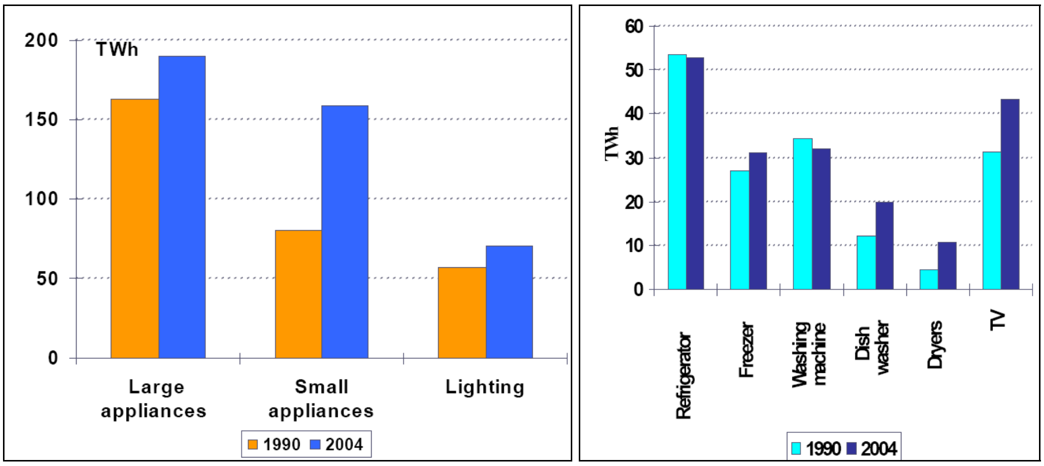


*Figure 1.1.13 – Residential sector: energy consumption for appliance type [4]*

At the same time, several voluntary agreements among manufactures and Governments, as well as the market trends, promoted the energy efficiency also for the other electric devices used in the residential sector (*e.g. TV sets, computers*).

However, in the last years, the diffusion of small electric equipments, related to the increased level of comfort and richness, becomes the main cause of the increased amount of the electrical energy uses.

Moreover, despite a spread of artificial lighting equipments, also about these, the adoption of low energy systems (*i.e. fluorescent lamps instead of incandescent ones*) determined a lower specific consumption.

The European various legal measures regarding the energy efficiency determined a progressive spread of efficient equipments; for example, with reference to the refrigerators, the shares of A and A+ energy classified systems passed from 2.5 % during the 1994 to the 54 % in 2004, with best practices in the central Europe Countries (*+60 % Germany and Belgium, +70 % Netherlands*). In figure 1.1.14, the market of A and A+ labeled systems for some EU-15 countries is reported. The best behavior characterizes the States historically more sensible to the energy efficiency culture.

Globally, the European promotion of energy efficiency in several fields, through several measures that promoted a more rational energy uses, determined, in the last 15 years, a progressive improving trend toward the energy efficiency in the building sector, both as regards the residential and tertiary sub-sectors. Several prescription across the European States, about the energy efficiency of the electric appliances and, above all, as regards the winter heating and summer cooling, determined an increase of the energy efficiency index of the European building stock.

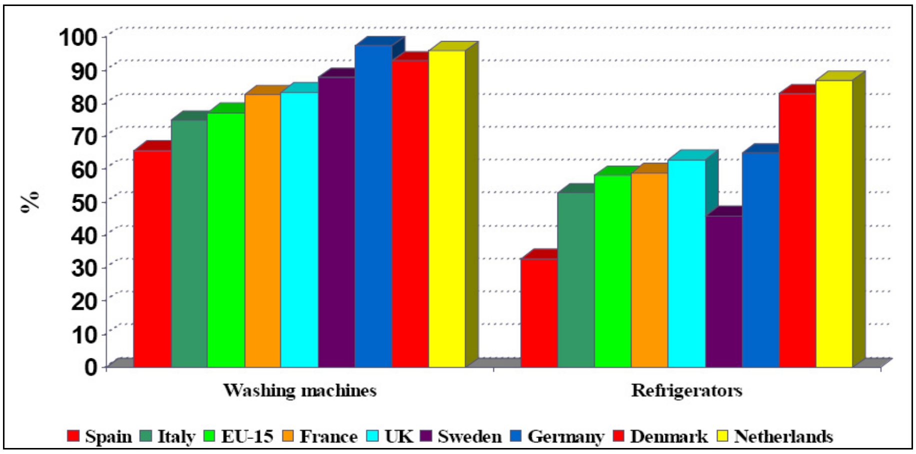


*Figure 1.1.14 – Market of A and A+ labeled electric equipments in some EU states (2004) [4]*

In figure 1.1.15, where the energy efficiency index has been calculated weighting the incidence of the most influent parameters (*space heating, cooking, electric appliance influence, lighting*), it is quite evident that, still today, the space heating plays the main role, so that the overall energy efficiency progress is strongly affected by the shape of space heating efficiency curve.

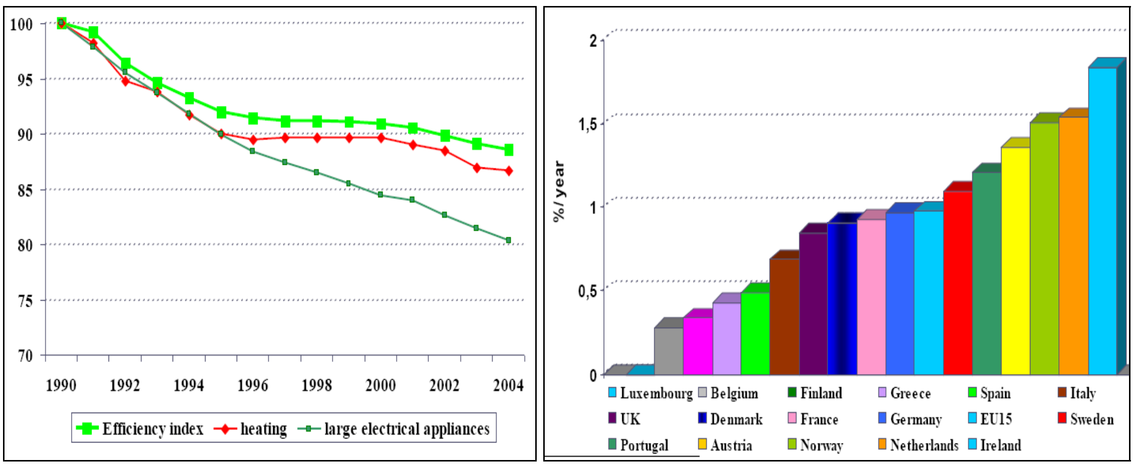


*Figure 1.1.15 - left: EU-15 Dwelling Energy efficiency progress; right: energy efficiency increment trends (source: ADEME - Odyssee indicators [4])*

In the period 1990 – 2004, as regards the residential sector, a global energy efficiency improvement around 11% can be estimated, and it means an annual mean improvement around

0.9%. Even if the specific energy efficiency, considering all the energy uses, is strongly improved, globally the dwelling energy consumption is decreased only around 3%. This can be understood considering that the spread of active energy systems, following the higher richness and the lifestyle changes, reduced significantly the benefits achievable. In particular, as already cited, greater dwellings, more numerous energy active appliances, user behaviors related to increased comfort demand caused a larger use of energy active equipments.

As regards the environmental pollution, actually the $CO_{2\text{-EQUIVALENT}}$ emission trend decreased a little bit more, because of the higher use of fuels characterized by lower greenhouse gas emissions (*such as natural gas, biomasses*) and diffusion, also with reference to the residential sector, of photovoltaic and solar thermal systems as well as other renewable energy sources.

In figure 1.1.16, the installed solar systems in some important Europe countries have been reported: photovoltaic and solar thermal systems have been selected because these, together with the biomasses, represent the energy renewable sources most diffused in the residential applications; the data are referred to 2006 and 2007 respectively as regards solar photovoltaic and thermal solar systems.

Despite a significant set of funding measures, in the last years and all around the European countries, has strongly promoted the adoption of renewable sources, the role of Germany remains, at the present moment, strongly preponderant in the use of solar energy sources. Actually, a great spread of the solar systems interests also the Italy: at the end of the 2008, the installed photovoltaic power results equal to 150 MW, while, as regards the 2009, the GSE - Italian Administration for electric services – estimates a global installation around 500 MW.

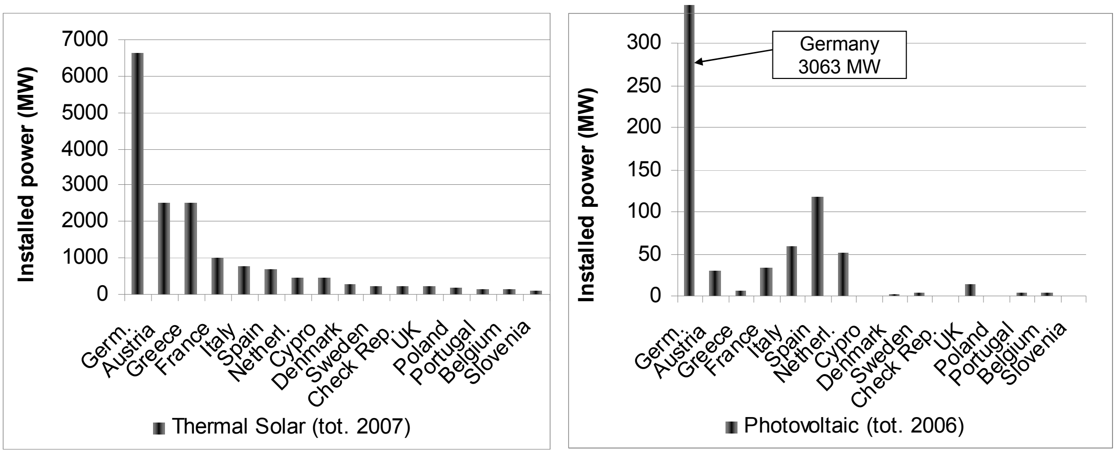


*Figure 1.1.16 – Installed solar systems in the EU countries left: thermal solar; right: photovoltaic*

### 1.1.3 INSTITUTIONAL, EDUCATIONAL AND TERTIARY SECTOR BUILDINGS

As regards the tertiary sector, it includes public and private services. With reference to the European non-residential buildings, three sub-sectors (*public offices and administration, trade and private offices*) require approximately two thirds of the overall energy request, while the educational buildings demand less than 10%; in figure 1.1.17, an exhaustive overview of the singular building share has been represented.

Globally, the weight of this sector, compared to the whole building stock, is increased in the last years (*13% of the overall energy uses in 2004, 12.5% in 1990*), because of the incidence of the information and technology equipments, interested by a large diffusion, as well as the air-conditioning systems.

With reference to the service sector, the main energy uses, still today, are the thermal ones; in particular, space heating, water heating and cooking require around 65% of the energy demand, followed by the I.T. equipments (15%), lighting (14%) and air-conditioning energy needs (5%). This last energy use, as represented in figure 1.1.18, presently is interested by a very rapid growth.

Globally, and so considering the overall energy uses, starting by 2002 the energy demand grew with the same rate of the productivity added value: i.e. around 2% yearly. In the previous years, the energy consumptions increased with a lower rate.

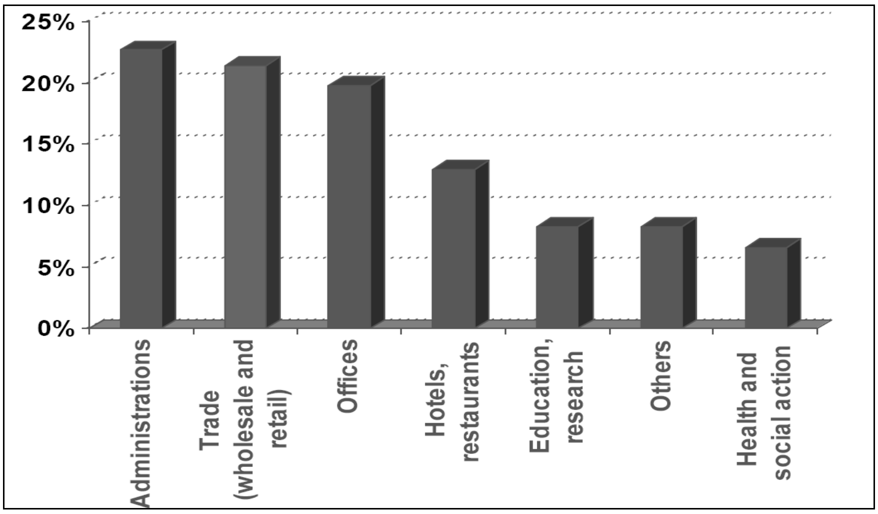


*Figure 1.1.17 - EU-15 Service sector: final consumption by sub-sector (4)*

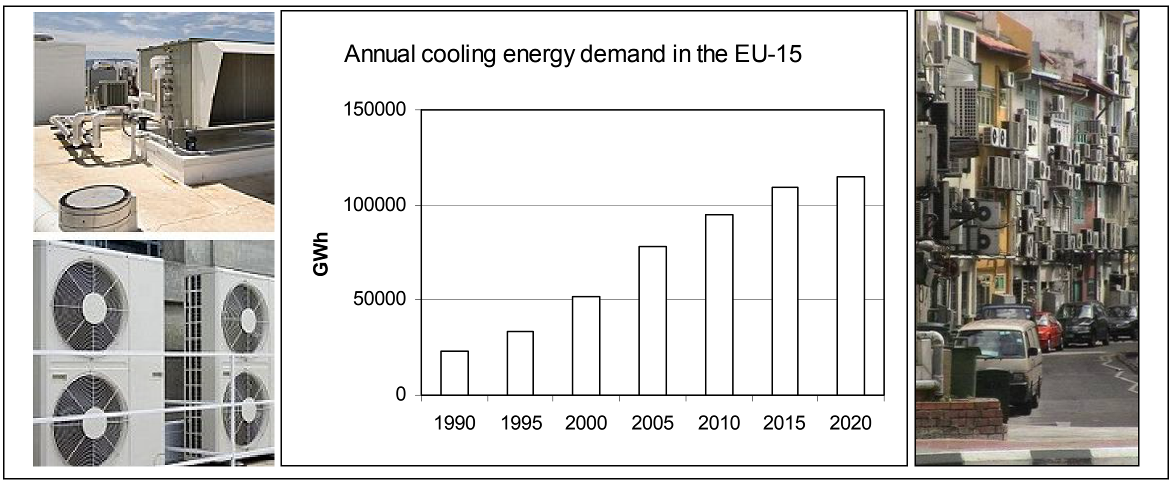


*Figure 1.1.18 - EU-15 Countries: summer cooling active system growth*

SPACE HEATING. All the European Countries (EU-15) have energy efficiency regulations for both residential buildings and service sector ones. In particular, several nations are already fully applying the new regulations derived from the EPBD, while many others are still involved in the transposition phase. Analyzing only the tertiary sector, the mean thermal energy required by the existing stock is represented in figure 1.1.19, with reference to the 5 countries that provided these data.

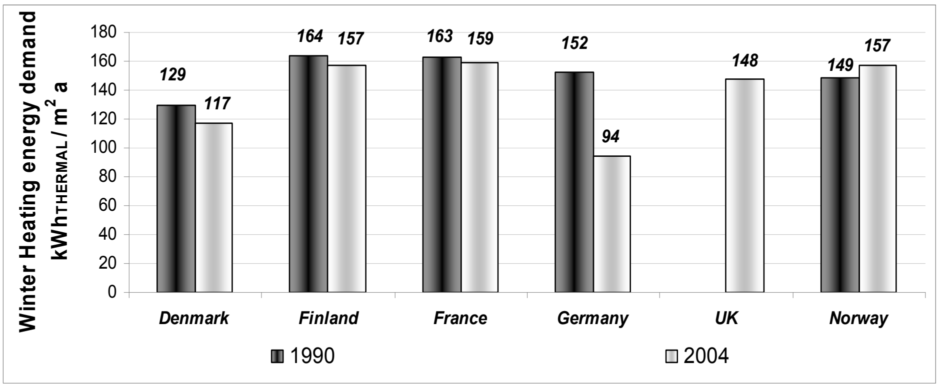


*Figure 1.1.19 – Specific space heating thermal energy consumptions*

Despite the graph is referred to the whole non-residential building stock, the Germany progress is very noticeable; this because, starting by the 1976, regularly the central Government and the Land administrations provide energy saving regulations, opportunely and periodically upgraded. A complete description of the measures is reported in the paragraph 1.3. The Germany high progress can be understood also seeing figures 1.1.8, 1.1.9 and 1.1.10, where, compared to the 1990 levels, the thickness of adopted thermal insulation is doubled in the 2001.

On the other hand, despite new regulations, in Norway no further savings are obtained compared to the 1990 levels.

It is important to underline that, with reference to the space heating requests for residential and non-residential buildings, analogues energy demand characterize only the France. In the other countries, the heating requests of the tertiary sector are meanly much higher; this because of the large amount of windows characterizing these buildings.

The effects induced by the recent regulations, understandable comparing the 1990 and 2004 values, are quite evident, also considering that the analysis concerns the whole building stock, characterized by a quite low turn-over rate [4].

ELECTRIC ENERGY DEMAND. Even if the final energy intensity of the service sector decreased, meanly, around 1% yearly with reference to the EU-15 countries, this value is strongly influenced by the incidence of the improvements regarding the building shell behaviors and the heating system efficiencies, so that, above all with reference to the wintertime space heating, significant savings have been meanly achieved.

Instead, about the electric energy demand, in the last 20 years a global growth of the energy requests can be seen; in fact, despite the spread of more efficient equipments (*e.g. the devices for lighting*), the diffusion of new instrumentations and the higher technological levels determined a global increase of the electric energy demand.

The electric intensity in the tertiary sector was interested by rapid growth in the period 1990 – 2004, with a mean growth rate around 0.7%/year. Meanly, this increase means an yearly electric energy consumptions around + 1000 kWh/employee; it corresponds to +22% compared to the 1990 levels (*2004 → 5400 kWh/employee; 1990 → 4400 kWh/employee*).

The higher increase rates interest the southern Europe countries, in particular Italy, Portugal, Greece, Spain. Actually, also Netherlands, Finland, Austria and Ireland show increasing trends; in the south-Europe, the main cause can be identified in the large diffusion and use of summer air-conditioning systems. As regards the Ireland, the high economic growth of the local economy explains the results.

In the last years, this progressive increase is showing a saturation tendency (*France and Luxemburg*), and, somewhere (above all in the strongly developed countries), also a decrease trend has been evidenced (*UK, Germany, Sweden, Norway*).

With reference to the most important services of the tertiary sector, figure 1.1.20 shows, for some European countries, the overall specific consumptions (*calculated per single employee*). Hotels and restaurants are the only functions that show values much higher than a mean value around 1 toe/employee. In figure 1.1.20, the energy requests are expressed in terms of primary energy.

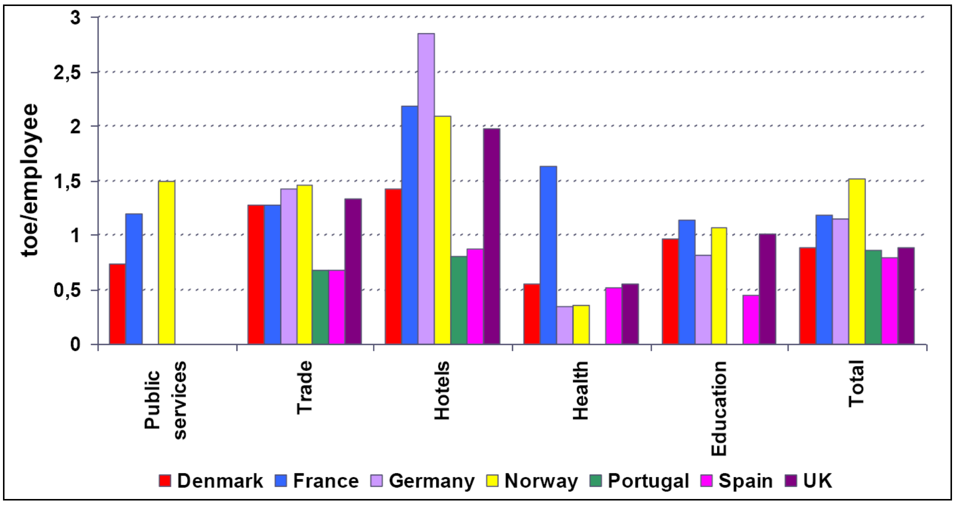


*Figure 1.1.20 – Tertiary sectors: unit consumption per employee in several branches (primary energy)*

As regards the private offices, exhaustive data are note available; actually, these functions should be require analogues energy consumptions of the public service sub-sectors.

As regards the $CO_{2\text{-EQUIVALENT}}$ emissions, although no complete data are available as regards the service sector, the estimated value of greenhouse emissions represents only the 5% of the overall $CO_2$ emitted in the EU-15; this value rises to 13% considering also the indirect emissions due to the use of electric energy.

Previously the high weight of the space heating in the tertiary sector (*around 2/3 of the total energy requests*) has been underlined; obviously, this energy use is the main responsible of the overall greenhouse gas emissions too.

Meanly for the EU-15, in the period 1990 – 2004 the $CO_{2\text{-EQUIVALENT}}$ emissions in the service sector rises around 3%, while the economic increase in the same period consists globally in +40%. This result depends above all by a larger use of natural gas instead of oil and the increased use of electric energy. Also computing the indirect $CO_{2\text{-EQUIVALENT}}$ emissions, related to the electric appliances, the total increase in is much lower than the economic growth, also because of the increase in the thermal-electric conversion efficiency interesting the European countries. In particular, with reference to the Italian electric energy conversion system, table I.2 reports the variation interesting the efficiency trend in the last years.

Table I.2: Improvements of the Italian system as regards the thermal-electric conversion efficiencies

| Year | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 |
|---|---|---|---|---|---|---|---|---|
| $\eta$-THERMAL-ELECTRIC (%) | 39.6 | 39.8 | 40.6 | 40.5 | 42.7 | 43.4 | 45.0 | 46.0 |

## 1.2 THE ITALIAN BUILDINGS

### 1.2.1 ITALIAN REAL ESTATE

In figure 1.2.1, the same trend of the European countries is shown as regards the Italian use of energy. In particular, also in this case a significant part of the overall energy use is required in order to satisfy the needs of the civil sector.

The recent assessed evaluations [9], published by the Italian Real Estate Observatory, reveals that the Italian building stock is constituted by 60’840’205 building property units, about which around 27’268’880 are dwellings.

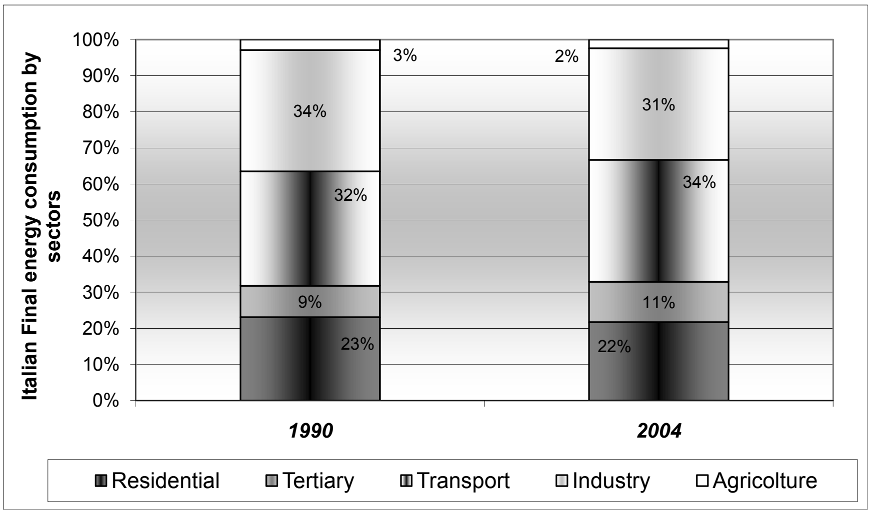


*Figure 1.2.1 – Division of the Italian energy uses per sector (ENEA)*

The building distribution on the Italian territory is not homogenous; dividing, in fact, the whole Italian Nation in several climatic zones depending on the winter degrees-day (table I.3 and figure 1.2.2), the higher density housing interests the climatic bands D and E (north area, fig. 1.2.3).

In order to better understanding the present asset of the Italian building stock, a brief description follows. Considering a schematic classification, three main building periods can be identified, depending on the evolution of the Italian legal measures as regards the energy efficiency in the building sector:

- the first temporary range can be identified until the 1976, when, caused by the international oil crisis, the first regulation about minimum efficiency in the building sector was enacted by the Italian Parliament (*Law 373/1976 [10]*). In this period, the rapid economic growth induced a high intensity of building activities, with a city demographic growth very accented during the 1950 – 1965;
- the second period runs form 1976 to 1991, when the main Italian regulation, still today in force (despite very significant modifications in the last four years) has been enacted: the Italian Law 10/1991 [11];
- the third period starts after the emanation of the Law 10 and arrives to 2005, when the last modifications to the previous legislation has been introduced by the Legislative Decree 192/2005 [12], then updated with the Legislative Decree 311/2006 [13].

Table I.3: Italian climatic zones

| Climatic Zones | Winter degrees-day (Kd) |
|---|---|
| A | dd ≤ 600 |
| B | 600 < dd ≤ 900 |
| C | 900 < dd ≤ 1.400 |
| D | 1.400 < dd ≤ 2.100 |
| E | 2.100 < dd ≤ 3.000 |
| F | dd > 3.000 |

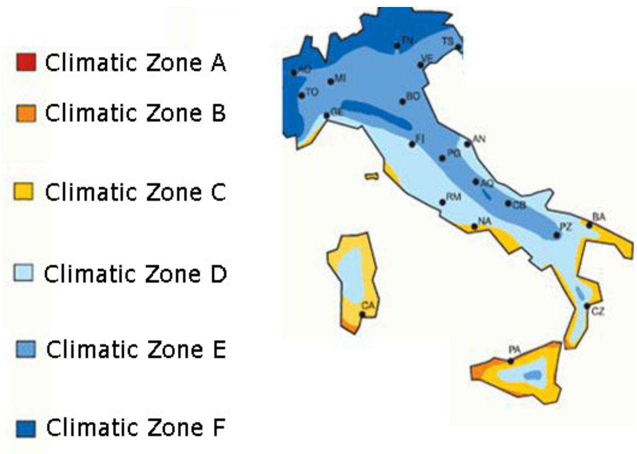


*Figure 1.2.2 – Italian climatic zones*

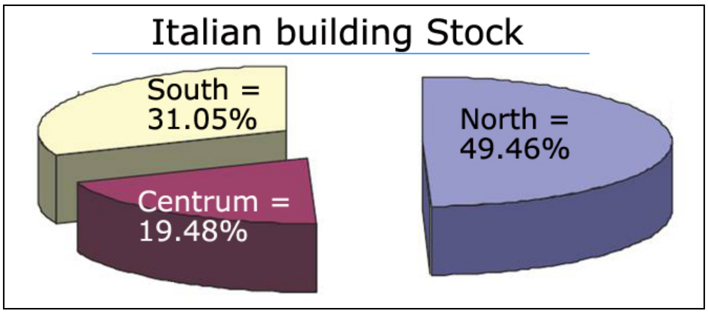


Figure 1.2.3 – composition of Italian building stock

The 70% of the Italian building stock has been built before the entry into force of the Law 373/1976, so that no attention to thermal insulation or to other energy efficiency measures has been posed. In particular, around 65% of the north-Italian buildings has been built before the

1976, so without any kind of thermal insulations, also in very cold climatic regions. All the construction ages of the Italian building stock are reported in table I.4.

Presently, the Italian building activity consists in the construction of less than 300’000 houses/year. With this growth rate, around 90 years are necessary in order to provide a number of energy efficient houses equal to the actual entity of the residential stock. These consideration is provided only in order to underline the primary importance of the existing building energy retrofits.

Table I.4: Italian building stock, divided for construction periods

| construction period (from – to) | houses in residential buildings | houses divided depending on the energy legislation upgrades | percentage of the different periods |
|---|---|---|---|
| Before 1919 | 3’893’567 | | |
| 1919 – 1945 | 2’704’969 | | |
| 1946 - 1961 | 4’333’882 | | |
| 1962 – 1971 | 5’707’383 | | |
| 1972 - 1981 | 5’142’940 | to 1976: 19’209’800 | 70% before 1976 |
| 1982 – 1991 | 3’324’794 | from 1977 to 1991: 5’897’734 | 22% between ’77 and ‘91 |
| 1992 - 2001 | 2’161’345 | from 1992 to 2001: 2’161’346 | 8% between ’92 and ‘01 |
| Total | 27’268’345 | | |

In table I.5, year by year with reference to the last period, the Italian building activity has been reported.

Moreover, buildings characterized by historical or cultural values, represent a significant part of the Italian building stock, above all in the city centers. This implies high complications in realizing energy effective retrofits, even if several measures to improve the energy performances can be anyway realized, improving the thermal performances of the building envelope by means of lightweight refurbishments or adopting effective technological active systems. Anyway, also if not insulated, the historical buildings do not represent a true problem, being the higher thermal mass (due above all to the high structure thickness), useful in order to rise the thermal resistance of the envelope, even if the material thermal conductivity is not optimal.

The main problem, contrariwise, is represented by the buildings in reinforced concrete realized during the economic growth following the 2$^{nd}$ war, where low quality material, light structures and no insulation determine catastrophic thermal performances of the building shell. In this period, around 14’500’000 houses have been built, thus approximately a 24% of the whole Italian building stock.

In the last years, the building sector has been interested, globally, by a stagnancy tendency. In particular, as shown in table I.6, starting by 2005 the overall capital investments in building have been interested by a decreasing trend. In particular, only new residential constructions show still positive trends until the 2006, while a significant brake affected the service sector renovation. This corresponds to the slackened economical development and to the reduced demographic growth.

According to the CRESME [14], during the 2008 the construction activity has been interested by a stagnancy phase, and, for the next future, the trend will decrease significantly, also because of the economical crisis interesting the whole Europe.

Therefore, considering the present situation and the necessary targets as regards a low-carbon future, the key-aspect of the problem is represented by the existing building re-qualifications; these, considering the large building stock and the present performances, require high public and private capital expenditures. Furthermore, a strong energy retrofit program would also contribute in restarting the Italian stagnant economy.

Table I.5: Italian building activity in the last years (*the values have to be multiplied by 1000*)

| | inside new residential buildings | | | *in non residential buildings or enlargement* | *OVERALL TOTAL* | *not authorized* |
|---|---|---|---|---|---|---|
| | Single family houses | Multi family houses | TOTAL | | | |
| **1985** | 107 | 180 | 287 | 48 | **335** | 60 |
| **1986** | 92 | 164 | 256 | 42 | **299** | 51 |
| **1987** | 79 | 148 | 226 | 37 | **264** | 59 |
| **1988** | 70 | 127 | 197 | 33 | **230** | 50 |
| **1989** | 68 | 141 | 209 | 32 | **242** | 45 |
| **1990** | 72 | 150 | 222 | 35 | **257** | 44 |
| **1991** | 74 | 147 | 221 | 30 | **251** | 46 |
| **1992** | 80 | 155 | 235 | 43 | **278** | 50 |
| **1993** | 78 | 154 | 232 | 38 | **270** | 58 |
| **1994** | 74 | 149 | 223 | 58 | **281** | 83 |
| **1995** | 71 | 144 | 215 | 50 | **265** | 59 |
| **1996** | 66 | 148 | 214 | 31 | **246** | 36 |
| **1997** | 57 | 134 | 191 | 31 | **222** | 28 |
| **1998** | 51 | 121 | 173 | 28 | **201** | 26 |
| **1999** | 46 | 113 | 159 | 34 | **193** | 25 |
| **2000** | 43 | 116 | 159 | 39 | **198** | 23 |
| **2001** | 48 | 127 | 175 | 47 | **222** | 22 |
| **2002** | 50 | 153 | 204 | 38 | **242** | 25 |
| **2003** | 50 | 164 | 214 | 38 | **252** | 29 |
| **2004** | 51 | 187 | 238 | 40 | **278** | 32 |
| **2005** | 49 | 211 | 260 | 44 | **304** | 32 |
| **2006** | 51 | 242 | 293 | 38 | **331** | 30 |
| **2007** | 48 | 250 | 298 | 36 | **334** | 28 |

Table I.6: Economic investments regarding the building sector (billions Euros [14])

| *unit = billions EUROS* | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 |
|---|---|---|---|---|---|---|---|---|
| NEW BUILDINGS | **5,6** | **8,4** | **7,9** | **1,4** | **3,6** | **1,4** | **0,5** | **-0,6** |
| - residential | 6,2 | 8,5 | 6,3 | 5,2 | 7,1 | 7,8 | 4,6 | -1,0 |
| - private non residential | 7,6 | 8,0 | 13,8 | -8,5 | -5,0 | -1,9 | -3,9 | 0,7 |
| - pubblic non residential | 2,5 | 8,5 | 4,2 | 4,4 | 5,4 | -3,5 | -5,5 | -1,0 |
| - engineer civil corps | 2,8 | 8,6 | 4,0 | 7,5 | 7,2 | -5,2 | -1,0 | -1,2 |
| RETROFITS | **5,8** | **2,1** | **-1,7** | **-0,6** | **1,0** | **-2,0** | **0,1** | **0,7** |
| - residential | 6,9 | 0,3 | -3,0 | -0,6 | 0,0 | -0,3 | 0,3 | 1,2 |
| - private non residential | 4,8 | 2,0 | -2,5 | -4,0 | -2,0 | -1,8 | 1,0 | 0,7 |
| - pubblic non residential | 4,0 | 4,0 | 1,0 | 2,9 | 4,0 | -6,0 | -2,0 | 0,0 |
| - engineer civil corps | 4,6 | 7,7 | 2,5 | 3,0 | 6,7 | -5,2 | -0,9 | -0,5 |
| TOTAL INVESTMENTS | **5,7** | **5,1** | **3,0** | **0,4** | **2,3** | **-0,2** | **0,3** | **0,0** |
| MAINTENANCE | **5,1** | **2,5** | **1,3** | **0,0** | **0,5** | **0,3** | **-0,2** | **0,3** |
| VALORE DELLA PRODUZIONE | **5,6** | **4,6** | **2,7** | **0,3** | **2,0** | **-0,1** | **0,2** | **0,0** |

In particular, considering around 21'000'000 of Italian families, a great part of these lives in energy ineffective dwellings, with a mean value of the primary energy necessary for the ordinary functions (*space heating, first of all*), similar to the EU-15 average request, despite the climatic conditions very favorable.

Historically, until the great diffusion (*in the last years*) of the active systems for the summer air-conditioning, the main Italian energy consumptions were related to the winter heating energy needs. The high energy required, for this scope, is of course connected to two events. From one hand, the thermal-physical behaviors of the Italian building envelopes are quite ineffective, because of the poor insulation levels realized until the last 20 years; this causes relevant energy losses and so elevated required thermal energy. On the other hand, the use of ineffective heating systems determined a further relevant increase of the energy losses, so that the amount of fuels necessary to supply the required thermal energy resulted (*…and still results…*) much higher compared to the real needs.

In the figures 1.1.8, 1.1.9 and 1.1.10 above-reported, the poor insulation of the Italian building compared to the mean values of the big part of the European countries has been evidenced. In particular, generally thermal insulation thicknesses lower than 5 cm have been used in Italy until the 2005.

As regards typological Italian building structures, the standard UNI 11300-1 [15] reports a set of walls traditionally used in Italy, dividing the typologies depending on the regional building traditions. In figure 1.2.4, some of the most typical Italian walls are represented.

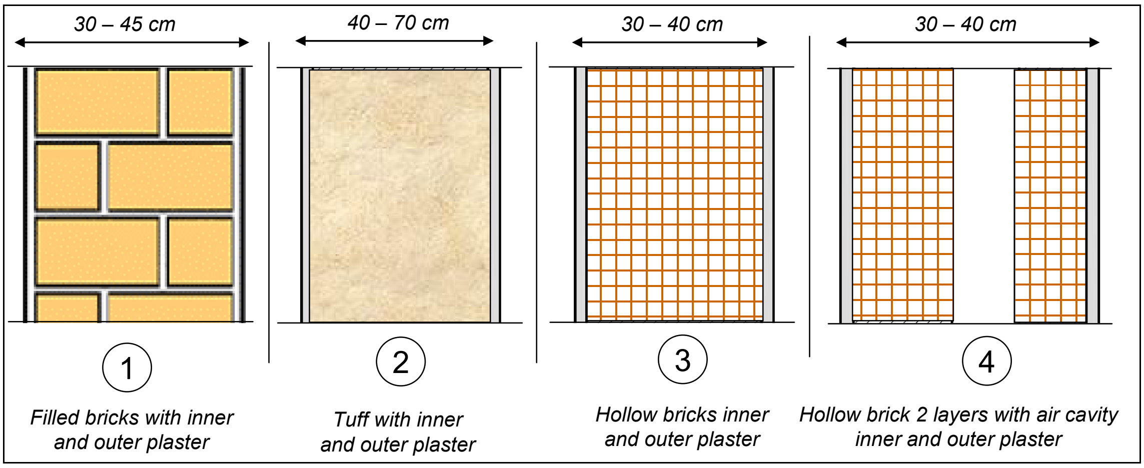


*Figure 1.2.4 – building envelope external wall: Italian typical structures*

As regards figure 1.2.4, the typologies numbered 1 and 2 have been strongly used in north-Italy respectively before and after the 1950. Instead, as regards the southern regions, the typologies 3 and 4 have had a large diffusion before and after the middle of the last century.

Depending on the variable thickness of the layers, the minimum and maximum values of the thermal transmittances are so calculated:

- wall 1: $U_{VALUE}$ between 1.52 W/m$^2$K and 1.98 W/m$^2$K;
- wall 2: $U_{VALUE}$ between 1.59 W/m$^2$K and 2.22 W/m$^2$K;
- wall 3: $U_{VALUE}$ between 0.62 W/m$^2$K and 0.81 W/m$^2$K;
- wall 4: $U_{VALUE}$ between 1.15 W/m$^2$K and 1.21 W/m$^2$K.

A paradox can be noted: in the warmer climatic regions, the use of hollow bricks induced lower values of the building thermal transmittances.

In table I.7, only as regards the building envelope walls, a set of un-insulated structures adopted in Italy before the 1976 is proposed.

Of course, after the emanation of the Law 373, the use of thermal insulation became mandatory. In table I.8, only with reference to the vertical walls, the kinds of structures adopted after the first energy regulation are reported. Analogues tables can be seen in the UNI 11300-1 [15] also for the other structures of the building envelope (*i.e. basement, roofs, inner walls…*).

Only as example, in the followings a simple calculation is carried out. Imaging a quite typological apartment, expressive of the Italian stock, the following boundary conditions can be considered:

- climatic zone C, mean outdoor T = 13 °C during the heating period (*5 months*);
- surface area = 100 $m^2$;
- opaque walls area = 80 $m^2$;
- window area = 10 $m^2$;
- vertical wall $U_{VALUE}$ = 2.11 $W/m^2K$;
- window $U_{VALUE}$ = 4.11 $W/m^2K$.
- surface-to-volume ratio = 0.3 $m^{-1}$;
- overall energy efficiency of the heating system = 0.63 (*e.g. radiators + gas heaters*).

Neglecting the solar heat gains and the endogenous ones, under the established boundary conditions, the apartment is characterized by an energy performance index, in wintertime and in terms of primary energy, around 83 $kWh/m^2a$.

Table I.7: Some typologies of un-insulated vertical walls ($U_{VALUE}$ = $W/m^2K$)

| *Thickness* | *Masonry wall, with inner and outer plaster* | *Filled bricks, with inner and outer plaster* | *Hollow bricks, with inner and outer plaster* | *Concrete wall* |
|---|---|---|---|---|
| 0.25 cm | 3.50 | 1.55 | 1.20 | 3.35 |
| 0.30 cm | 3.20 | 1.30 | 1.15 | 3.15 |
| 0.35 cm | 2.90 | 1.20 | 1.10 | 3.00 |

*The reported results have been calculated considering typical thermal conductivity values*

Table I.8: Some typologies of insulated vertical walls ($U_{VALUE}$ = $W/m^2K$)

| *Thickness* | *Insulated walls* | |
|---|---|---|
| | Minimum $U_{value}$ | Maximum $U_{value}$ |
| 0.25 cm | ≈ 1.20 | ≈ 0.60 |
| 0.30 cm | ≈ 1.15 | ≈ 0.50 |
| 0.35 cm | ≈ 1.10 | ≈ 0.40 |

*The reported results have been calculated considering typical thermal conductivity values*

This value of the $EP_{INDEX}$ is quite elevated, and, unfortunately, quite typical. Even if the mean value of the Italian building stock results around 150 – 180 $kWh/m^2a$ [16], considering the warm climate considered (*climatic region C*) and the reduced S/V ratio, this energy performance results very poor.

Improving the building envelope and the heating system, in particular adopting the minimum efficiency value reported by the annex C of the Italian Legislative Decree n. 311/2006 [13] for this climatic conditions (*vertical wall $U_{VALUE}$ = 0.4 $W/m^2K$, window $U_{VALUE}$ = 2.6 $W/m^2K$, overall energy efficiency of the heating system = 0.85*), the $EP_{INDEX}$ results around 17 $kWh/m^2a$.

Thus, despite the simplified calculation, the order of magnitude of the enormous energy losses characterizing the Italian buildings has been easily quantified.

In the above reported example, a quite inefficient heating system has been considered. About this, with reference to the residential buildings, is interesting to examine the Italian distribution of the adopted heating technologies. In figure 1.2.5, numbers and kinds of heating systems, divided depending on the age of construction, have been reported.

During the city demographic growth, in the period 1961-1971, a great diffusion of the centralized heating equipment has been registered, while, in the last 25 years of the last century, an increasing diffusion of autonomous equipments happened [17]. The conversion from centralized systems to single-house ones has been caused and promoted by the diffusion of the methane-served houses, induced by the evolution of the national legislation (*for example, the emanation of the Italian Republic Presidential Decree 412/93 [18]*) and by the changes regarding the lifestyles, following the greater national prosperity.

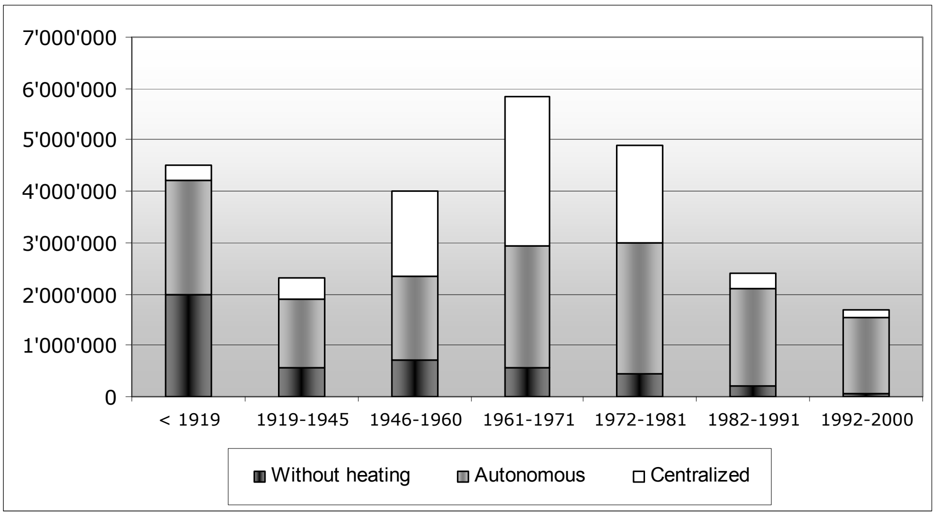


*Figure 1.2.5 – Heating systems depending on the installation period [18]*

Recently, a new consciousness about the higher energy efficiency of the central systems stopped a further diffusion of autonomous ones. Furthermore, also the Presidential Decree 59/2009 [19] underlines the higher efficiency of centralized systems. In particular, the article 4 paragraph 9, reports: "*…it is preferable the maintenance of central heating installations where existing…*".

Presently, the single-house heating systems represent around 56% of the installed plants; this percentage rises to 80% if also the single-room equipments (*electric or gas fires*) are considered (figure 1.2.6). Comparing the energy efficiency of these systems with respect to the centralized ones, the autonomous plants are characterized by lower performances, due to the higher thermal losses in the production, distribution and regulation sub-systems. Also a not contemporary functioning in the heating use, so that an elevated amount of thermal energy is dispersed toward the close apartments (*not heated in the same time*) causes, globally, a lower effectiveness. Furthermore, in order to contain the costs, the adopted internal control system is quite always manually managed (*even if in many cases a time or temperature based controller exists*).

Actually, the kind of Italian building stock influenced strongly the adopted heating system typologies; in order to better understand, it is enough considering that more than 40% of the whole building park is constituted by single family or two-family houses, so that a spread of autonomous systems was been, practically, inevitable. Furthermore, if all the buildings containing since 4 apartments are considered (figure 1.2.7), then the percentage rises to 60% of the whole Italian stock.

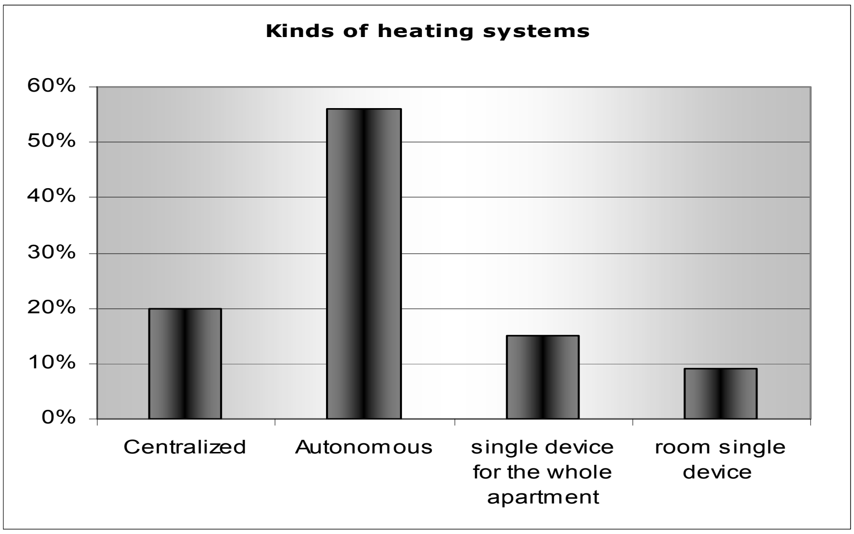


*Figure 1.2.6 – Italian distribution of heating systems [20]*

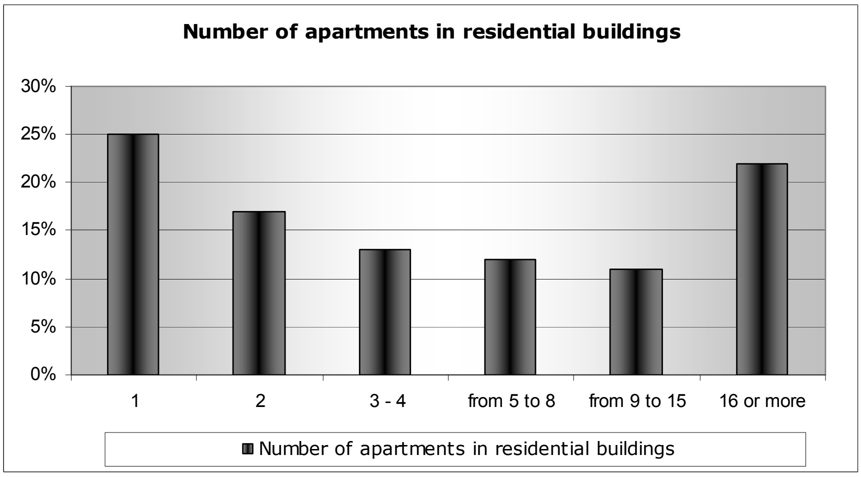


*Figure 1.2.7 – Distribution of the apartment number as regards the Italian residential buildings*

As regards the energy use in the civil sector, the energy share of different functions is so defined: space heating → 68.4%, hot water production → 10.6%, kitchen uses → 5.3%, electric uses → 15.7%; the data sources is [21].

Despite a favorable climate, also in Italy the weight of the space heating is still today very significant, even if in the last years the summer air-conditioning is assuming a considerable incidence.

In figure 1.2.9, the increasing trend of the cooling systems in the residential sector is represented. In particular, it is estimated that [17], in Italy, in the period 2000-2005, around seven millions of air-conditioners (figure 1.2.9) have been sold; it means that around the at 15% of the Italian dwellings are equipped with an active system for the summer cooling.

Despite the levels of the U.S. have been not yet reached (≈ *50% houses provided with active cooling*), a constant growth in the installations is determining serious problems as regards the summer peak load demand, the city summery heat islands, the electric energy consumption in summertime.

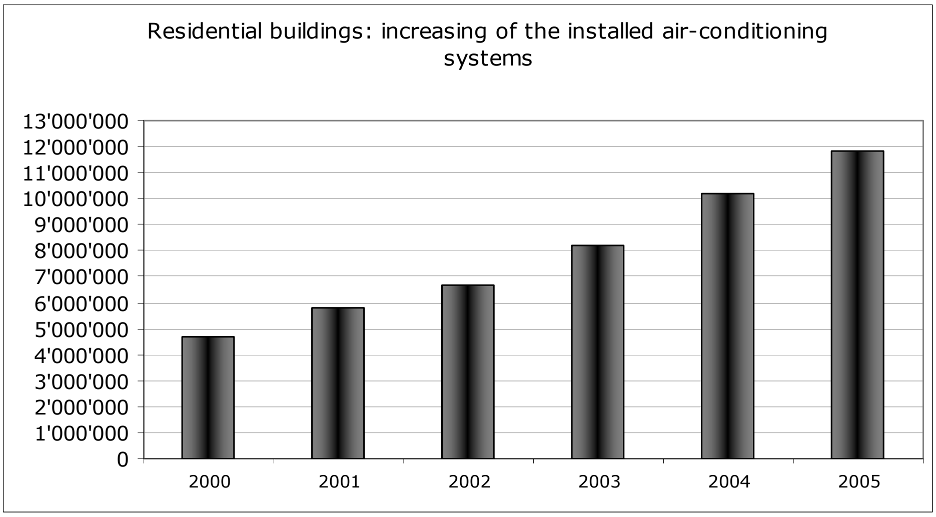


*Figure 1.2.9 – Air-conditioning systems installed in Italy in the period 2000-2005*

### 1.2.2 ENERGY REQUESTS OF THE BUILDING SECTOR

During the last 20 years, the total primary energy consumption in the Italian civil sector passed from 62.4 Mtoe in 1991 (total Italian consumption 167 Mtoe; *i.e. ≈ 37% of the whole energy demand is due to the building sector*) to 80 Mtoe during the 2006 (availability of 197 Mtoe; *i.e. the share of the civil buildings is 40%*).

The electric energy today represents around 30% of the overall building energy use; the trend grows constantly, passing by the 19% (1991) to the 26% (2000) [22].

The non residential buildings, and so the tertiary sector, is interested by an increase of the share of energy use. During the 2000, the residential stock required 67% of the whole energy demand (33% service sector) while, at 2005, the residential influence decreased (64%), while the share of the non residential raised (36%) [22].

Presently, natural gas and electric energy satisfy around 82% of the building energy demand, while oil, solid fuels and others provide the remaining 18%.

The increase of electricity consumption from 1991 to 2005 is higher than 13.5%, while, in the same period, the natural gas demand increased around 11%. Because of the great diffusion of cooling systems, after a progressive rising trend (figure 1.2.10), for the first time during the 2006 the summer peak request of electric energy resulted higher than the wintertime one.

During the 2007 (figure 1.2.11) [23], this overtake has been meanly confirmed (*the data referred to the 2009 are not definitive, while the 2008 ones are not yet completely analyzed*).

Even if, globally, a progressive increase is interesting the electricity consumption in Italy, in the last two years the annual energy demand remains stable; this results derive from the balance between a lower winter electric energy use and a higher request in summertime. In particular, during the August 2007, the electricity demand in Italy amounted to 25.7 billions of kWh, with an increase equal to +3.8% compared to the same month 2006. The main reason consists in the use of air-conditioning equipments.

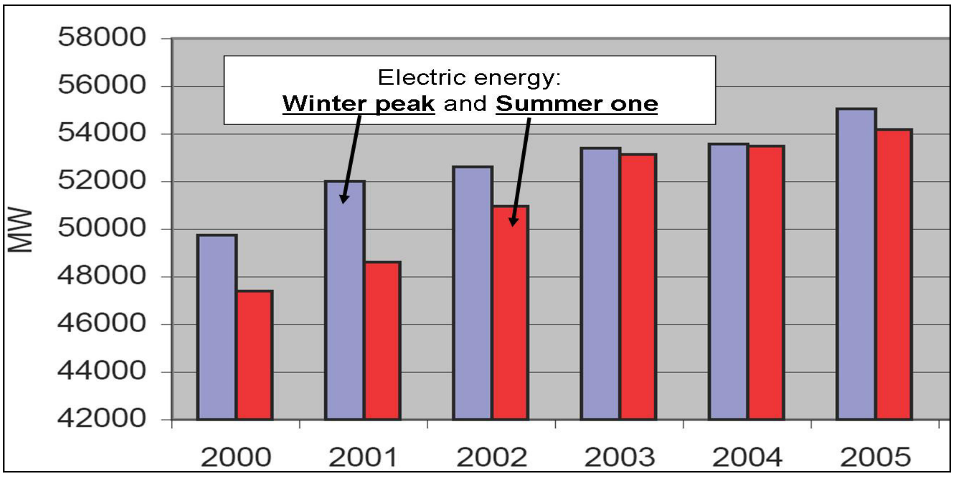


*Figure 1.2.10 – Electric energy: comparison between the summer and wintertime peak requests*

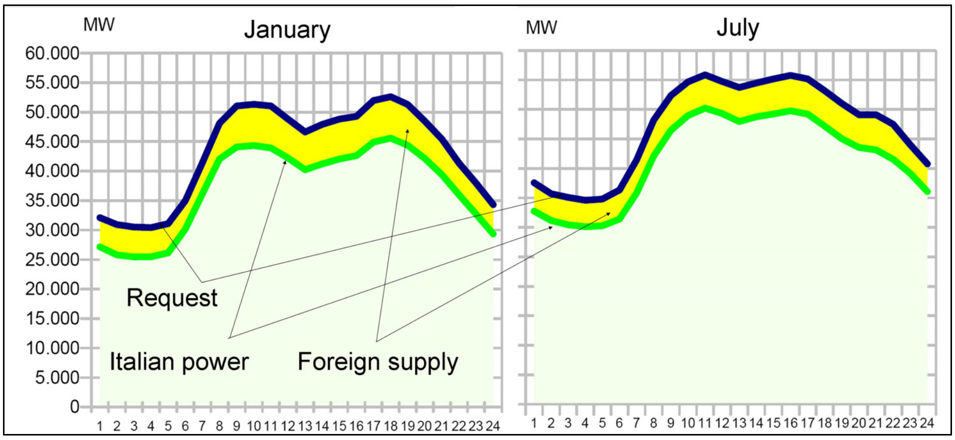


*Figure 1.2.11 – mean hourly distribution of Italian electric energy demand in January and July [23]*

For the same working days, two factors influenced this result:

1. a large <u>use</u> of air-conditioners → august 2007 was characterized by a mean temperature higher, monthly, of about 0.8 °C than the same thermal level referred to August 2006;
2. a large <u>diffusion</u> of air-conditioners → comparing the data, corrected considering the same ambient mean temperature, the variation would amount to + 2.2% [23].

As regards the non-residential sector, this is characterized by a constant increase trend; the increase of electrical energy demands is particularly high for the trade applications, hotels, restaurants and communication categories.

In particular, the growth regards both the electricity use and the natural gas demand, resulting respectively +18% and +17% during the 2005 compared to the 1991 values.

An average national dwelling, around 90-100 m$^2$, in a multilevel building characterized by a typical qualitative construction level, requires around 1.55 toe/year (*figure 1.1.6*). Considering that the 68% of the primary energy demand is due to the necessary space heating, it means an annual energy demand around 1.05 toe/apartment, thus around 123 kWh/m$^2$a; this number corresponds to the national average energy performance of the building stock.

Moreover, considering that the construction energy costs are around 5.5 toe/apartment, it can be noted that:

- in a time a little bit longer than 5 years, an Italian dwelling requires, to satisfy the winter heating needs, the same energy used for its construction;
- considering all the energy uses, necessary in order to guarantee an indoor standard comfort, this time decreases to 3 years and half.

Through this simple example, the importance of upgrading the energy efficiency of buildings can be easy understood. At the same time, also the correct management and maintenance of the active energy devices represent key aspects in order to improve the energy efficiency.

The same graph reported in fig. 1.1.15 (*left side*) and referred to the whole European Union, is reported in figure 1.2.12 with reference to the Italian building stock.

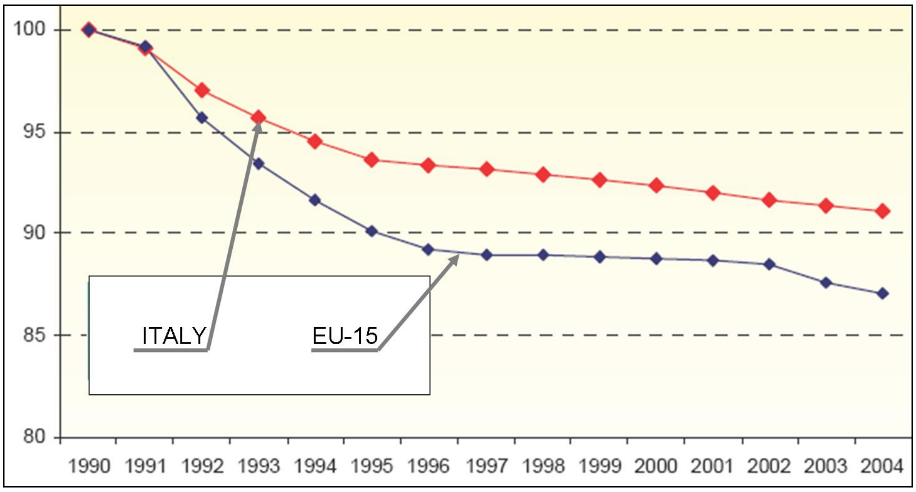


*Figure 1.2.12 - Italy and EU-15 energy efficiency trend of dwellings in the last years*

It is quite evident that, starting by the 1990, the Italian improvements of energy efficiency have been lower than the value characterizing the other European countries. The graph, elaborated inside the ODYSSEE project [4] represents a non-dimensional energy efficiency index; assumed a base value equal to 100, a decreasing trend indicates lower consumptions and improving performances. The index considers the overall building energy use, weighting the incidence of the different energy functions.

Even if Italy had legal regulations also better than the other nations (*in particular, the Law 10/91*), these prescriptions have been characterized by a poor level of application; therefore, the results of figure 1.2.12 are a direct consequence of it.

Other limits of the Italian system can be indentified in "*non-technological barriers*", such as the level of information and training of professionals/citizens not yet adequate, the poor diffusion of a clear legislation, the poor law application and complex beaurocracy, the market still volatile, the poor diffusion of the Energy Efficiency Bonds.

Finally, the low national attention and culture toward the energy and environmental sustainability represent the main causes of the poor energy performances of the Italian building stock.

## 1.3 INTERNATIONAL AND EU MEMBER STATE LEGAL INSTRUMENTS TOWARD THE BUILDING ENERGY EFFICIENCY

### 1.3.1 THE EPBD – ENERGY PERFORMANCE OF BUILDING DIRECTIVE

The Energy Performance of Buildings Directive 2002/91/EC, well known as EPBD, has been approved on December 16, 2002 and come into force on January 4, 2003. In order to harmonize the energy efficiency measures of the single member States, the European Parliament and Commissions enacted the Directive as framework to orient the member countries toward a common promotion and improvement of the energy performance of buildings within the EU, through cost-effective measures. The following main principles, to be transposed into the single national legislations, can be identified:

- the general framework for a methodology of calculation of the integrated energy performance of buildings;
- the application of minimum requirements regarding the energy performance of new buildings;
- the application of minimum requirements as regards the energy performance of large existing buildings that are subject of significant renovation;
- the introduction of a scheme to provide the mandatory energy performance certification of buildings;
- the establishment of regular inspection of boilers and of air-conditioning systems in buildings and in addition an assessment of the heating installation with boilers older than 15 years;
- the definition of minimum requirements for experts and inspectors involved in the energy certifications of buildings.

Within these general frameworks, each EU countries had to choose and harmonize the energy regulations in order to transpose properly the new European targets into the national laws. Furthermore, the EPBD underlines the necessity of collaboration and information exchanges, in order to facilitate and harmonize the implementation. The impact of the 2002/91/EC regards a very large participant number, on several levels and with different roles: *architects, designers, engineers and consultants, manufacturers, building experts, owners and tenants*.

After 6 years from its emanation, a consumptive analysis on the EPBD effects reveals a great role played in the promotion of large investments in energy efficiency measures, representing a great challenge for the transformation of European building sector, not only with reference to the building and plant efficiencies, but also as regards the spread of renewable energy sources.

The official deadline of the EPBD transposition into the all EU States national laws was January 4, 2006 (*January 2007 for Bulgaria and Romania*). As regards the definition of measures to regulate building certification and system inspection, the lack of well-defined methods and competences determined an additional transposition period of further three years, so that an EPBD full transposition has to be completed within January 2009. In the followings, a brief description of the EPBD main points is reported.

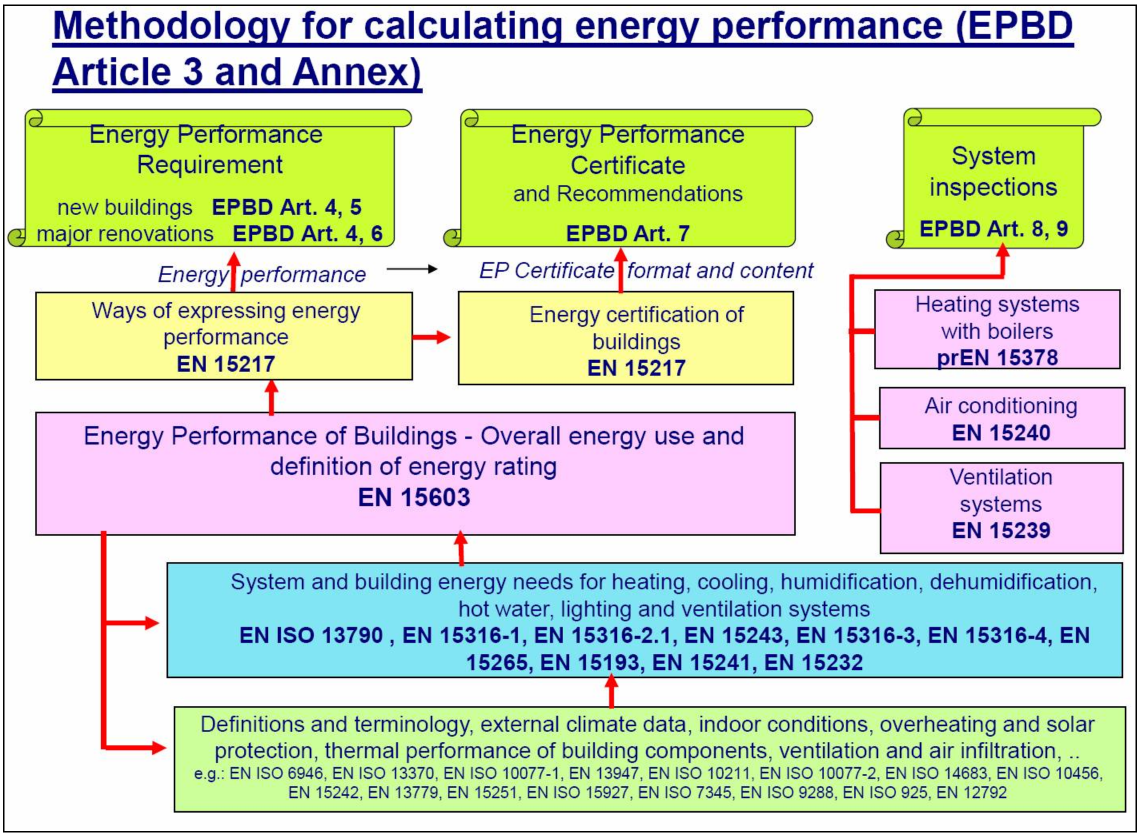


*Figure 1.3.1 – EPBD: Methodology for calculating the energy performances of buildings [source: CEN "Umbrella Document" EN 15615]*

ESTABLISHMENT OF A CALCULATION METHODOLOGY. The EU Member States have to implement a methodology for the calculation of the energy performance of buildings, taking into account all factors that influence the energy performances. The specification of a calculation methodology is central in the EPBD, establishing restrictive requirements for both the building energy regulations and the energy performance certificates. The Directive, as in the following described, does not specify a detailed calculation methodology, demanding to the CEN - European Technical Committee - the development of harmonized calculation methodologies.

The mandate given to the CEN committee, in order to develop appropriate calculation procedures in order to support Member States in the national applications, includes the assessment of a complete set of EN technical standards EN, that must results harmonic, accurate and apt to future modification [24].

On this technical base, the Member States define the details, providing, with regular upgrading, a protocol apt to evaluate the overall energy performance of buildings, inclusive of all the energy services. The EPBD specifies that the calculation and evaluation methodologies shall include at least the following aspects:

- detailed evaluation of thermal characteristics of the building envelope and internal partitions, possibly including also the air-tightness;
- meticulous design of the building, particularly as regards the position, exposure, adaptation to local climate and optimization of the natural ventilation possibilities;
- attention to the lighting, favouring the natural daylight and adopting energy effective devices for the artificial equipments;
- adoption and technical evaluation of apt solar protection systems, in order to reduce, as much as possible, the summer overheating;
- promotion, when possible, of passive solar systems, in order to provide a free heat gain in wintertime.

The EPBD specifies that the single State regulations have to provide minimum energy performance requirements for new buildings and for large existing buildings when interested by significant refurbishments.

MINIMUM ENERGY PERFORMANCE REQUIREMENTS. The EPBD articles 4, 5 and 6 describe the procedures for setting up energy performance requirements in the member States. The several countries can differentiate the requirements among new and existing buildings, also taking into account different building categories, in particular as regards:

- strategies regarding national minimum EP requirements;
- building categories considered or excluded by the energy efficiency application;
- methods to consider the general indoor climate conditions;
- level of applications for major renovations;
- different types of rating and evaluation kinds (design, asset or tailored), based on measured or calculated data.

The article 4 of the EPBD reports "*...Member States shall take the necessary measures to ensure that minimum energy performance requirements for buildings……. These requirements shall take account of general indoor climate conditions, in order to avoid possible negative effects such as inadequate ventilation, as well as local conditions and the designated function and the age of the building*".

Furthermore, the EPBD specifies that some categories of building can be excluded by the energy improvement application, such as:

- buildings and monuments officially protected because of their special architectural or historic merit, if the energy renovations would unacceptably modify their characters;
- buildings used for religious activities;
- temporary buildings (*i.e. permanence equal or shorter than two years*);

- industrial sites and non-residential agricultural buildings with low energy demand.

The EPBD article 5 imposes, about the new buildings, mandatory minimum energy performances; in particular, for large architectures (>1000 $m^2$) technical, environmental and economic feasibility of alternative systems should be evaluated. In particular, it is suggested the use of:

- decentralised energy supply systems based on renewable energy;
- compression and adsorption heat pumps, when favourable conditions are identified;
- promotion of district or block heating and cooling, if locally available;

Moreover, the article 6, referred to existing buildings, imposes that, contemporarily to major renovations of large buildings, these must by also energetically refurbished, in order to improve their energy performances to meet minimum energy satisfactory characteristics.

ENERGY PERFORMANCE CERTIFICATE. The energy performance certificate is stated in article 7 of the Directive; this is mandatory for new buildings, but also when existing buildings are interested by sale or tenancy. The energy performance is calculated on the basis of the official methodologies (CEN-derived) before cited; the certification should be carried out "*in an independent manner by qualified and/or accredited experts*". The energy certificate, for new and existing buildings, must clearly identify the present building energy performances; about it, for a first phase the energy performances are referred only to the space heating and the hot water production energy uses. This label comprises information about the adopted calculation methodologies, which quality these assure, which evaluation methods are suitable for existing buildings (*data collection*), the qualitative level assured by the calculation tools. Furthermore, exhaustive information about the building and its plants, as well as possible adoptable energy improvements, should be indicated too.

The Governments could delay the implementation of these aspects up January 2009 (*only in July 2009, in Italy, a national certificate scheme has been released*). The certificate typologies can be diversified for different sectors (*housing, other buildings, new constructions, property sales and rentals*).

The energy performance certificate should classify the buildings on a banded scale, ranging from Class A (*the best one*) to the Class G (*the worst one*), similarly to the energy label already used for several electrical devices, based on the annual $CO_2$ emissions per unit floor area. In particular, the overall scale should cover a wide range of emissions, starting to the carbon neutral building and including also the performances of the less efficient buildings (*e.g. the existing stock*). Finally, the A-G band will provide broad indicators for:

- the energy performances of the building, expressed in kwh/$m^2$year;
- the annual $CO_2$ emission, expressed in kg/m².

The recommendations accompanying the energy performance certificates are an important topic of the Directive; these must suggest cost-effective improvements of the analysed building. These improvements regard the thermal insulation measures, improvements of the heating systems and their controls, advices about other services such as lighting.

In order to facilitate the calculation of energy performance and the assessment of improvement measures for existing buildings, the member States can provide typical data of their specific building stock, such as the $U_{VALUES}$ of construction elements (*based on construction type and age*) and typical efficiency values for existing heating plant.

As regards the large public building (*public authorities or institutions providing public services*), the energy certificate must be clearly displayed, in a well-visible place and so clearly shown to the public.

INSPECTIONS OF BOILER AND AIR-CONDITIONING SYSTEMS. The EPBD makes provisions for regular control activities of the right functioning of boilers and air-conditioning plants. The Directive gives different options for boilers, diversifying the time-step between the controls depending on the size of the system, the kind of used fuels, the age of the heat generator.

The single State Governments can provide adequate advices on boiler replacement and other modifications of the heating systems, in order to improve both security and overall energy performances.

The inspections regard also the air-conditioning systems higher than 12 kW output; these need regular inspections, also with reference to the assessment of efficiency and the apt sizing of plant compared with the building cooling requirements. The inspections are considered part of regular maintenance, and are realized through observations of the plant conditions and quantitative measurements. The control regards not only the heat generator equipments but also other operative devices, such as the distribution ducts of the air and the heat emission.

INDEPENDENT EXPERT. Finally, the EPBD article 10 states issues such as the specifications and the training requirements of the professionals involved in the inspections and in the evaluation of the energy performances of the buildings. The Directive reports that "*...Member States shall ensure that the certification of buildings, the drafting of the accompanying recommendations and the inspection of boilers and air-conditioning systems are carried out in an independent manner by qualified and/or accredited experts, whether operating as sole traders or employed by public or private enterprise bodies…*".

The same article requires also that the single EU member States provide indications and criteria about the resource needed at the specific national level, such as the number of required experts, the modalities to assure a right competence of these, different functions and different level of expertise, criteria for their accreditations, code of practice. This point represents a key-aspect in order to make truly effective the EPBD.

In the next paragraph, with reference to 2002/91/EC key points, above reported, a status of the application of the Directive in all the EU-27 States will be singularly and shortly described. The Italy status of EPBD transposition, instead, is reported, in detail, in the paragraph 1.4.

### 1.3.2 EU COUNTRIES LEGISLATIONS FOR THE ENERGY EFFICIENCY IMPROVMENT

Briefly, in this sub-paragraph a current level of transposition, as regards the implementation of Directive 2002/91 (EPBD) in the EU States, is described, with reference to each one of the EU-27 members.

As before said, the EU member States had to transpose the current Directive EPBD into national laws within January 2006. At the time of the 2006 deadline, only Germany had fully implemented the European legislation, while many other countries (*Denmark, Belgium and Netherlands, above all*) were interested by a satisfactory rate of implementation (*today, quite completed*). The most part of other European countries, still now, do not present an adequate state of art.

Even if a full satisfactory implementation is not yet reached, most countries operate with partial measures, recurring to the additional three year period: generally, the States (*for example, Italy and Austria*) provided with a previous energy legislation based of CEN-derived national standards, were able to easily upgrade their measures according to the new EPBD requirements.

On the other hand, above all with reference to the new EU-members, these are characterized by substantial problems largely due to their past, which has excluded them from the European calculation methods and communitarian legislation schemes.

In the followings, a description of the present rate of implementation in the EU-countries is reported, with a little bit more detailed descriptions for the greater countries of the EU, and shortly for the littler member and/or new member States.

**Germany:** the implementation of the EPBD is under the responsibility of the Federal Ministry of Transport, Building and Urban Development, the Ministry of Economics and Technology and the Ministry for the Environment, Natural Conservation and Nuclear Safety.

Energy saving measures, as regards the building sector in Germany, have been enacted staring by the 1976, so that the EPBD transposition is realized inside the legislative corpus of the previous energy saving acts.

Presently, the current Energy Saving Ordinance (*EnEv 2009 - Energieeinsparverordnung*) [25] represents the upgrade of the previous versions 2002, 2004 and 2007, and it fully transposes the EPBD. Further upgrades are periodically established.

The main calculation tools are based on the national technical standard DIN 18599, derived from the European Standard EN 13790 [26]: the calculation methodologies provide holistic assessments of the building thermal envelope; evaluation procedures for lighting, heating, ventilation, cooling and hot water production are also included.

The energy efficiency performance minimum values depend on the surface-to-volume ratio. For existing buildings, the energy performance prescriptions are mandatory for new plant installation, when heating or cooling systems are installed for the first time or renovated.

For significant renovations of the building envelope, the thermal transmittance values provided by the law must be respected and the buildings have to obtain energy performance index not higher than 140% of the limits referred to new building.

About the energy certificate, this is mandatory for new buildings since 2002. Starting by July 2008, it is mandatory for all residential buildings built before 1965, while recent buildings and non-residential ones must adopt the energy label by July 2009.

In large public buildings, the certificate has to be displayed at the building entrance. Architects, civil engineers, and other professionals with an energy related background may issue the energy certificates. The accreditation requirements are responsibility of the German "*Bundesländer*"; about this, significant penalties are established for unauthorised person that issues energy certification. Furthermore, the building owners can be assessed if they do not make an energy certificate accessible to buyers or tenants.

About development and upgrade, the *EnEv 2009* reduces the admitted limit value around 30% compared to the EnEv 2007, and, starting by the 2012 a further 30% reduction has been already programmed.

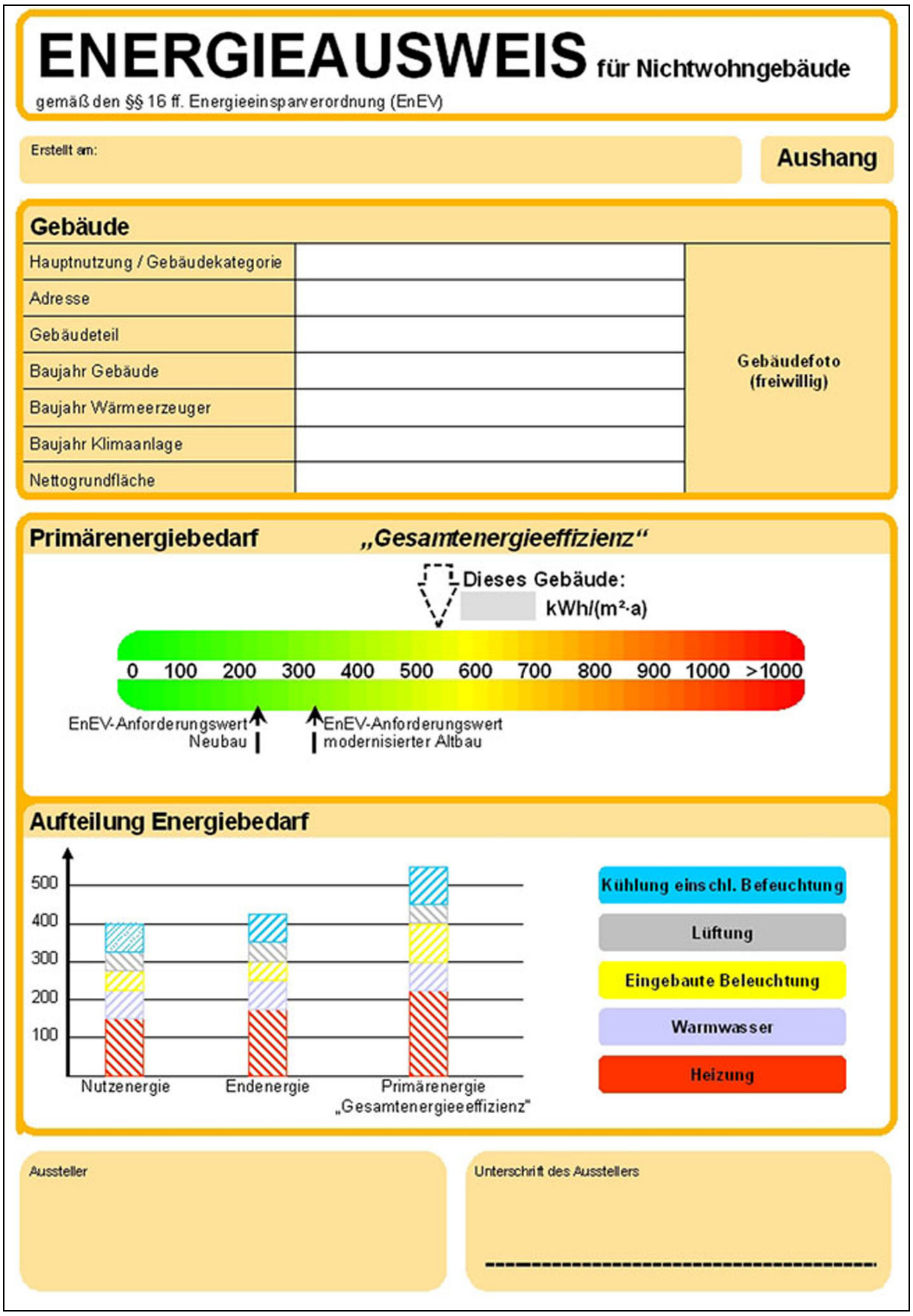


*Figure 1.3.2 – The German energy certificate (Energieausweis)*

**France:** the "*Ministère du Logement et de la Ville*" is responsible for the EPBD implementation. In March 2007, a national Decree (n. 20007-363) was enacted in order to make operative the Directive key-points relative to the energy diagnosis and certifications of buildings, the calculation methods and the inspection criteria, as well as the prescriptions related to the expertise and independence of the involved professionals.

The calculation tool, based on the technical standard RT2005, includes climatic conditions, position and orientation of buildings, indoor microclimate, active solar systems and natural lighting. With "5-years" time step, the methodology is revised and each revision cuts around 15% the energy efficiency requirements. The energy evaluation can be realized both evaluating the historical energy consumptions and using pre-calculated values, based on the estimated characteristics of building and plants.

The energy requirements are diversified depending on the building function and type (*residential, office buildings, schools etc.*). As regards the existing building, the new envelope components will need to fulfil minimum requirements, while, with reference to large renovations, the same limits of new buildings are applied. The energy certificate is mandatory since 2006 for new residential and non-residential buildings, and for existing architectures interested by sale. Furthermore, starting by 2007, the energy label is necessary also when the buildings are rented.

Public buildings over 1000 $m^2$ must show the energy certificate; this is valid for 10 years. Still today, no definitive measures to establish a regular inspection of boilers and systems are completely defined. The experts must guarantee appropriate knowledge and competence, even if no particular degree or experience are necessary; anyway, an exam is required for their accreditation; the exams are organized by company accredited by the French Committee for Accreditation (*COFRAC - Comité Francais d'Accréditation*).

**Spain:** three Royal Decrees implemented the EPBD; the present legislative measures are based on the "Technical code for the edification" published on March 2006, the "Regulations for Thermal Installations in Buildings" published on August 2007 and the "Basic Procedure for Energy Performance Certification of New Buildings" come in force also during the 2007. The Ministry of Housing releases the "*Energy Performance Building Regulations*" (EPBR). Actually, these measures do not implement the CEN standards, so that the prescriptions and methodologies are partially different compared to the methods adopted in the big part of EU countries.

The Spanish methods cover both new buildings and existing ones. The evaluations are realized on the basis of the asset rating: therefore, fixed boundary conditions are considered without attention to the real operational use of the buildings.

The Spanish legislation requires a minimum use of the renewable energy sources, above all as regards the solar thermal systems and the photovoltaic ones.

About the energy performances, the requirements depend on the climatic zones and the building shape, but also on the levels of occupancy. The energy demand of the building should be lower than the request of a reference building. About this, free official softwares are available. Under this national framework, the regional authorities can adopt stricter criteria, providing also more detailed provisions.

All the buildings realized after October 2007 have to be provided with energy certificates. The inspections of heating and cooling systems are differenced on the basis of the kind of systems, the used fuel, the age of the plants. About the heating systems, the time step, among the inspections, are 2, 4 or 5 years, while as regards the cooling devices the controls have to be realized each 1 or 2 years depending on the installed cooling capacity. However, each 6 years, an inspection of the whole system is necessary, contemplating all the sub-systems (*generation, distribution, emission, regulation*).

The inspectors must be well formed, because a great attention to the safety aspects is requires; instead, about the energy certificates, architects and engineers must frequent an additional training and a specific exam in order to be involved in the energy diagnosis and building certificationa. The training is based on regional methodologies and the specific local authorities define modalities for courses and exams.

**<u>Sweden:</u>** the implementation of the EPBD is under the responsibility of the Ministry of Enterprise, Energy and Communications and the National Board of Housing, Building and Planning (BBR).

Starting by the 2006, the Parliament adopted a law regarding the transposition of the EPBD, followed by other upgrading Decrees and Ordinances enacted in the February 2007. The new edition of the Building Regulations (BBR), come in force during the 2008, contains mandatory provisions and general recommendations, upgrading and substantially modifying the old energy prescriptions contained in the Planning and Building Act and Decree (1987, n. 383), in the Act on Technical Requirements for Construction Works (1994) and in the Decree on Technical Requirements for Construction (1994).

The energy verifications adopt always the operational rating (*described in the Chapter 2 of the Thesis*). Thus, for all buildings, the most complete and reliable analysis method provided by the EN 13790 is established. No measured values are available, so that only a physical calculation can be used. The Sweden adopts an official national software (ENORM) [26], that requires diversified input data depending on the kind of building (*residential or not*). The Swedish laws impose, furthermore, maximum energy consumptions for several energy uses (heating, cooling, domestic hot water) per square meter of useful building surface, diversified for the two climate zones characterizing the State. The energy documentation has to be transmitted to the public authorities within 24 month after the building realization, and, about it, inspections and controls of the municipalities are rigorous and frequent.

Starting by the 2009, the energy certification is mandatory for new buildings, while for public ones the energy label has been prepared and shown since the 2008. As regards the existing buildings, the energy label is mandatory, starting by January 2009, when rented or sold.

About the heating/cooling systems, minimum energy efficiency performances are mandatory; it is interesting to note that solid fuel appliances have to be designed with an accumulator, in order to guarantee a correct management of the system.

All the energy certifications and plant inspections have to be carry out by certified experts, accredited from an authorized company. Experts need a degree of technical education, and at least 2-years experience in the building energy audit; anyway, a theoretical exam is however necessary in order to release the energy certificates.

**Denmark**: the Danish Energy Authority and the National Agency of Enterprise and Construction provide the implementation of the EPBD in the state legislation. Even before the 2002/91/CE, in Denmark the building activity was regulated strictly, under the energy efficiency point of view, by a national legislation. Thus, substantially, the EPBD transposition introduces only few new aspects, among which the energy certification and inspection using the new label schemes. An official software must be used and this provides methodologies for different types of buildings. Starting by January 2006, the limits of the energy efficiency parameters have been reduced around 25% compared to the previously admitted values.

All new buildings need an energy diagnosis if heated, with exception of the buildings used for commercial and/or energy production. The admitted energy performances are diversified on the basis of the building function; for example, as regards the dwellings, no lighting verifications are necessary.

During the 2005, an apposite Decree was enacted to regulate the energy labelling of buildings; this imposes energy certification mandatory when the building is built, rented or sold. The energy certificate is valid for 5 years. The certification of blocks of apartments is realized with reference to the whole building with an additional individual certificate for each flats.

The energy certificates include advices to improve the building energy performances; furthermore, in case of renovations, the owner must assure that the new installations, both with reference to the building envelope and the technical equipment, guarantee a good use of energy.

**Belgium:** the transposition of the EPBD is strongly diversified on regional basis; the Brussels Capital Region implemented the EPBD partially in July 2008, with the "*Ordonnance relative à la performance énergetique et au climat intérieur des bâtiments*". The Region had a previous regulation as regards both new and renovated buildings. A quite advanced implementation of the EPBD started during the 2009. The type and level of prescriptions are related to the kind of building (*residential buildings, offices, schools, etc.*). About the energy certification for new and existing buildings, this is mandatory since July 2008. For public buildings and other existing architectures when rented or sold, the certificate became mandatory during the 2009.

The Flemish Region, instead, implemented partially the EPBD during the 2005, establishing a new calculation procedure for several kinds of new buildings; the methods evaluate the envelope thermal insulation, the overall energy performance level and the indoor climate. The prescriptions and methodologies are diversified for each construction type (*new building, refurbishment of a small existing building, extension of an existing building*).

Finally, the Walloon Region implemented the EPBD on 19 April 2007. The calculation procedures have been released on October 2007 and are included in a regional official software. The calculation methods are based on the evaluation of the energy efficiency of the building envelope and technical appliances, as well as on the achievable indoor comfort. Also in this region, methodologies and prescription are diversified on the basis of the building kinds, new or renovated, and the type of use. The requirements for new residential buildings, offices and schools are very strict.

**Netherlands:** the implementation of the EPBD is the responsibility of the Ministry of Housing, Spatial Planning and the Environment (VROM). With the Decree on the Energy Performance of Buildings (BEG), enacted during the 2006, the EPBD was legally implemented. Really, it represents only a harmonization of the previous legal measures, in force since 1995, concerning new buildings and major renovations of existing ones.

Today, for the existing building, the Energy Performance Advice (EPA) has been enacted; With reference to each kind of building, residential or concerning the tertiary sector, compliance of the building energy performances must be given before the construction works finish; the same prescription regards also the major renovations. The local authorities are involved about the controls.

In Netherlands, the energy certificate is necessary for all new buildings and existing flats, if renovated, rented or sold; this last prescription is in force since January 2009.

Inspections are mandatory, with different time-steps, for all the boilers and the air-conditioning systems. Both as regards the building certification and the system inspection, architects and engineers must demonstrate a satisfactory experience referred to the energy efficiency field. Of course, a technical education is required; anyway, also an additional and specific curse in order to become an energy performance inspector is necessary.

**Austria:** the main responsibility for the EPBD implementation regards the Ministry of Economy and Labour, even if local requirements can be inferred also by the regional Governments "*Bundesländer*". On August 2006, the Energy Certification Providing Act (*Energieausweisvorlagegesetz – EAVG*) [28] came into force, together with the OIB-Guideline.

For the new buildings, the prescriptions are in force starting from January 2008, while for the existing ones the deadline is January 2009. At the present moment, the EPBD results fully implemented. The calculation methodologies are quite sophisticated, because of the necessity of harmonization among the old codes and the new European (CEN) standards. The main energy efficiency descriptor is the Energy Index (*Energiekennzahl*). Starting from the 2010, the use of renewable energy sources becomes mandatory for new buildings.

The calculation methodologies for new and existing buildings are the same, even if, in this second case, main default (typical) values can be used. About the proof of compliance, this is necessary both before and after the building realization; also in this nation, the control on the energy measure applications is responsibility of the municipal authorities.

The OIB-Guideline defines the scheme of the energy certificate, mandatory for new buildings and for existing architectures when sold or rented. As in many other European countries, the energy label has to be displayed in all public buildings. About the inspections of boilers and air-conditioners, the frequencies depend on the kind of used fuels and the size of the systems.

Even if the energy efficiency is not a new matter in the Austrian building activity, all the involved professionals must obtain further qualifications in order to operate inspections and energy audits. For architects and civil engineers no further education is necessary.

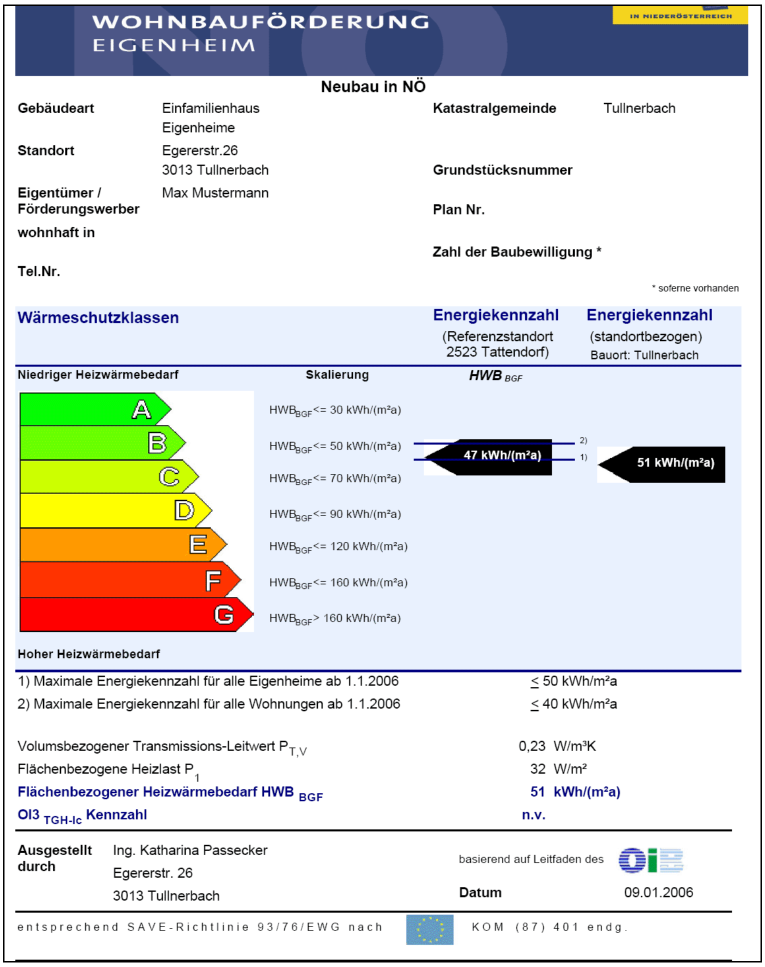


*Figure 1.3.2 – The Austrian energy certificate (Energiekennzahl)*

**<u>Finland:</u>** the implementation of the EPBD is the responsibility of the Ministry of the Environment and the Ministry of Trade and Industry. In April 2007, the Parliament adopted two new acts: "*Act on Building Energy Certification 478/2007*" and "*Act on Inspection of Air-conditioning Systems - 488/2007*". At the same time, the revision of the "*Land Use and Building Act*" (January 2008) completed the new legislation. However, effective saving measures were in force since 1995. The present calculation method, derived form the old one, has been harmonized with the new CEN standards, and published on the National Building Code in 2007. All types of buildings are considered, and progressively the energy requirements become more restrictive. The limit values are the same for all the buildings; today those enacted during the 2003 are in force.

The energy certification is mandatory for all new buildings starting by 2008; existing buildings, when rented or sold, must be provided with an energy certificate starting by January 2009. The boiler and air-conditioner inspections are voluntary and not mandatory. As regards the inspections and the energy audit/certification of buildings, public or private accredited experts can do these: further than a specific technical education, also a theoretical exam is necessary in order to be qualified as certifiers.

**Unit Kingdom:** about the UK, a diversification in the description of the EPBD implementation is necessary. In England and Wales, the transposition is responsibility of the Department for Communities and Local Government, supported by the Department for the Environment, Food and Rural Affairs.

A set of regulations has been enacted during the 2006-2007. The requirements for new and existing buildings came into force during the 2006. An Energy Performance Certificate (EPC) is required before the building construction, but also for existing buildings when sold or rented. The energy certificate (*based on thermal transmittance values, energy efficiency in heating, cooling and lighting*) is valid for 10 years.

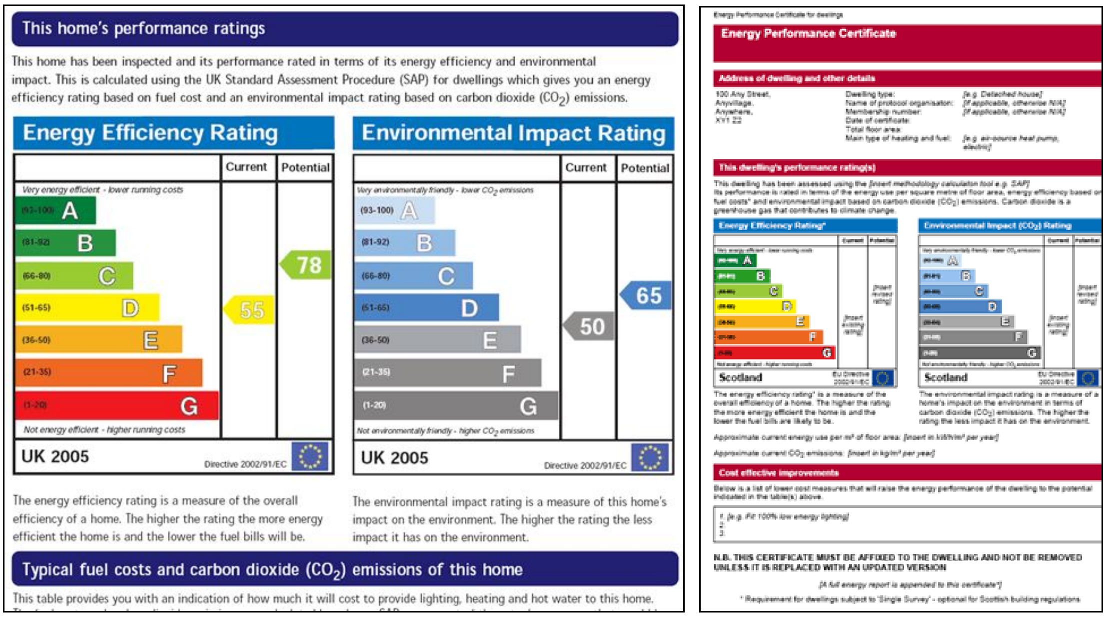


*Figure 1.3.3 – The energy certificates in GB (left) and Scotland (right)*

In Scotland, the transposition of the 2002/91/EC is carried out by the "*Scottish Building Standards Agency (SBS)*", officially involved by the Government. The EPBD has been implemented with the legal measure "The Building Act 2003", even if many other laws and measures were enacted during the 2004, 2006 and 2007; through these, the procedures for a national calculation methodology for building energy performance applicable throughout the UK have been established. In Scotland, the main indicator is based on the $CO_2$ emissions, compared to a limit maximum value (*for* $m^2$); about it, the Government developed software tools.

The energy performances more restrictive are applied to new buildings, extensions, alterations and replacements/rebuilding of existing constructions. The energy certificate must be clearly displayed since January 2009 with reference to all public buildings. When sold or rented, energy certification becomes mandatory also for existing buildings. The Scotland doesn't use the same software (EPC) adopted in England, Wales and Northern Ireland.

Finally, in Northern Ireland, energy requirements for new and existing buildings came into force during the 2006, with technical standards fixed in the "*Technical Booklet F1*".

In the whole UK, the various Governments are involved, together with the heating and hot water industries and manufactures, in the development of a new energy efficiency program toward new efficiency concepts and requirements. A simple checklist and recommendations accompany the inspections, in order to provide guidelines and best practice knowledge.

In England, Wales and Northern Ireland the professional competence of "*energy assessors*" has been created; they require educational competences (technical degree) and must be registered in an official list, after the accreditation at the "National Occupational Standard in Energy Inspection". In Scotland, there is no specified qualification for energy certifiers.

**Ireland:** the implementation of the EPBD is the responsibility of the Department of the Environment, Heritage and Local Government, the Department of Communications, Marine and Natural Resources (DCMNR).

The 2002/91/EC has been transposed into the Irish law during the 2006. After a public consultation, in August 2006 the "*Action Plan for Implementation of the EPBD in Ireland*" was published, setting a punctual timetable to achieve an EPBD full implementation.

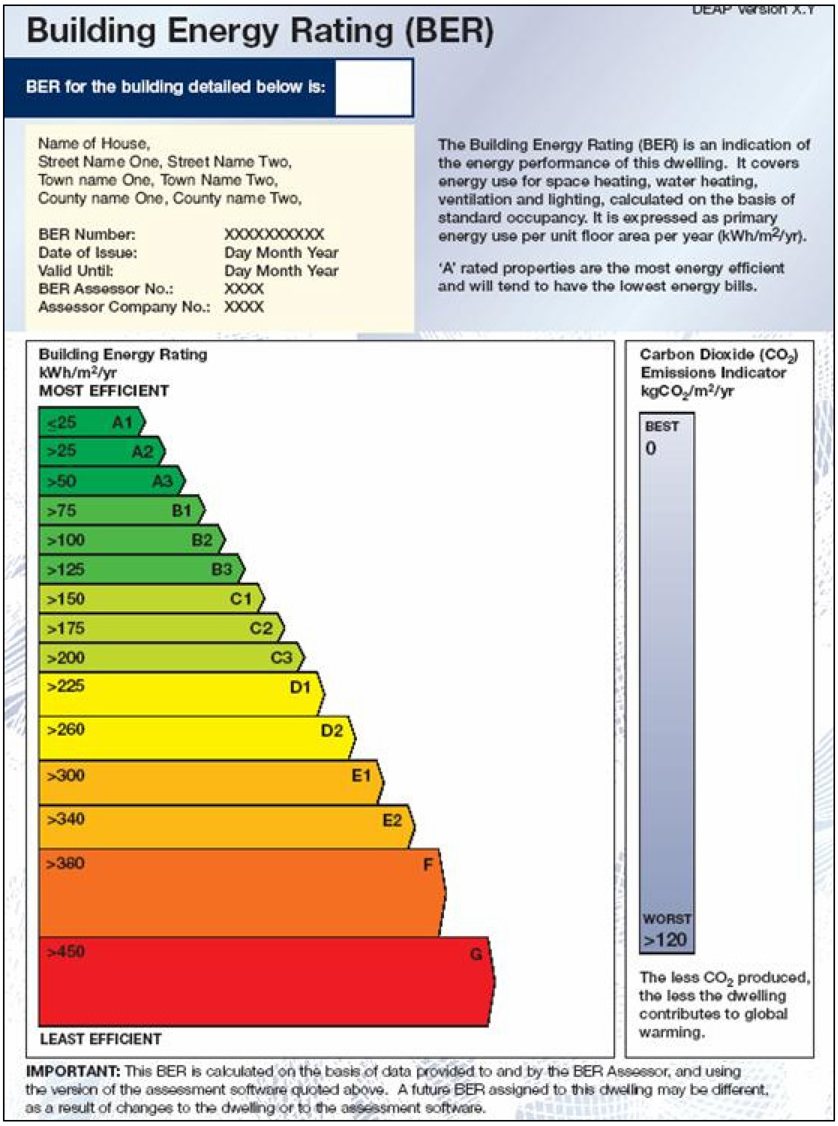


*Figure 1.3.4 – The Irish energy certificate according to the Building Energy Rating (BER)*

The energy performances of new buildings, when residential, are described in the "*Dwellings Energy Assessment Procedure (DEAP)*"; the energy required for space heating, ventilation, water heating and lighting are evaluated.

The evaluations are necessary in order to obtain the construction permit. Type and levels of energy performances depend on building uses (*residential, office buildings, schools…*). Generally, the following limitations are provided: limitation of the building envelope heat losses, limitation of greenhouse gas emissions, minimum efficiency for space heating devices and hot water supply systems. A partial application, with reference to only the renovated parts, interests the existing building since the 1991.

The energy certifications for new buildings are mandatory since 2007; an energy label called "*Building Energy Rating (BER)*" is released during the 2008 for non-residential buildings; this becomes necessary also for existing building starting by 2009. The energy classification uses a scale form A1 to G; besides the present energy performances, the energy certificate contains also advices for the building and appliance improvements.

The "Home-Heating Appliance Register of Performance" regulates the Inspections of boilers and A/C systems. The BER Assessors, that require a technical education (*usually they are building professionals like architects, engineers, etc*), can carry out energy certificates; their registrations at the national list must be renovated yearly.

**Portugal:** the Government has adopted three Decrees during the 2006. The Decrees n. 78/2006, n. 79/2006 and n. 80/2006 represent the transposition of the EPBD into the national legislation. During the 2007, the "*Portaria N.461/2007*" and the "*Portaria N.835/2007*" established timetable for implementation of the building energy certification. The calculation methodologies, harmonized with the European Standards, are defined in the building regulations for residential buildings and in the HVAC regulations for non-residential buildings. A national official software exists and it provides energy audits for both residential and not-residential buildings.

As regards the residential buildings, all the software implementing the admitted calculation standards (*asset rating*) can be used, while, as regards the non-residential large buildings, dynamic energy simulation based on the ASHRAE standard 140-2004 must be used.

During the 2007, the new "*National System for Energy and Indoor Air Quality Certification of Buildings*" came into force, with the 2 primary targets: 1. to save energy, ensuring, at the same time, comfortable conditions; 2. to ensure an acceptable level of indoor air quality.

The new energy requirements and limits are mandatory, in order to achieve the building permits, since 2006. Type and level of requirements depend on the type of building. About the energy certification, this is mandatory for all new buildings (*in a first phase only with reference to those larger than 1000* $m^2$), and it uses a scale ranging from A+ (high efficiency) to G (poor efficiency).

Certifiers must be accredited at a web based central registration system. Inspections of boilers and air-conditioners are covered by the HVAC regulations adopted by the central Government during the April 2006. Only qualified experts can release energy certificates. As regards the inspections of boiler, heating system and air-conditioners, recognised architects or engineers must have an experience at least of 5 years; furthermore, qualified experts must attend recognised courses and pass the necessary national exams.

**Luxemburg:** the implementation of the EPBD is the responsibility of the Department for Energy of the Ministry of Economy and Foreign Trade. Today the modifications at the previous act "*Loi du 5 août 1993 concernant l'utilastion rationnelle de l'energie*" are applied. In particular, at the end of the 2007, the Grand-Ducal Regulation concerning energy performance in buildings was adopted. Also legislative measures to improve the performances of existing buildings have been enacted (*the main reason of this consists in the very poor turn-over rate of the building activity in Luxemburg*). New buildings are interested by energy requirements lower around 30 – 50% compared to the present building stock.

The verifications concern: maximal $U_{VALUES}$ of building elements; air tightness; shading systems; insulations of the pipes, qualitative behaviours of the ventilation systems, the heating demand expressed in primary energy. The same parameters must be evaluated for large renovations.

All new buildings, renovated or existing buildings rented or sold, require a mandatory energy certificate. Regular inspections are necessary for boilers since 2000 (*more frequent when these are older than 15 years*). For the air-conditioners, the amended "*Grand-Ducal Regulation 2004*" covers the inspection mechanisms. Architects, technical engineers and/or accredited experts can carry out the energy evaluations. Finally, as regards the energy certificate, this should contain three indicators: primary energy consumption, heating consumption, $CO_2$ emissions. Each parameter has evaluated on a scale ranging from 1 to 9. The certificate includes also information about the hot water production and energy improvements suggested for the building.

**Malta:** the little island adopted measures to implement the EPBD into national law in November 2006 (LN 238). With this act, the Government issued the minimum requirements for the energy performance of buildings. Today the Decrees of complete transposition of the EPBD are still under discussion; about this, no specific calculation procedure are already available.
Today, a technical document "*Conservation of Fuel, Energy and Natural Resources*" contains all the prescriptions in force. The requirements include verifications of the thermal transmittance values of the building fabric, limitation of window area and containment of the solar heat gains, insulation for cooling and heating system distribution devices, minimum values for the energy efficiency rate of the artificial lighting equipments, conservation and re-use of the rainwater.

These verifications regard new and renovated buildings; with reference to the proof of compliance, this must be provided after the building realization. For residential houses, the calculations have to be done adopting the asset rating (*calculation in standard conditions*), while for large buildings tailored (*operational*) rating evaluations are necessary.

Malta is still working on finalising the national methodologies based on the CEN standards. All new buildings and renovated ones, such as the old buildings rented or sold, need the energy certificate. With reference to inspectors, they must frequent specific courses and relative exams, in order to be accredited at Malta Resources Authority. This institution delegates to other entities the administration, monitoring and enforcement of the provisions. Finally, as regards the inspections of the boilers and of the A/C systems, these are diversified depending on the size and the age of the plants.

**Greece:** A significant delay in the EPBD implementation (*responsibility of the Ministry of Development and the Ministry of Environment*) is registered. On June 2007, about this, European Court of Justice by the European Commission processed the Greece for no information given about the transposition status. Not definite and not exhaustive measures regard, today, the energy calculation, based on the EN 832 (*cancelled by the CEN*). Software tools are still waited for, even if, theoretically, since 2009 the energy certification came into force. Proofs of compliance, with respect to the reference energy performances, are mandatory for all kind of new buildings. The standard A-G label will be used, with a further subdivision in A+, A, and A- (*so that the building efficiency competition can be stimulated*).

**Bulgaria:** during the 2004, the National Assembly of Bulgaria adopted the Energy Efficiency Act (*Decree 54/2004*) and it became law during the 2007, implementing the energy certificate (*label*) as part of the technical passport of the building. The evaluation methodologies have been adopted with the Ordinance on Energy Conservation and Heat Retention of Buildings, in March 2005. Strict energy requirements are provided both for new buildings and renovated ones. The designer technical staff, before the beginning of the construction activity, has to issue the energy label; this document includes the energy performance parameters corresponding to the normative and project requirements.

**Estonia:** the Ministry of Economic Affairs and Communications is involved for the EPBD implementation; still today (*Autumn 2009*), only a draft was approved by the Parliament. The application establishes diversified requirements for new buildings or renovated ones. Theoretically, the energy certification became mandatory starting from 2009.

**Latvia:** the Ministry of Economics has the national responsibility for the EPBD implementation, even if, operatively, the "*Valsts Agentura*" is providing the technical transposition. The methodologies are based on climate conditions and indoor necessities, even if, presently, a delay in the harmonization with the European standards is quite evident. Some requirements already exist about the maximum transmission heat loss coefficient (*overall* $U_{VALUES}$ *of the building*). However, Latvia is using the 3 years prorogation time provided by the European Institutions.

**Czech Republic:** the Ministry of Industry and Trade is responsible for the EPBD implementation. The new legislation came into force during the 2006, with new upgrades of the "*Act of Energy Management*". The new valid calculation methodologies are full based on the CEN standards (*EN 13790 first of all*). The energy performances of new buildings are compared with reference values. The considered parameters are the thermal transmittance of the building envelope and the efficiency ratio of all the technical systems. Certification became mandatory for new buildings and renovated existing architectures starting from January 2009. For inspectors and certifiers, 6 years of relevant experience are required; otherwise, a training course and a state exam should be frequented and passed.

**Slovakia:** on November 2005, the National Council of the Slovak Republic approved Act n. 555/2005, regarding the transposition of the EPBD in the national law; the execution order for this Act was published during the 2006. The National Energy Agency, existing since 1998, in the last years, extended its competences in order to include the new procedures. Inside a national framework, the Regional Authorities established requirements for new and existing buildings, as regards the inspections and the energy certifications. The energy certificate is mandatory for new buildings and major renovations of existing buildings. Furthermore, regular inspections of boiler, air-conditioners and heating systems are also mandatory.

About the certifier accreditation, the Slovak Energy Agency supervises the energy auditor courses, necessary also for all the technical professionals.

**Romania:** the EPBD implementation Law 372/2005 has been adopted by the Parliament. This fixed the national calculation methodologies. Minimum energy efficiency requirements are necessary for new buildings, renovations or extensions. Proof of compliance with respect to the limit values has to be demonstrated before the building construction, and reported in the energy certificate that includes also the reference values.

Presently, the energy certificate is mandatory only for new buildings, while, starting by 2010, this will be mandatory also for existing houses when sold or rented. Inspections for boilers are mandatory since 2007 (*since 2008 as regards the air-conditioners*). About the requisites for certifiers, a specialised course, carried out at the Universities, should be frequented; alternatively, a ministerial exam is necessary.

**Cyprus:** the Laws n. 101/2006 (*"Streets and Buildings Law"*), n. 142/2006 (*"law for the regulation of the energy performance of buildings"*) and the K429/2006 (*"Streets and Building regulations"*) transposed the EPBD into the national legislation. No previous calculation methodologies were available (*Cyprus did not have any previous building energy regulation*).

For this reasons, two ministerial Decrees are still strongly waited for, in order to transpose correctly the European-harmonized calculation procedures. Actually, a simplified methodology for residential building is expected, while, in a second phase, a more detailed calculation procedure for non-residential large building will be developed.

**Hungary:** the Ministerial Decree TNM 7/2006 was enacted and then rejected due to a change in the political administration. Today, no definitive legislative measures are available, and the present administration declares that at the end of 2009 some transposition Decrees will be released. Surely, the MSz-En standard (*directly derived form the EN 13790*) will be adopted. Some commercial computer tools already have been developed, in close cooperation with the ministerial working staff, even if all the other world-famous software (*ESPr, TRYNSIS, and EnergyPlus*) will be accepted.

Although the method of the certification is still under discussion, the rating system and the numeric values were in force since September 2005: the new requirements are mandatory in order to obtain the building permits, and these limits are referred to new buildings and major renovations. Finally, the Chambers of Engineers and Architects agreed for a common examination in order to release the licenses for certifiers and inspectors.

**Lithuania:** the EPBD transposition is under the responsibility of the Ministry of Environment and the Ministry of Economy. The main provisions are contained in the "*Law amending the Law on Construction*" and in the "*Law on Energy of the Republic of Lithuania*". The Building Technical Regulation STR 2005 describes the calculation procedures. Furthermore, a technical standard, the "*Energy Performance of Buildings; Certification of Buildings*" has been also developed. There is a national software based on the EU standards and on the national harmonized ones.

The energy certificate assigns a class, variable from A (*good thermal performances*) to G (*very bad behaviours*); new buildings must results at least C. The limit values are applied only for new buildings, while, for existing buildings sold or rented, anyway a classification has to be done. Inspections are mandatory for heating systems and air-conditioners higher than 12 kW.

The certifiers must frequent and pass the mandatory exams at the "*Architecture and Building Institute*" of the Kaunas Technological University or at the "*Quality Management Centre*" of the Vilnius Technical University. About the inspectors of boilers and A/C, high technical education and three years experience are necessary.

**Poland:** the Ministry of Transport and Construction is responsible for the EPBD implementation. Presently a methodology for calculation, harmonized with the EU standards, has been released: each building is compared to a reference building. For new buildings, proof of compliance has to be issued before the construction. The energy certificate is mandatory since January 2008 (*one year later the deadline for existing buildings when sold or rented*). About the inspections and certification, all the candidates (*building consultants, engineers, architects*) must have a relevant technical education and pass an additional exam.

**Slovenia:** the Ministry of Environment and Spatial Planning is involved for the EPBD transposition. Actually, a full implementation is not operative. Minimum energy requirements are part of the "*Regulation on efficient use of energy in buildings*". The verifications concern the heat demanded for heating and cooling, such as the overall energy uses. Today, the heat energy demand has to be lower, for the new buildings, compared to the 2002 limits. For new buildings, a feasibility analysis is necessary in order to evaluate the best apt technologies. All the new regulations are based on the "*Energy Act*". The energy certification of new buildings and public architectures started during the 2008, while, for the existing buildings, in the first months of 2009. The present "*Environmental Protection Act*" and "*Energy Act*" regulate also the inspections for boilers and air-conditioning systems. As regards the certifiers, qualified engineers release the energy labels; however, an additional training course and exam (*accredited by a central State Commission*) are necessary.

## 1.4 The Italian legislative State of Art

### 1.4.1 National legal framework before the EPBD emanation

The Kippur War (1973), at the same way interesting the whole Europe, caused the acute explosion of the energy question also in Italy, inducing the first national laws as regards a rational use of energy in several sectors.

Today, the same questions about energy savings are still strong actual, not only because of economic reasons and, often, difficulties in the energy supply from foreign lands, but also due to the need to limit emissions of pollutants and greenhouse gases associated to the too large use of fossil fuels.

*Law 373/76*

The first national measure enacted in order to induce, for the new constructions, significant savings as regards the energy demand for the building space heating, was the law 373/1976 [10], emanated as a result of the first energy crisis that led to an international growth of the oil prices. The approach of this act and its implementing Decrees, despite important new requirements regarding the minimum energy efficiency and thermal performances for housing constructions, takes no account of the active heating system energy rates. Contrariwise, minimum energy efficiency indicators of building envelope were fixed, through the introduction of the two parameters Cd and Cv, respectively defined as volumetric thermal coefficient of dispersion for transmission and volumetric thermal coefficient of dispersion for ventilation. In other words, this legal measure fixed limits to the power of heating system, regulating the building envelope thermal losses. No information on the calculation method used for the thermal evaluation was released; about this, the Italian involved professional technicians spontaneously adopted the UNI standard 7357 [29].

Practically, the Law 373/76 introduced the first prescriptions as regards the building thermal insulation, forgetting, completely, the efficiency of the active energy systems

It should be noted that the limitation on power was not at all a real and effective limit, since the UNI 7357, aimed to the calculation of the thermal load for the heating system sizing, gave boundary conditions too much increased, in order to over-size the plant. For example: the considered climatic data were over-estimated, no evaluations of the solar gains were considered, a coefficient of safety was added to the north-exposed structures, no thermal inertia of the building envelope was considered.

Therefore, a significant exasperation of the heat losses was carried out in order to size the heating system to balance any critical condition. It is quite clear that this approach, as regards the limitation of the annual energy requests, is useless.

For these and other reasons, the Law 373 was quite ineffective, even if this Act had the merit to introduce a new interest concerning the energy savings in the building sector.

*Law 10/91*

On January 16, 1991 was published in the Italian Official Gazette the Law January 9, 1991 n. 10 [11], regarding the energy saving in the building sector, and, two years later, the

Presidential Decree n. 412/93 [18] was published, implementing and making feasible the main aspects of this fundamental legal Act.

Theses measure, certainly innovative, set new concepts and energy performance limits with reference to both the building envelope and heating systems, as regards new buildings and existing ones, even if, as regards the building renovations, no application has be done. The new laws applied the UNI technical standards for both the energy balance calculations and the required energy performance verifications.

The contents of the Law 10/91 and the principles on which its application Decrees were based, represent a remarkable and undeniable leap in quality compared to the concept of the previous Law 373/76. In fact, instead of a simple limitation of the heating system power (*not so significant with reference to the annual energy demand*), the limitation of the annual primary energy need was imposed.

Therefore, new technical standards were also necessary, in order to provide the calculation of the building useful energy needs and to evaluate the performance of heating and hot water production systems [16].

*NEW ITALIAN TECHNICAL STANDARDS SUPPORTING THE LAW 10/91 AND THE D.M. 27/07/2005*

In the late ‘80s, the works of the ISO first and then those of the CEN TC 89 provided to the Italian Subcommittee CTI 1 the necessary elements in order to develop the standard UNI 10344 “Calculation of energy” [30]. This technical standard, for the first time at the end of 1993, enabled the calculation of the annual requirement of useful energy for the building envelope in wintertime.

This standard, also promoted by the Ministry of Industry for a full application of Law 10/91, used a corollary set of other standards, such as the UNI 10345 [31], 10346 [32], 10347 [33], 10349 [34], 10351 [35] and 10355 [36].

The UNI 10348 “*Heating system efficiency, calculation methods*” [37], released in the same period, provided a calculation methodology to calculate the four efficiency ratios characteristic of the space heating system ($\eta_{PRODUCTION}$, $\eta_{REGULATION}$, $\eta_{DISTRIBUTION}$, $\eta_{EMISSION}$). The heating plant efficiency ratios, together with the useful (thermal) energy required by the building ($Q_H$ *– evaluated by means of the UNI 10344*), allowed to the evaluation of the overall energy consumption of the building. This new indicator was called FEN (*e.g. Italian acronym for: “building normalized energy need”*) and it was expressed in kJ/m$^3$Kd.

The principles of the new regulations were surely innovative, also considering the energy saving acts enacted, in those years, in the whole Europe. Contrariwise, the support technical standards were completely inadequate, because:

- the FEN (*UNI 10379 - FEN - Method of calculation and verification [38]*) resulted conceptually incorrect and practically not useful. This because the Cd (*volumetric thermal coefficient of dispersion for transmission*) and $\eta_{OVERALL}$ (*annual energy efficiency ratio of the space heating system*) limits, when respected, implied an automatic FEN satisfaction (*with optimal results, much below the limit*): thus this indicator was totally useless.
- the technical standards UNI 10344 and UNI 10379 were characterized by serious

mistakes, and thus would provide data with no practical usefulness.

During the 1994, the Ministry of Industry implemented the cited methods, and, still some years later, the pressing demands for their corrections and upgrading were unheard. Only recently, especially thanks to the evolving European legislation, considerable progress as regards the calculation methods was developed. In particular:

- the UNI-EN 12831/2003 "*Heating systems in buildings - Method for calculation of the design heat load*" [39] replaced the UNI 7357 for the calculation of winter thermal loads;
- the UNI-EN 832 "*Thermal Performance of Buildings - Calculation of Energy Use for Heating - Residential Buildings*" [40] (*today cancelled by the CEN*) replaced the standard UNI 10344;
- the EN-ISO 13788/2001 "*Hygrothermal performance of building components and building elements - Internal surface temperature to avoid critical surface humidity and interstitial condensation - Calculation methods*" [41] provided a new method for testing the walls under the humidity and water condensation point of view;
- the recommendation CTI R03/03 [42] provided the parameters and data for the national implementation of the UNI-EN 832 and UNI 10348, in order to upgrade and better carry out the calculations necessary for the building energy certification;
- the standard UNI EN 13790/2005 and 2008 "*Energy performance of buildings - Calculation of energy use for space heating and cooling*" [26] extended the method of calculation provided by the UNI EN 832, including the energy requirements of non-residential buildings and the evaluation of the building summer performances. As it will shows in the followings, this standard, transposed in Italy during the 2008 by means of the UNI TS 11300 [14, 43, 44, 45], represents the main document as regards the evaluation of the building energy performances and for the EPBB target calculations.

About the summer energy verifications, even if introduced during the 1991 by the Law 10, these became a legal real prescription only 15 years later, with the emanation of Ministerial Decree 27/07/2005, which collects some indications of the European Directive 2002/91/EC. As regards the energy certification, although introduced and required by the text of the Law 10/1990 and confirmed by Presidential Decree 412/93, was not defined and, therefore, never came into force.

As before cited, the Ministerial Decree 27/07/2005 amended the methods for the determination of Cd, multiplying it by some corrective coefficients which were related to the building envelope thermal mass. Practically, the new formulation was designed in order to favourite the buildings with high thermal mass, predictive, in the mind of the legislative committee, of a certain capability in containing the summer indoor overheating (*guarantying better behaviours of the building shell during the cooling season, above all in reducing and shifting the diurnal peak load*).

Despite the new Cd was characterized by a very short life, being removed 1 month later with the emanation of the Legislative Decree 192/2005, it introduced some new signs. In fact, the new concepts of attenuation factor and time lag effect of the summer thermal wave were transposed into the Italian energy legislation. These two parameters, respectively indicated as (fa) and (S), such as defined by the European Technical standards EN 13786/2001 (*upgraded during the 2008*) [46], are expressive of the building thermal inertia, and so of the building attitude to store the thermal energy, shifting its transfer inside the spaces and reducing, meanly, the peak indoor temperatures. In the Chapters 2, 3 and 4 of this Thesis, the effects of a high massive building envelope will be exhaustively described.

The Ministerial Decree 27/07/2005 (article 7) also established other requirements for new buildings, for example about the mandatory uses of window shading systems (*fixed or mobile, such to stop the 70% of the direct solar radiation in summertime*) and as regards the mandatory calculation of the indoor temperature during the warm season considering the building as naturally ventilated.

The new parameters and summer performance indicators were surely not at all defined and useful; however, already 4 years ago, the summer performance was considered a primary aspect of the overall system building behaviour and quality. Only 4 years later, the Presidential Decree 59/2009 [19] made finally effective this new attention, both in reducing the active cooling needs in air-conditioned buildings and to limit the indoor temperature increases in naturally ventilated ones.

### 1.4.2 THE EPBD TRANSPOSITION: LEGISLATIVE DECREES 192/2005 AND 311/2006

Following the emanation of the EPBD, in Italy, the implementation of the European Directive was demanded to the Ministry of Economic Development, in collaboration with the Ministry of Environment and the Ministry of Infrastructures.

The first official transposition Act was enacted on August 19, 2005, when the Council of Ministers approved the Legislative Decree n. 192/2005 [12], representing a general framework for the EPBD transposition. One year later, on December 2006, the Council of Ministers adopted a new Legislative Decree, n. 311/2006 [13], regarding modifications and extensions of the Decree 192/2005.

At the present moment, after the emanations of the Legislative Decree 115/2008, the Presidential Decree 59/2009 and the Ministerial Decree 26/06/2009 (*containing the so-called Guidelines for the Energy Certifications of Buildings*) a quite complete implementation of the EPBD in the national legislation is achieved, even if some specifications have to be still emanated.

However, the federal scheme of the Italian asset, under the energy topic, makes possible the setting of technical Guidelines, rules and general inspections diversified at regional level, inside a national framework. Presently (*Autumn* 2009), some Regions provide autonomously, others, instead, adopted the national methods.

As above described, in Italy previous regulations about the energy performance of buildings were already based on technical standard provided by the UNI, Italian Organization for Standardization, which recently bases the new developed standards on the European ones, in particular referring the calculation methodologies to the CEN indications.

The publication of the Energy Performance of Buildings Directive was followed up by an official Mandate to the CEN for developing a set of standards related to the building energy efficiency; the mandate M343/2004 [24] was officially enacted to support the EU Member States for the specific implementation of the EPBD. All the standards (around 30) are defined in the CEN "Umbrella Document" (CEN/TR 15615 2007 [47]), and, today, are quite all published and into force.

The UNI standards, thus, represent a national transposition of the CEN ones, so that the Italian legislation, in the last years, varied the calculation methodologies depending on the state of art of the European methods and the national technical transposition. In the following chapter, a full description of the present methodology will be reported.

The Italian Government revised the minimum requirements of all new buildings during the 2006, with the emanation of the Legislative Decree 311. The minimum requirement applications are phased according to the date of the building permit request:

- first step: building permit requests after 1 January 2006;
- second step: building permit requests after 1 January 2008;
- third step: building permit requests after 1 January 2010.

Practically, designers and director of the works have the responsibility of the satisfaction of the minimum energy efficiency performances, both as regards the building and the related active energy systems; type and level of performance requirements for heating vary according to the function of the building (*residential, non-residential*). As regards the controls of the legal application, the competence is of the municipality where the building is located.

Furthermore, in all new buildings, the Italian legislation requires mandatory installation of solar thermal systems for domestic hot water production and photovoltaic systems to integrate the electric supply.

As regards the existing buildings when interested by renovations, the Government imposed the verification of the energy performance indexes, through a gradual approach:

- integral application to the whole building in case of total retrofit or demolition and reconstruction of existing buildings; this when the building has a useful surface higher than 1000 $m^2$;
- integral application, but limited to the new parts, when the building extensions regard more than 20% of the original volume;
- application limited to single parameters, performance levels and prescriptions when the intervention on an existing building regards specific components or active energy equipments.

With reference to the energy certification of the buildings, theoretically this started 30 days after the publication of the new Decree 311 (*February 2007*). Actually, only in the summer 2009, with the promulgation of the National Guidelines for the Building Energy Certification, a certification scheme has been defined, so that, until the last summer, only a qualitative evaluation could be carried out, without placement of the building into the graduate scale ranging from A to G (*expressive of the energy quality of the architecture*).

The energy audit provided by the Decree 192/05, as amended by Decree 311/06, concerns the enforcement of minimum (*or maximum*) values of the following parameters:

- thermal transmittance $U_{VALUES}$ of opaque vertical, horizontal and inclined opaque walls, as well as for the components of transparent surfaces;
- verification of the overall energy efficiency ratio of the heating systems ($\eta_{OVERALL}$);
- calculation of the index of energy performance for the winter space heating (*the so-called* $EP_i$).

According to the Legislative Decrees 192/2005 and 311/2006, the energy performance index of the building is calculated only for the wintertime (*i.e. the* $EP_i$). Today, after the entry into force of the Presidential Decree 59/2009, also the summer cooling energy need has to be verified, only with reference to the building envelope (*i.e. the* $EP_{e,invol}$) and so neglecting the increasing effects due to the cooling system inefficiencies.

Before a description of the main verifications, some definitions should be clarified. In particular, the annual requirements of primary energy for the winter heating, $EP_i$, is defined as the amount of primary energy globally demanded yearly to keep the rooms at the indoor set-point temperature (*in Italy → 20 °C*) considering a continuous use (24h) of the system during the heating period. The EP is calculated per unit area of the building and expressed in kWh/m$^2$ year.

Different maximum values, depending on the climate zone and on the surface-to-volume ratio, are reported into the Annex C of the Decree 311/2006, progressively more restrictive ranging the application period 2006, 2008, 2010, as expressed in the following tables I.9 and I.10.

Table I.9: energy performance index for the winter heating ($EP_i$): admitted values for dwellings.

| *2006 - Limit of the $EP_i$, depending on the year, degrees-day, surface-to-volume ratio (kWh/m$^2$a)* | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| S/V | Climatic zone | | | | | | | | | |
| | A | B | | C | | D | | E | | F |
| | Kd | Kd | Kd | Kd | Kd | Kd | Kd | Kd | Kd | Kd |
| | < 600 | 601 | 900 | 901 | 1400 | 1401 | 2100 | 2101 | 3000 | > 3000 |
| ≤ 0,2 | 10 | 10 | 15 | 15 | 25 | 25 | 40 | 40 | 55 | 55 |
| ≥ 0,9 | 45 | 45 | 60 | 60 | 85 | 85 | 110 | 110 | 145 | 145 |
| | | | | | | | | | | |
| *2008 - Limit of the $EP_i$, depending on the year, degrees-day, surface-to-volume ratio (kWh/m$^2$a)* | | | | | | | | | | |
| S/V | Climatic zone | | | | | | | | | |
| | A | B | | C | | D | | E | | F |
| | Kd | Kd | Kd | Kd | Kd | Kd | Kd | Kd | Kd | Kd |
| | < 600 | 601 | 900 | 901 | 1400 | 1401 | 2100 | 2101 | 3000 | > 3000 |
| ≤ 0,2 | 9,5 | 9,5 | 14 | 14 | 23 | 23 | 37 | 37 | 52 | 52 |
| ≥ 0,9 | 41 | 41 | 55 | 55 | 78 | 78 | 100 | 100 | 133 | 133 |
| | | | | | | | | | | |
| *2010 - Limit of the $EP_i$, depending on the year, degrees-day, surface-to-volume ratio (kWh/m$^2$a)* | | | | | | | | | | |
| S/V | Climatic zone | | | | | | | | | |
| | A | B | | C | | D | | E | | F |
| | Kd | Kd | Kd | Kd | Kd | Kd | Kd | Kd | Kd | Kd |
| | < 600 | 601 | 900 | 901 | 1400 | 1401 | 2100 | 2101 | 3000 | > 3000 |
| ≤ 0,2 | 8,5 | 8,5 | 12,8 | 12,8 | 21,3 | 21,3 | 34 | 34 | 46,8 | 46,88 |
| ≥ 0,9 | 36 | 36 | 48 | 48 | 68 | 68 | 88 | 88 | 116 | 116 |

As regards the heating system, the Decree 192/2005 (*modified according to the Decree 311/2006*) provides prescriptions about the minimum requirements of the overall seasonal energy efficiency ratio, defined as "*the ratio between the thermal demand for the winter heating and the energy requests in terms of primary energy sources, including the electric demands for the auxiliary equipments*". The $\eta_{OVERALL}$ was calculated adopting the apposite technical standards (*UNI 10348 [37] when the legislative Decree 311/2006 was enacted, the UNI TS 11300-2 [43] at the present moment*).

Table I.10: energy performance index for the winter heating (EP): admitted values for the other buildings

| All the other buildings | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| *2006 - Limit of the $EP_i$, depending on the year, degrees-day, surface-to-volume ratio (kWh/m$^3$a)* | | | | | | | | | | |
| S/V | Climatic zone | | | | | | | | | |
| | A | B | | C | | D | | E | | F |
| | Kd | Kd | Kd | Kd | Kd | Kd | Kd | Kd | Kd | Kd |
| | < 600 | 601 | 900 | 901 | 1400 | 1401 | 2100 | 2101 | 3000 | > 3000 |
| ≤ 0,2 | 2,5 | 2,5 | 4,5 | 4,5 | 7,5 | 7,5 | 12 | 12 | 16 | 16 |
| ≥ 0,9 | 11 | 11 | 17 | 17 | 23 | 23 | 30 | 30 | 41 | 41 |
| | | | | | | | | | | |
| *2008 - Limit of the $EP_i$, depending on the year, degrees-day, surface-to-volume ratio (kWh/m$^3$a)* | | | | | | | | | | |
| S/V | Climatic zone | | | | | | | | | |
| | A | B | | C | | D | | E | | F |
| | Kd | Kd | Kd | Kd | Kd | Kd | Kd | Kd | Kd | Kd |
| | < 600 | 601 | 900 | 901 | 1400 | 1401 | 2100 | 2101 | 3000 | > 3000 |
| ≤ 0,2 | 2,5 | 2,5 | 4,5 | 4,5 | 6,5 | 6,5 | 10,5 | 10,5 | 14,5 | 14,5 |
| ≥ 0,9 | 9 | 9 | 14 | 14 | 20 | 20 | 26 | 26 | 36 | 36 |
| | | | | | | | | | | |
| *2010 - Limit of the $EP_i$, depending on the year, degrees-day, surface-to-volume ratio (kWh/m$^3$a)* | | | | | | | | | | |
| S/V | Climatic zone | | | | | | | | | |
| | A | B | | C | | D | | E | | F |
| | Kd | Kd | Kd | Kd | Kd | Kd | Kd | Kd | Kd | Kd |
| | < 600 | 601 | 900 | 901 | 1400 | 1401 | 2100 | 2101 | 3000 | > 3000 |
| ≤ 0,2 | 2 | 2 | 3,6 | 3,6 | 6 | 6 | 9,6 | 9,6 | 12,7 | 12,7 |
| ≥ 0,9 | 8,2 | 8,2 | 12,8 | 12,8 | 17,3 | 17,3 | 22,5 | 22,5 | 31 | 31 |

The annex I of the Decree 192 shows the formula for calculating the $\eta_{OVERALL}$ minimum threshold:

$$\eta_g = (75 + 3 \log Pn)\%$$

where log PN is the logarithm to base 10 of the nominal energy efficiency of the heat generator, expressed in kW. For values higher than 1000 kW, the minimum threshold for the $\eta_{OVERALL}$ is 84%.

About the three verifications (*i.e. 1: $EP_i$; 2: thermal transmittances, 3: heating system efficiency*), the first never can admit values higher than the maximum ones, while, as regards the $U_{VALUES}$ and $\eta_{OVERALL}$, more permissive values are allowed when the calculation of the EP gives satisfactory results.

For a full description of all the mechanisms, variable depending on the kind of building (*new or renovated*), the Annex I of the Legislative Decree 192/2005 describes all the various possibilities.

ENERGY PERFORMANCES OF THE BUILING ENVELOPE COMPONENTS. As regards the building envelope, all the opaque horizontal and vertical structures have to guarantee a satisfactory thermal insulation, so that maximum values for their thermal transmittances are provided in the Annex C of the Decree 192/2005.

Of course, the more restrictive values are related to the external envelope structures, even if, also for the internal partitions, limit values are prescribed.

The thermal transmittance is a well-indicated parameter only in order to verify the wintertime building envelope performances, being, during the heating season, the transient phenomena less influent than in summertime.

The method to evaluate the $U_{VALUES}$ is provided by the UNI EN ISO 6946 [48] as regards the opaque structures, while for the transparent components, the UNI EN ISO 10077-1 [49] and UNI EN ISO 10077-2 [50] provide respectively a simplified calculation and a more detailed one, based on the numerical methodologies of the finite differences.

In the tables I.11 – I.14, the limits of the thermal transmittance values for each type of component and climatic zone, as prescribed by the Decree 192/2005 – Annex C – are reported.

As regards the transparent building components, the Decree 192/2005 provides the average thermal transmittance of the whole window including frames and glass, and also referred to the only transparent part (table I.14).

Table I.4.11: Decree 192/2005 - $U_{VALUES}$ for vertical walls

| Vertical Wall Thermal Transmittance - Maximum Values | | | |
|---|---|---|---|
| Climatic Zone | 2006 | 2008 | 2010 |
| | W/m$^2$K | | |
| A | 0.85 | 0.72 | 0.62 |
| B | 0.64 | 0.54 | 0.48 |
| C | 0.57 | 0.46 | 0.40 |
| D | 0.50 | 0.40 | 0.36 |
| E | 0.46 | 0.37 | 0.34 |
| F | 0.44 | 0.35 | 0.33 |

In the reported tables, very low values imposed for the opaque structures can be noted, above all starting by the 2010 (*when the Italian legislation will be full operative*). As regards the transparent components, the admitted $U_{VALUES}$, depending on the different climatic zones, are very different, because, above all in the southern-Italy, the winter obtainable solar free gains are not negligible, so that, globally, well-positioned windows do not cause always energy losses (*this point will be accurately clarified and critically discussed in the Chapter 3 of this Thesis*).

Table I.12: Decree 192/2005 - $U_{VALUES}$ for roof

| Roof Thermal Transmittance - Maximum Values | | | |
|---|---|---|---|
| Climatic Zone | 2006 | 2008 | 2010 |
| | W/m²K | | |
| A | 0.80 | 0.42 | 0.38 |
| B | 0.60 | 0.42 | 0.38 |
| C | 0.55 | 0.42 | 0.38 |
| D | 0.46 | 0.35 | 0.32 |
| E | 0.43 | 0.32 | 0.30 |
| F | 0.41 | 0.31 | 0.29 |

Table I.13: Decree 192/2005 - $U_{VALUES}$ for basement

| Basement Thermal Transmittance - Maximum Values | | | |
|---|---|---|---|
| Climatic Zone | 2006 | 2008 | 2010 |
| | W/m²K | | |
| A | 0.80 | 0.74 | 0.65 |
| B | 0.60 | 0.55 | 0.49 |
| C | 0.55 | 0.49 | 0.42 |
| D | 0.46 | 0.41 | 0.36 |
| E | 0.43 | 0.38 | 0.33 |
| F | 0.41 | 0.36 | 0.32 |

Table I.14: Decree 192/2005 - $U_{VALUES}$ for windows and glasses

| Windows Thermal Transmittance - Maximum Values | | | |
|---|---|---|---|
| Frames + Glass (only glass) | | | |
| Climatic Zone | 2006 | 2008 | 2010 |
| | W/m²K | | |
| A | 5.50 (5.00) | 5.00 (4.50) | 4.60 (3.70) |
| B | 4.00 (4.00) | 3.60 (3.40) | 3.00 (2.70) |
| C | 3.30 (3.00) | 3.00 (2.30) | 2.60 (2.10) |
| D | 3.10 (2.60) | 2.80 (2.10) | 2.40 (1.90) |
| E | 2.80 (2.40) | 2.40 (1.90) | 2.20 (1.70) |
| F | 2.40 (2.30) | 2.20 (1.70) | 2.00 (1.30) |

As above-mentioned, a further limit regards the thermal transmittance of the building internal partitions; the imposed maximum value is equal to 0.8 W/m$^2$K in all the Italian climates.

As regards the thermal bridges, no limitations are imposed, even if their presence induces the increase of the calculated wall thermal transmittance, because the weighted media between the current wall and the part characterized by the thermal criticality should be considered. When the thermal bridge is characterized by an $U_{VALUE}$ lower than 1.15% of the current wall, it is considered "correct" and no further verifications are required.

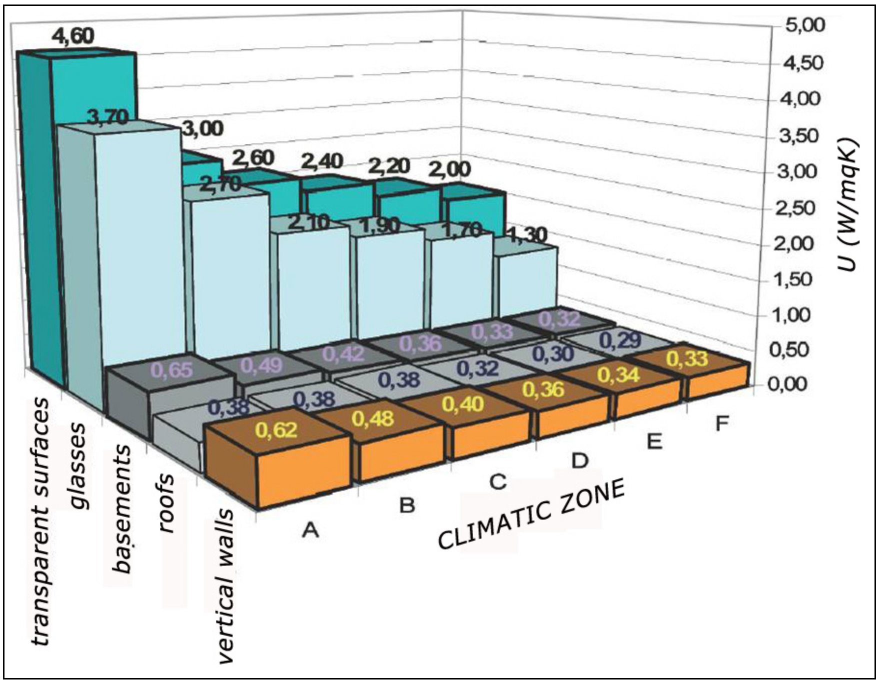


*Figure 1.4.1 – Admitted U $_{VALUES}$ depending on the climatic zones*

It is important to underline that, considering the typical European building technologies for housing (*reinforced concrete and hollow bricks*), without any attention to the most common thermal bridges (*pillars, beams perimeter edge, balconies, etc.*), also an increase around 30 – 40% in the amount of the thermal losses in wintertime can be determined. About this aspect, often the designers do not consider that the thermal bridges are much more penalizing in high insulated buildings.

QUALITATIVE REQUIREMENTS. The Legislative Decree 192 also imposes a number of "*qualitative*" additional verifications; in particular, some characteristics and behaviours of the building envelope require a great attention during the planning phase, in order to reduce the summer heat gains and to increase the indoor comfort conditions in naturally ventilated buildings. Furthermore, during the design phase, the professionals have to verify that the opaque structures do not be interested by formation of condensed water, due to the vapour flux through these in wintertime: the verification must be carried out considering different classes of indoor vapour condensation, or imposing the internal conditions (*relative humidity = 65%, temperature = 20°C*) in air-conditioned buildings.

As regards the summer performances of the building envelope, the Legislative Decree 192/2005 doesn't impose quantitative verifications, because the cooling season evaluation results much more complicated compared to the winter one, due to the dynamic phenomena that cannot be neglected. Therefore, only qualitative indications were suggested, such as:

- the mandatory use of windows shadings, in order to reduce the entering radiative energy through the transparent building envelope surfaces;
- verification of the thermal mass of the building envelopes: in particular, in the Italian locations characterized by an average daily solar irradiation (*during the month characterized by the higher intensity*) higher than 290 W/m$^2$, the building structures must be realized with a thermal mass higher than 230 kg/m$^2$. This was established in order to guarantee an elevated time lag of the thermal wave and a satisfactory attenuation factor of this. The prescription, substantially, imposed a high thermal inertia of the building. This thermal parameter (*function of specific heat, density and thermal conductivity of the envelope structures*) describes the shell ability in storing thermal energy, delaying and mitigating the thermal transfer. The technical standard of reference (Annex M) is the UNI EN ISO 13786 – "*Thermal performance of building components - Dynamic thermal characteristics - Calculation methods*" which specifies the characteristics related to the dynamic thermal behaviour of a building component and provides methods for the necessary calculations;
- instead of the verification of a high inertia of the building envelope (*obtained adopting high masses for the opaque structures*), the Decree 192/2005 admits also verifications based on other methods, in order to achieve the same results with different technologies. In fact, the Annex I admits (*if accompanied by apt documentation of equivalence*), alternative solutions if the obtainable time lag and attenuation effects are effective. Therefore, also innovative solutions can be used, among which the phase change materials (*not directly cited*), included in multi-layers components. This technology, applied for example inside the internal plaster, if correctly designed, can increase effectively the wall heat capacity during the PCM phase transition. Of course, a well-apt design is necessary, above all as regards the selection of the material and its melting temperature, in order to obtain significant heat storing effects; for these reasons, the Decree 192 requires a punctual documentation of effectiveness.

*As it will be described in the followings, the recent Presidential Decree 59/2009 [19] and Ministerial Decree 26/06/2009 changed significantly some of these prescriptions and related verifications, above all as regards the summertime energy performances.*

THE BUILDING ENERGY CERTIFICATION. The previous Italian Government imposed that the energy certification gradually became mandatory for all new constructions, and also when an existing building was sold or rented, according to the following three steps:

- July 2007 → buildings above 1000 m$^2$;
- July 2008 → buildings below 1000 m$^2$ (excluding single flats);
- July 2009 → all flats.

With the Law 133/2008 "*Conversion in law, with modifications, of Decree 25 June 2008, n. 112, bringing urgent dispositions for the economic development, the simplification, the competitiveness, the stabilization of the public finance and the fiscal measures*", the Italian Institution annulled the necessity of the energy certification for the flats sold or rented. This represents a dangerous reverse step as regards the application of an effective energy policy (*actually, the energy certification is, however, necessary even if not indispensable to make effective the legal property transfer act*). Anyway, about this, the European Union, during the 2009, processed the Italian Institutions.

For new buildings exceeding 1000 $m^2$, the clear display of the certificate is still today required. The same obligation is extended to existing public buildings, when new energy service contracts are signed (*starting by July 2007*).

BOILER AND A/C INSPECTIONS. About the inspections of boilers, gas heaters and air-conditioners, several modifications with respect to the prescriptions of the Law 10/91 have been applied with the new legislations.

In particular, the Decree 311/2006 modified some procedures, giving more responsibility to the local Authorities (*Regions and Municipalities*), admitting also longer time step for the inspections of small gas boilers, both with reference to the maintenance operations and the control activities.

About the air-conditioning systems, the procedures for inspection of A/C systems are still under discussion, so that the Italian Government has required the three years derogation period. At the same way, the requisites necessary for certifiers and inspectors not yet are clear; some regions (*Lombardia, Liguria, Emilia Romagna, Piemonte and a couple of others*) provided with regional methodologies for diagnosis, certifications and accreditation of certifiers. Nationally, at the present moment, the Presidential Decree that defines the procedures necessary to become energy certifiers are not yet available (*at the same way, a great delay interested also the emanation of the "Guidelines for the building energy certification", being this enacted only at the end of June 2009*). Really, the Decree 192 imposed that a full application of the new legislation should be enacted within 180 days.

*Well, after 4 years, some Decrees are not yet available!*

Moreover, since 1 January 2007, the energy certificate is required in order to have access to any type of public incentive for improving the energy performances, like:

- a 55% fiscal deduction for the costs related to the building energy renovations;
- the new premium rate program – the "*Feed-in-Tariffs*" - for photovoltaic systems.

For new buildings exceeding 1000 $m^2$, the compulsory display of the certificate is mandatory. As previously already mentioned, the energy certificate is also mandatory for the existing public buildings, when an energy service contract of any type is signed, starting since the July 2007.

REQUISITES FOR CERTIFIERS. About the training of experts for the building energy audit and certification, as shown in the followings, the Italian law establishes the competence of both Regions and Central State, in the same time. About this, the training of independent experts varies thorough the various Italian Regions, even if, generally, professionals qualified by a technical education should however frequent a training regional course and related exam (*and also a registration/accreditation at regional level is quite always required*).

*Some anticipations of the future national rules for the certifier qualifications, automatically seem qualify Architects and Engineers.*

### 1.4.3 THE LAST LEGAL ACTS: LEGISLATIVE DECREE 115/2008, PRESIDENTIAL DECREE 59/2009 AND MINISTERIAL DECREE 26/06/2009

At the present moment, the EPBD transposition is quite complete, even if some minor legal Acts are not yet enacted, so that no all the European Directive topics are completely transposed. In the last months, the main legal measures enacted toward a full application of the EPBD are:

- the Legislative Decree 115/2008 "Actuation of the EU Directive 2006/32/EC on the end-use efficiency and energy services" [51];
- the Italian Republic Presidential Decree 59/2009 "Criteria, methods of calculation and minimum standards for buildings and plants" [19].
- Ministerial Decree 26/062009, containing the "*National Guidelines for the Building Energy Certification*" [52].

#### A) LEGISLATIVE DECREE 115/2008

The Decree 115 came into force in the Italian legislation during the July 2008, transposing, into the national legal context, the prescriptions of the European Union as regards the end-energy uses. The Decree 115 is strongly linked to the energy efficiency measures above described and regarding the building sector, representing a great novelty as regards the Italian contexts, fixing several prescriptions, both building related and not, with reference to various uses of energy. In the followings, a brief summary and description of the most important news are reported.

First of all, the ENEA, Italian National Agency for the new Technologies, Energy and Environment, is involved into the role of Official National Agency for the development, adoption and control of the efficient use of energy. Thus, the ENEA, will assist officially the Ministry of the Industry in all the supporting activities for the best implementation and diffusion of a new energy culture.

The Decree 115 officially defines the role of the ESCO (*Energy Service COmpany*), identifying these as private or public agencies characterized by the functions of service societies, with the missions of technical and financial supports to various energy efficiency actions. The Decree introduces also financial measures to support the ESCO activities.

Furthermore, a better division and clarification as regards the national and local competences about the energy strategic topics are also reported, in order to improve and harmonize the national energy policy. Other important and significant news involve changes relatively to the mechanism of the white certificates (*described in the next sub-paragraph*): among these, the extent of the obligations for the companies selling energy and the strengthening of instruments in order to facilitate the submission of projects.

About the energy efficiency in the building sector, the Decree 115 establishes the simplification of several authorizations and administrative necessities (such as the building permit for the realization of renewable sources plant), in order to favourite energy oriented building improvements. In particular, an important role is assigned to the public sector, that must be strongly oriented to the best uses of the technical, financial and economic instruments to spread actions for the energy efficiency diffusion (*i.e. promoting: the building energy audits, the building renovation toward to a best energy use, green procurements, promotions of third party financing actions*).

The Decree 115 promotes the high formation and qualification of the professionals involved into the energy sector, also evidencing the necessity of higher user information and awareness. About this, for example, a higher transparency in the energy bills (*in order to spread the consumer involvement and to reduce the energy waste*) is also suggested.

This legal Act also designs several financial, technical and legal accompanying measures in order to make effective the energy efficiency actions and plans. A complete definition of the “energy service contract” and “energy service contract plus” (*introduced previously by the Presidential Decree 412/93*) is reported; about this, the importance for the public sector to identify a counterparty (*the energy manager, where applicable*) is underlined.

Finally, the criteria and competences required for the qualification of the professionals involved in the energy certification activity are partially clarified. In particular, authorizations are automatically achieved, at National level, for technician qualified to the design of buildings and plants (*Architects, civil Engineers*), if accredited at the specific professional orders. Otherwise, the Regions and autonomous Provinces can qualify, after courses and examinations, other professionals too, but only for the energy certification of the buildings and not for the design of energy efficiency measures.

### B) Italian Republic Presidential Decree 59/2009

Three years later than the expectation time, some points regarding the full implementation of the EPBD (*delayed by the Decree 192/2005 to future legal acts*) came into force during the June 2009.

The Presidential Decree 59/2009 [19] represents a fundamental part of the Italian Legislation, having determined the overtaking of the transient regime established by the Annex I of the Decree 192.

The D.P.R. (*i.e. Italian Republic Presidential Decree*) 59/2009 defines criteria and methods for energy calculation and minimum energy requirements as regards both the building envelope and the installed active energy equipments. Several points are really innovative, while many others provide a simple transposition into the definitive energy legislation, of the same criteria characterizing the transient regime (*Annex I, Legislative Decree 192/2005*).

In particular, the Presidential Decree 59 makes operative the articles 4 and 6 of the legislative Decree 192, respectively concerning:

- the calculation methodologies and the building energy requirements (*minimum values*);
- the new procedures for the energy certification of the building, specified by the Ministerial Decree 26/06/2009 [53].

Starting by the end of June 2009, the D.P.R. 59/2009 regulates both the public and the private building sectors, with reference to the new edifications and renovations of existing construction.

The provisions introduced are applied only to the Italian Regions that not yet have enacted a specific legislation. In fact, as above-mentioned, the energy policy in Italy is both competence of the Central State and of the local authorities and, in the last years, some Regions already approved a full direct implementation of the EPBD.

The D.P.R. 59/2009 gives national methods for the energy calculation, in particular introducing the technical standard UNI TS 11300; this standard is divided in 4 parts (*at the present moment, only the 1$^{st}$ and 2$^{nd}$ have bee already published*):

- UNI TS 11300 part 1: Energy performance of buildings: evaluation of energy need for space heating and cooling [14];
- UNI TS 11300 part 2: Energy performance of buildings: evaluation of primary energy need and of system efficiencies for space heating and domestic hot water production [43];
- UNI TS 11300 part 3: Energy performance of buildings: evaluation of primary energy need and of the cooling system efficiencies [44];
- UNI TS 11300 part 4: Energy performance of buildings: use of renewable energy sources and other energy generation for the space heating and the production of domestic hot water [45].

The above cited standards (*the parts 3 and 4 are not yet available*) are defined by the D.P.R. 59/2009 as current official calculation method for the energy audit and the energy certifications (*actually, already the Decree 115/2008, before described, cites, explicitly, such methodologies*).

The UNI TS 11300 standards, as will be better described in the Chapter 2 of the Thesis, represent the Italian harmonization of the procedures contained in the technical instruments elaborated by the CEN for the EPBD application; in particular, the EN ISO 13790 represents the main reference for the building energy evaluations.

Several other news are reported by the D.P.R. 59, above all with reference to the calculation methodologies and the final energy requirements of buildings and, some of these represent important novelties toward a higher energy efficiency in the building sector.

Actually, other prescriptions are not yet operative. For example as regards the building energy certification, the National Guidelines (*included in the Ministerial Decree 26/06/2009 [52]*) provides mandatory prescriptions only as regards the space heating, the hot water production and the thermal need in summertime, remanding to future Decrees the application also of the primary energy evaluation for the space cooling and lighting.

The D.P.R. 59/2009 decides also about two key points not fully defined by the Decree 192/2005, in particular regulating:

- the actuation of energy requirements referred to the design, the installation, the use, the maintenance, the inspection of heating and cooling systems, the containment of the energy demand both for the winter heating and the summer cooling (*and this is the main new element*). Only with reference to the service the sector, also the limitation of energy used for the artificial lighting is imposed;

- the criteria for an energy efficient public and "state controlled" housing, as well as for the private buildings, also as regards the renovation of existing architectures.

Anyway, the most important news introduced by the Presidential Decree 59/2009 concern the summer energy performances of the building. In fact, while the Decree 192/2005 contains only some qualitative prescriptions (*such as the mandatory uses of window shading systems and high massive structures in the location with high summer solar radiation*), the D.P.R. 59 imposes numerical verification.

First of all, the new necessary evaluation of the summer cooling energy, required by the building, is imposed and about this, maximum value are also fixed. In particular, the new regulation establishes, as regards the limits to the building envelope thermal energy needs in summertime, the following values:

- climatic zones A and B → maximum value = 40 $kWh/m^2a$;
- climatic zones C, D, E and F → maximum value = 30 $kWh/m^2a$.

The above reported limits are referred to the thermal energy necessary in order to maintain the indoor temperature at 26 °C during the summer season, without attention to the cooling systems energy efficiencies and so, contrariwise with respect to the $EP_i$, this new indicator ($EP_{e,invol}$) isn't expressed in form of primary energy. In other words, this parameter defines a building envelope quality level and so it can be calculated also when a cooling system is not installed.

Another significant new disposition, introduced by the Decree 59, regards the limitation of the indoor temperature in summertime. The verification of the thermal mass (> 230 $kg/m^2$) is still admitted for the vertical walls, even if an alternative method is proposed: *the evaluation of the dynamic thermal transmittance ($Y_{12}$) and the verification that its value results lower than 0.12 $W/m^2K$.*

About the horizontal structures, only the verification of the dynamic thermal transmittance is admitted starting by the June 2009; in particular, with reference to roofs, the values of $Y_{12}$ must result lower than 0.20 $W/m^2K$. The calculation of the dynamic thermal transmittances is carried out by means the methodologies contained in the standard EN 13786/2008 [46].

Other new prescriptions regard other energy performance parameters, among which:

- the energy efficiency, the greenhouse emissions, the insulation of the building envelope, when the buildings are equipped with biomass heaters;
- the evaluation of the effectiveness of shading systems for windows and/or the use of low-solar transmittance glasses;
- further reductions (-20%), as regards the wintertime primary energy need ($EP_i$) for new public buildings.

Anyway, the Presidential Decree 59 should be followed by two further legislative acts, regarding a definitive and clear criterion to verify the requisites and the qualification procedures for the building energy certifiers.

C) MINISTERIAL DECREE 26/06/2009

After around 4 years from the emanation of the Legislative Decree n. 192/2005 and 3 years later the Decree n. 311/2006, at the end of June 2009, the Decree of the Ministry of Economic Development (*together with other Ministries*) 26/06/2009, containing the National Guidelines Lines for the Energy Certification of Buildings, was been finally published.

This new legal measure represents, together with the above-described Presidential Decree 59/2009, an important document for a complete application and national transposition of the EPBD into the Italian law.

Thus, at the present moment, only another important document is not yet into force, the Presidential Decree that will define the professional requirements and the accreditation criteria for the building energy certifiers and the organisms of certification. This document was necessary in order to assure the qualification and the independence of people and institutions involved into the certifications of the building energy performances. Furthermore, also the procedures to guarantee adequate inspections of the air-conditioning systems are not yet available.

The Ministerial Decree 26/06/2009 is mainly directed to the Regions that have not yet a full developed legislations as regards the building energy certifications, even if, also the Regions that already provided local rules should taking into account the national prescriptions in order to guarantee a national common framework with reference to the building energy efficiency. In particular, without specifying modalities or temporary limits, these Regions have to upgrade their rules as regards the following points:

- the informative data that must be contained in the building energy certificate, the limit values for the minimum admitted energy performances, the benchmark values, the achieved energy classes for an easy comparisons and comprehension of the energy performances, recommendations about the more useful and economically convenient possible improvements;
- the technical standards used as reference and containing the main calculation procedures and input data, both national (*e.g. UNI, CTI…*) or enacted by the international organisms (*e.g. CEN and ISO*);
- the calculation methodologies for the evaluation of the building energy performances, comprehensive of the used simplified methods finalized to diminish the energy evaluation costs;
- professional requirements and independence criteria for the individuation and selection of energy certifiers and accreditation organisms;
- the maximum temporal validity of the energy certificates and the prescriptions related to this, as regards the modernization and upgrading of the energy labels both in presence of improving actions on building and plants or, on the contrary, after degrading events.

As regards the procedure for the obtainment of the energy certificate, the building owner, sustaining himself the whole cost, requires the energy label to an energy certifier accredited according to of the criteria identified by the apposite Presidential Decree (*that is not yet enacted*). The procedure for the energy certification of the buildings can be synthesized in the following system of operations, carried out from the above-mentioned certifiers:

1. execution of an energy diagnosis, *in situ* or by means the verification of the design documents, finalized to the determination of the energy performances and to the identification of the possible energy improvements, convenient under the economic point of view;
2. finding of the input data, relatively to the climatic characteristics of the locality and to the building characteristics of use, as well as information related to the building energy use and to the active energy system characteristics;
3. determination of the building energy performances, by means of the application of appropriated methodologies regarding all the energy uses, expressed through indices based on the partial and total energy indicators;
4. analyses and evaluation of possible energy improvements, both with reference to the building and its energy systems (*heating, cooling, domestic hot water production*), convenient both under the technical and economic sides;
5. classification of the building energy performances, according to the achieved energy indices compared to the law limits;
6. release of the building energy certificate.

The most important news introduced by this last Decree of course concern procedures, scheme and involved energy performances in order to define the building energy certifications.

In particular, as reported in the Annex A of the Ministerial Decree, containing the above-cited Guidelines, the overall energy performance of the building ($EP_{gl}$) is expressed as sum of partial energy indicators. These are represented by the energy indexes referred to the space heating ($EP_i$), the ones related to the domestic hot water production ($EP_{acs}$), to the summer air-conditioning ($EP_e$) and the artificial lighting of the building ($EP_{ill}$).

All these indicators are expressed in the same unit (kWh/m$^2$a) and calculated in terms of primary energy. The formula reported in the Annex A of the Decree is in the followings proposed. All the above reported indexes are referred to a unitary area, so that the overall energy demand has to be divided considering the useful - net - surface of the building.

The Guidelines report also the official energy certification scheme (figures 1.4.2 and 1.4.3), where, besides all the information necessary in order to identify building, construction typology, surface-to-volume ratio, geometry and climatic zone, legal limits for the energy performances, property and energy certifiers, all the global and partial energy indicators are clearly shown.

$$\boxed{EP_{gl} = EP_i + EP_{acs} + EP_e + EP_{ill}}$$

The energy certificate reports also a list of possible improvements energetically efficient and economically convenient. This last part represents an important aspect of the energy certificate. Moreover, with reference to the energy performance of the building referred to the wintertime space heating, both indications about the building envelope performances and regarding the energy efficiency ratio of the heating system should be provided, so that, besides the global performances, also the critical points of the building/plant global systems can be clarified.

## 9. NOTE

**EDIFICIO.** Tipologia costruttiva: Struttura portante in muratura a sacco. Tamponature verticali in muratura, solai in tecnologia mista, con travi in legno, panconcelle e riempimento in calcestruzzo con armatura di ripartizione.

**IMPIANTO TERMICO.** Autonomo per riscaldamento ambienti e produzione di acqua calda ad uso sanitario.
Tipo di terminali di erogazione del calore: Radiatori.
Tipo di distribuzione: Tubazioni di mandata e ritorno, collocate in traccia nel lato interno delle tamponature esterne e nel massetto sottopavimento, con diramazioni in parallelo ad ogni corpo scaldante.
Tipo di regolazione: Centralizzata con cronotermostato. Tipo di generatore: Caldaia a gas metano da rete.

**RISTRUTTURAZIONI.** Nel mese di Maggio 2007 sono stati eseguiti i seguenti interventi di qualificazione energetico/ambientale:
1. ristrutturazione degli interni dell'edificio;
2. sostituzione dei serramenti con componenti conformi alle nuove disposizioni in materia di contenimento dei costi energetici nell'edilizia (D. Lgs. 192/2005, D. Lgs. 311/2006).

## 10. EDIFICIO

| | | | |
|---|---|---|---|
| Tipologia edilizia | Residenziale E1 (1) ex D.P.R. 412/93 | | |
| Tipologia costruttiva | Unità immobiliare in condominio. Il complesso presenta in tutto 10 appartamenti. Il blocco a cui appartiene l'appartamento si costituisce di 4 abitazioni | | |
| Anno di costruzione | Antecedente al 1800 | Numero di appartamenti | 25 |
| Volume lordo riscaldato V (m³) | 257.56 | Superficie utile m² | 62 |
| Superficie disperdente S (m²) | 128.8 | Zona climatica/GG | D/1415 |
| Rapporto S/V | 0.5 | Destinazione d'uso | Residenziale |

## 11. IMPIANTI

| | | | | |
|---|---|---|---|---|
| Riscaldamento | Anno di installazione | <'90 | Tipologia | Caldaia |
| | Potenza nominale (kW) | 24.40 | Combustione | Metano |
| Acqua calda sanitaria | Anno di installazione | | Tipologia | Caldaia |
| | Potenza nominale (kW) | 24.40 | Combustione | Metano |
| Raffrescamento | Anno di installazione | | Tipologia | |
| | Potenza nominale (kW) | | Combustione | |
| Fonti rinnovabili | Anno di installazione | | Tipologia | |
| | Energia annuale prodotta (kWhe/kWht) | | | |

## 12. PROGETTAZIONE

| | | | |
|---|---|---|---|
| **Progettista/i architettonico** | Dato non noto | | |
| Indirizzo | | Telefono/e-mail | |
| **Progettista/i impianti** | | | |
| Indirizzo | | Telefono/e-mail | |

## 13. COSTRUZIONE

| | | | |
|---|---|---|---|
| **Costruttore** | Dato non noto | | |
| Indirizzo | | Telefono/e-mail | |
| Direttore/i lavori | | | |
| Indirizzo | | Telefono/e-mail | |

*Figure 1.4.2 – The Italian energy certificate: side referred to the description of the building, active energy systems and energy performances*

As regards the calculation methods (*as it will be better described in the Chapter 2 of Thesis*), the Ministerial Decree identifies, such as provided by the CEN standards, different calculation procedures, varying depending on the scope of the energy audits.

The energy certificate evaluation, such as established also by the Legislative Decree 192/2005 and relative modifications, is mandatory for new buildings and for the exiting ones when rented or sold, even if, as regards this last point, with the Law 133/2008 the Italian Parliament eliminated partially this prescription. About this, recently the European Union opened an infraction procedure against the Italian political Institutions.

The energy certificate is valid for ten years, and it should be upgraded if significant renovations interest the building, varying its energy characteristics. In particular, each action on the building envelope (*regarding at least the 25% of the total shell area*) or relative to active energy plants induces the necessity of a new energy label.

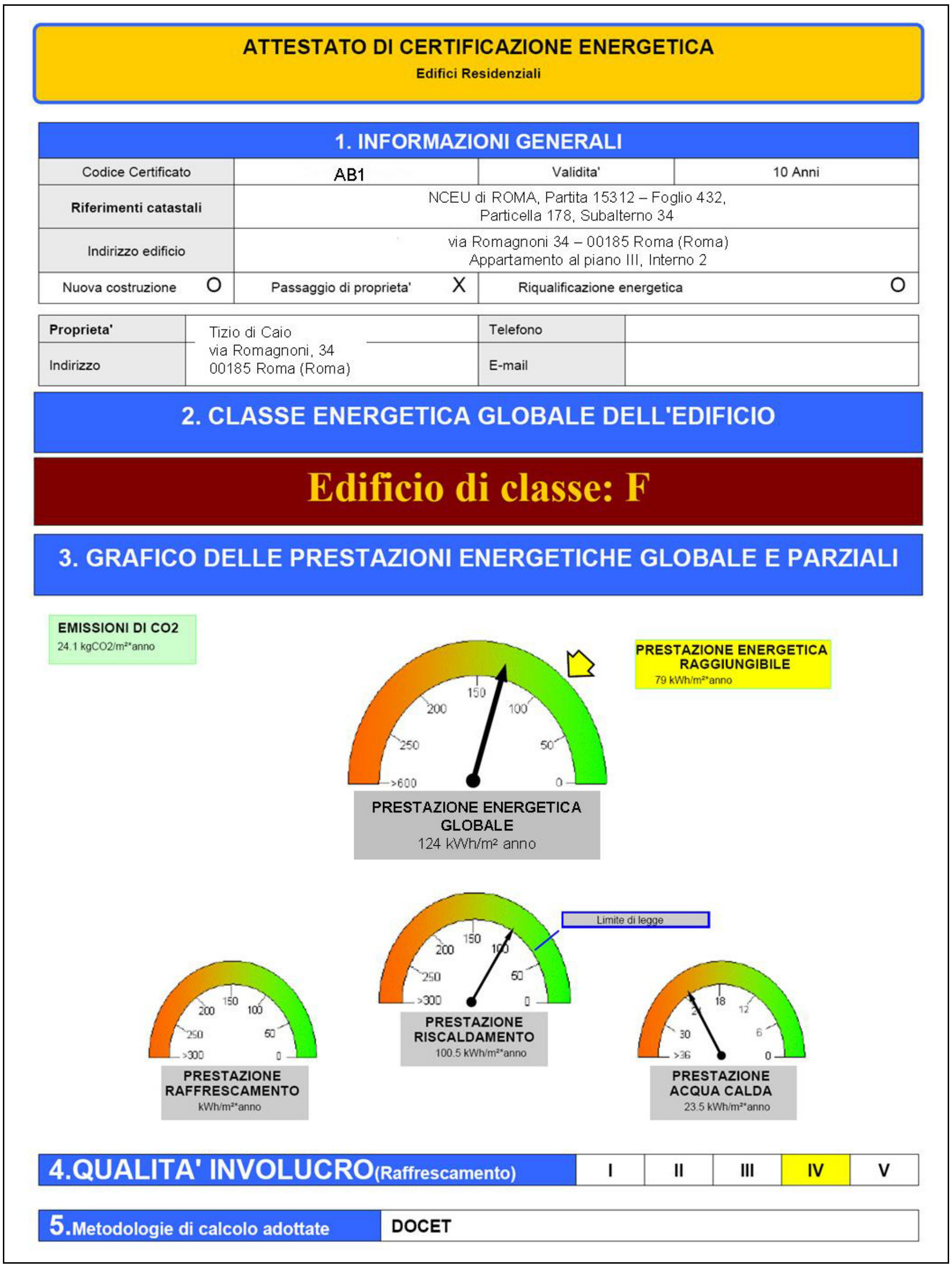


*Figure 1.4.3 – The energy certificate: side with graphical expression of the energy performances*

The National Guidelines provides also the methods to define the energy classes, depending on the value of the maximum admitted limit, considering multiples or fractions of this. For example, with reference to the winter heating, the method for the class definition is reported in figure 1.4.4.

Similar methods are proposed also for the class definition as regards other energy uses, such as the production of domestic hot water (*Decree 26/06/2099, Annex 4*) and the same logic is used also to built the overall energy classification scheme.

As regards the calculation methodologies, also the Ministerial Decree 26/06/2009 cites the UNI TS 11300 standards (*the Italian transpositions of the European standards, elaborated by the CEN during the last years for the implementation of the EPBD*) as official national calculation procedures. Actually, already the legislative Decree 115/2008 and the Presidential Decree 59/2009 already established the role of the technical standards UNI TS 11330, as national references for the building energy audits.

**Classe Ai+** < **0,25** $\mathbf{EPi_L}$ (2010)

**0,25** $\mathbf{EPi_L}$ (2010) ≤ **Classe Ai** < **0,50** $\mathbf{EPi_L}$ (2010)

**0,50** $\mathbf{EPi_L}$ (2010) ≤ **Classe Bi** < **0,75** $\mathbf{EPi_L}$ (2010)

**0,75** $\mathbf{EPi_L}$ (2010) ≤ **Classe Ci** < **1,00** $\mathbf{EPi_L}$ (2010)

**1,00** $\mathbf{EPi_L}$ (2010) ≤ **Classe Di** < **1,25** $\mathbf{EPi_L}$ (2010)

**1,25** $\mathbf{EPi_L}$ (2010) ≤ **Classe Ei** < **1,75** $\mathbf{EPi_L}$ (2010)

**1,75** $\mathbf{EPi_L}$ (2010) ≤ **Classe Fi** < **2,50** $\mathbf{EPi_L}$ (2010)

**Classe Gi** ≥ **2,50** $\mathbf{EPi_L}$ (2010)

*Figure 1.4.4 – Definition of the energy classes based on fractions and multiples of the law $EP_i$ limit*

In particular, these standards define three calculation methods: design, asset or tailored ratings. The UNI TS 11300-1 (*as it will be better described in the next Chapter*) defines and explains all the various calculation methodologies.

Only as regards the summer cooling and the artificial lighting energy evaluations, presently the whole calculation methodology is not yet applicable, so that, in a first phase regarding the residential buildings, there are some limitations related to the calculation of these two energy uses. For these reasons, the summer cooling energy performance index presently is referred only to the thermal need of the building, without considering the efficiency ratio of the air-conditioning system, while, as regards the artificial lighting, this energy use initially is not evaluated in the energy certificate.

Thus, in a first period, the above expressed formula becomes:

$$\boxed{EP_{gl} = EP_i + EP_{acs}}$$

Finally, the National Guidelines contain also other prescriptions and indications, regarding for example simplified procedure for the energy performance evaluations of the building, both with reference to the envelope and to the determination of the energy efficiency ratios of the heating systems (as well as other procedures concerning the energy evaluation of building without heating systems).

### 1.4.4 ENERGY EFFICIENCY PROMOTION AND FUNDING MEASURES

The technical economical convenience of energy-oriented actions during the building renovation assumes a great role in order to increase the energy efficiency of the building sector and, in particular, with reference to the less efficient part of the Italian Stock, realized before the Law 373. Substantially, three different mechanisms to promote the building energy re-qualification are available:

- capital financing;
- economic funding programs for the energy productions (e.g. "*feed-in-tariffs*");
- favourable banking loans.

#### MINISTERIAL DECREE APRIL 24, 2001

Some months before the emanation of the EPBD, in Italy some Ministerial Decrees (e.g. *D.M. 24 April 2001 [53]*) were enacted in order to promote the energy efficiency in several sectors, funding the voluntary energy renovations by means Regional, Local, State or also European financings. The base idea was to promote the financial assistance of research and commercialization of new high efficiency technologies, and also to promote and spread the energy efficiency in the European areas less developed, for example funding the private/public users less economically capable.

Today, the direct financings are quite exclusively of Regional competence or by means spot programmes of the EU institution, while the central State operates above all admitting fiscal deductions and other indirect benefits. For examples, starting by the 2004, in Italy the building renovations are promoted with national funding programs, enacted in order to support the building stock renovations.

In particular, for each house, and for a limit costs of 48'000 €, a tax deduction of 36% (*calculated with respect the renovation costs*) has been provided; this deduction is accompanied by a further VAT reduction as regards the sustained material costs. The fiscal benefit, still in force, must be divided during 10 years (*5 or 3 for old age people*), and, inside the admitted funding actions, the energy re-qualification is expressively mentioned. The same legal measures establish that the Value Added Tax (VAT), applied for the materials necessary for the building renovations is reduced to 10% (*instead of 20%*). The same reduced VAT is also applied for the installation of thermal solar systems, both new and renovated.

#### FINANCIAL LAWS 2007 (L. 296/2006) AND 2008 (L. 244/2007)

Starting by the Italian Financial Law 2007 (L. 296/2006 [54]), significant fiscal deductions, higher than the 36% previously established, are introduced to promote directly the building energy renovations. In particular, even if some modifications occurred in the last years, above all as regards the time during which the deductions are divided, the main funding actions consist in fiscal savings, with respect to the costs of the energy renovations, for the following works:

- whole energy re-qualification of existing building;
- energy re-qualification of vertical walls, basements and roofs;
- new windows, glass and frames characterized by low thermal transmittance;
- installation of solar thermal system for the domestic hot water production or to assist the space heating system;
- installation of high efficiency heat generators (*high efficiency heat pumps, condensation heat boilers..*).

The above described energy re-qualifications make possible a financial saving on the paid taxes equal to the 55% of the renovation costs. The economical funding, for these actions, has been guaranteed until the 2010 [55], even if, during the 2008, new and stricter performance levels of the new components have been imposed and also the number of years during which the deduction is divided is changed (*about his, today the benefit must be divided in 5 years*). The present performance levels, defined by the Decree 11.03.2008, are valid until the end of the 2009, while new minimum targets will be defined for the 2010.

FEED-IN-TARIFFS; MINISTERIAL DECREE 27/02/2007

The promotion of photovoltaic systems, in Italy, has been recently interested by the concept of energy conversion through technologies integrated inside the building envelope.

The first legal Act, enacted to promote the installation of photovoltaic systems, was the "*photovoltaic roofs*" program, promoted by the Ministry of Environment during the 2001. This program caused an installation of around 50 MW of PV systems, determining a great increase in the Italian photovoltaic energy production compared to the previous years. This first experiment was followed by the actuation of the EU Directive 2001/77/EC "*Directive on Electricity Production from Renewable Energy Sources*".

On July 24, 2005, a first version of the "*feed-in-tariffs*" Decree was released, and, at the end of the February 2007, the final version was enacted [56]; the National target, within 2016, was fixed at 3000 MW of photovoltaic installed power. The base principle consists in the funding of the photovoltaic technology by means of favourable tariffs paid for the produced energy; the duration of the incentive rate period should be enough long to guarantee the economical convenience of the investments.

The new Decree introduces a system of funding tariffs (the incentive rates before cited) diversified depending on the kind of photovoltaic systems and the size of these. At the same time, the energy efficiency is contemporarily promoted, so that a significant further increase of the tariffs can be obtained when the building is interested by an energy renovation. The present version of the "feed-in-tariffs" Decree granted the incentives for a period of 20 years.

The incentive rates are applied to the whole energy produced by the photovoltaic plants, so that the Italian State gives to the citizens and owners of photovoltaic installations a significant contribution for the production of electricity (*reducing to around 10 years, the payback times typical for this technology, with reference to the Italian electric energy costs and climates*).

*Figure 1.4.5 – Full Integrated typologies of photovoltaic systems*

*Figure 1.4.6 – Partially Integrated typologies of photovoltaic systems*

*Figure 1.4.7 – Non-integrated typologies of photovoltaic systems*

The funding tariffs, represented in table I.15, may be granted to all photovoltaic systems when connected to the national electric network. The corporation deputed to provide this incentive is the GSE (*Italian Electrical Services Manager*).

The great part of the photovoltaic systems installed in Italy (*adopting the "feed-in-tariffs"*), is provided by the "net metering" contract. This agreement, often called *"equal exchange of energy"*, is a service provided by the electricity company, which regulates the input and the output of electricity to and from the national electric network.

All the photovoltaic systems connected to the national net, if characterized by a capacity between 1 and 20 kW, since the 2005 could adopt this energy exchange, for the whole duration of the plant's life. Substantially, the energy produced by the plant and not used is turned to the network and measured by a meter. At the end of the year, the GSE makes a balance between the energy consumption and energy input.

Some modifications to the net metering contract structure have been applied during the 2008, above all as regards the size of the photovoltaic system (*at the present moment, to 200 kWp)* and as regards the duration and the economical obtained energy credits.

Table I.15: Ministerial Decree 27.02.2007 – feed-in-tariffs: funding tariffs for PV systems

| | Power of the photovoltaic system P(kWp) | Not integrated system | Partially integrated system | Totally integrated system |
|---|---|---|---|---|
| A) | 1 ≤ P≤ 3 | 0,40 | 0,44 | 0,49 |
| B) | 3 < P≤ 20 | 0,38 | 0,42 | 0,46 |
| C) | P > 20 | 0,36 | 0,40 | 0,44 |

WHITE AND GREEN CERTIFICATES

*Even if not strictly connected to the energy efficiency referred to the building sector, briefly in this sub-paragraph some words will be spent to describe other legal mechanisms, enacted by the EU and Italian Institutions, in order to promote the energy efficiency: the white certificates and the green certificates.*

WHITE CERTIFICATES. During the 2003, the Italian Authority for Electricity and Gas (AEEG) has published Guidelines for projects finalised toward the energy conservation and increase in the use of renewable energy. In particular, the AEEG decision n. 103/2003 [57] identifies the criteria to prepare, execute and evaluate projects that are aimed at the increasing in energy efficient end-uses and savings, such as a greater use of renewable energy sources. The same decision clarifies the modalities for the assignment of the "energy efficiency bonds" (*TEE in Italian, i.e. Titoli di Efficienza Energetica [57*), explaining also how the costs spent by the companies for the design realization could be recovered. In particular, the "energy efficiency bonds", which have a validity period of 5 years from when the savings started to be obtained, can be diversified in these three types: electricity (type I), natural gas (type II) or other sources (type III). During the January 2005, the AEEG has begun a preliminary work on the market of the energy efficiency bonds (*the so-called white certificates*) that represent the new mechanism to encourage energy savings.

The white certificates are tradable and combinable with obligations to achieve a determined target of energy savings. In particular, producers, suppliers / distributors of electricity, gas and oil are required to undertake energy efficiency measures, in order to obtain energy savings in terms of primary sources.

The energy savings are expressed by a pre-defined percentage calculated with reference to the annual energy deliverance. If the companies do not meet the mandatory targets, a penalty is required to pay; otherwise, the white certificates are given to the producers (*together with a fixed economical bonus*) when the purposed amount of energy is really saved. Then, the producers can use these certificates for their own target compliance or also can sell these to other parties that cannot meet their established purposes.

Initially, the economic value of the "energy bonds" was of 100 €/toe (= *11628* $kWh_{THERMAL}$, *5347* $kWh_{ELECTRIC}$); today, their values are interested by the variations linked to the energy market trends. The minimal threshold for the obtainment of the white certificates depends on the typology of undersigned plan, ranging between minimum savings of 25 ÷ 200 toe/year [57].

The dealing of the TEE can happen bilaterally between the interested parts or inside the specific market managed by the GSE (*the already cited Italian Manager of Energy Services*). Instead, the AEEG (*the Italian Authority for the Electric power and Gas*) authorizes the release of the energy efficiency bonds. Starting from the 2006, the ENEA assists the AEEG in the evaluation of the energetic saving effectively obtained by the participants.

As regards this last point, the distributors can be obliged to subscribe the white certificate mechanisms when they are characterized by a final user amount higher than 100'000 unities; otherwise, the smaller distributors are not obliged to do it, even if they can enter voluntarily into the mechanism.

GREEN CERTIFICATES. The green certificates represent the new structure of renewable source incentive, instituted with the liberalization of the energy market disciplined by the Italian Legislative Decree 79/99 [58]. The Laws 9 and 10, enacted during the 1991 and the provision of the CIP 6 (1992) defined the precedent normative.

A green certificate is a form of electric power boosting derived by renewable energy sources; these consist in negotiable bonds, already diffused in other European Countries (*Netherlands, Sweden and UK*) and in the United States.

The green certificates correspond to an amount of avoided $CO_2$ emissions. When an energy conversion plant determines lower greenhouse emissions due to the adoption of renewable sources instead of fossil fuels, the plant manager obtains a number of green certificates that he can sell to other entities that require necessarily these bonds (*e.g. because not respectful of the mandatory integration – 2% - of the electric production by renewable*).

In Italy, the green certificates are released by the GSE. The Decree 79/99 establishes that these can be required for 8 years (*energy plants built or renovated after the 1999*) or 15 years (*energy plants built or renovated after the December 2007*).

The green certificates allow the companies that produce energy from conventional sources (*oil, coal, methane, etc*.) to respect the law that obligates each producer (or importer of energy) to use at least a 2% of renewable sources. In other word, the company buys the green certificates necessary to reach its own threshold of 2% of clean energy production (*the initial threshold increases, each year from 2004, of + 0.35%*).

On the other hand, companies, producers and distributors that use significant renewable sources of energy can accumulate green certificates and then sell these. Presently (2009), the value of each one green bond is approximately 180 €/MWh (*and the price of the electric energy transfer must be also included, e.g. a further value around 70 €/MWh should be added*).

The main consequence of the green bond mechanism consists in the creation of an energy market where some virtuosos producers can obtain right economic benefits, while the less enlighten must pay for the old and polluting adopted technologies. The result (*theoretical, in a* *first phase)* was a promotion of clean energy technologies, with the aim to reduce the greenhouse gas emissions.

About this, the first Italian Decree failed, because also the "*assimilated-to-renewable sources*" were funded with the green bonds; i.e. also polluting systems such as the use and combustion of waste industrial materials were compared to the renewable sources, so that a legal distortion happened. It is important to underline that the diction "*assimilated-to-renewable sources*" was a definition adopted only in Italy, without analogues in Europe.

Fortunately, an useful 2$^{nd}$ Decree corrected this distortion, so that only the traditional and really renewable sources are today funded.

By themselves, the mechanisms of the "energy efficiency bonds" (*i.e. the white certificates*) and those related to the use of renewable (*i.e. the green certificates*) are not sufficient in order to stimulate adequately a low-carbon future.

Anyway, it is right to recognize that, at the same way of the most sensible European Countries, also the Italy promoted, during the last few years, new and important policies of sustainability.

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# Chapter 2:

# Buildings and technical systems: the calculation methodologies of the energy performance indexes

## 2.1 THE EUROPEAN TECHNICAL STANDARDS FOLLOWING THE EPBD

### 2.1.1 INTRODUCTION: THE MANDATE M343

The EPBD officially came into force as European Directive at the beginning of January 2003. In order to support a harmonic implementation of the Directive into the specific national laws, in the first months of 2004, the European Commission issued a formal mandate, the M/343 [1], to the CEN. In particular, a complex set of new technical standards was demanded to the European Committee for Standardization, covering 31 different items related to the building and technical plant energy performances.

The M/343 concerns a full package of calculation methodologies, released in order to permit a complete evaluation of the building related energy uses and polluting emissions, determining an integrated approach for the complex system building envelope – technical appliances.

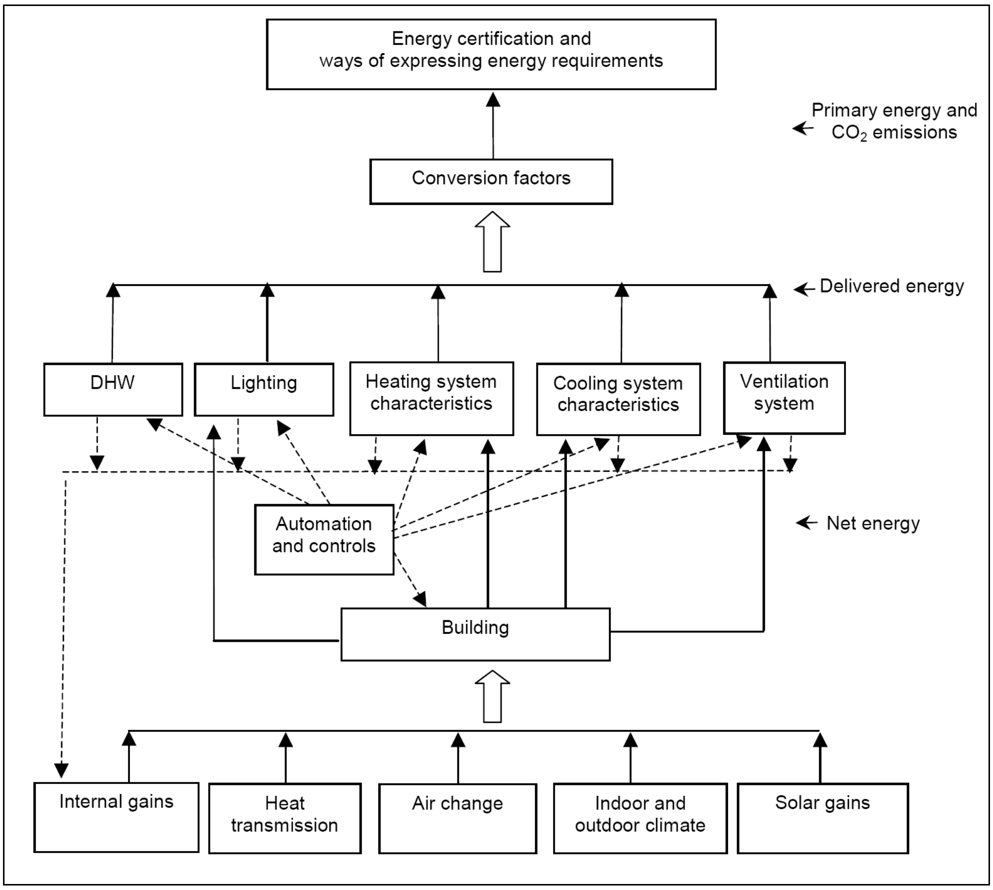


*Figure 2.1.1 – Layout for the energy evaluation of buildings (source: CEN/BT WG 173 EPBD N 15 [2])*

Today (*Autumn 2009*), quite all the demanded standards have been released, and many of these also transposed into the various national procedures. The CEN work was immediately distributed into five different sub-sectors (*CEN TC, i.e. technical committee*):

- CEN/TC 89: Thermal performance of buildings and building components;
- CEN/TC 156: Ventilation for buildings;

- CEN/TC 169: Light and lighting;
- CEN/TC 228: Heating systems in buildings;
- CEN/TC 247: Building automation, controls and building management.

The assignment, contained into the mandate M/343, represents a complex work, so that, besides its division into several sub-technical committees, also another one was instituted, the CEN/TC 371 - *Project Committee EPBD* – with the only task of coordination among the other involved committees.

Among the various involved sub-committees, one of the main roles was assigned to the TC 89, charged with the assignment of the elaboration of energy evaluation procedures for the building components and the evaluation of the whole building envelope thermal behaviours.

It is important to underline that the present procedures for the building performances evaluation are strongly related to the logical approach followed to harmonize the various standards. In particular, as it is quite clear in the above cited work division, the general procedure (*energy performances = building envelope performance / system efficiency, equation 1*) can be fast identified simply seeing the criteria among which the CEN work was divided (figure 2.1.1).

In other words, the energy performances of the building and those related to the active energy plants were been disconnected and successively reconnected by means of the equation (1).

$$\mathrm{EP} = \frac{\text{Building envelope performance}}{\eta_{\text{TECHNICAL SYSTEM}}} \qquad (1)$$

where, as better shown in the followings, the EP represents the primary energy request of the integrated system building-active energy devices.

Of course, the EP is expressed in terms of primary energy, so that in the evaluation of the technical system efficiency ratio, the conversion thermal – primary energy has to be also considered (*in particular when the used energy is the electrical one*).

Besides the main division of the CEN technical committees involved in the standardized calculation platform, several other sub-committees were also involved, in order to support, as regards specific items, the above-mentioned committees:

- CEN/TC 33: Doors, windows, shutters, building hardware and closures;
- CEN/TC 125: Building walls;
- CEN/TC 129: Building glasses;
- CEN/TC 46: Oil stoves;
- CEN/TC 110: Heat exchangers;
- CEN/TC 48: Domestic Hot Water heaters;
- CEN/TC 57: Central heating boilers;
- CEN/TC 62: Independent gas-fired space heaters;
- CEN/TC 88: Thermal insulating materials and products;

- CEN/TC 109: Central heating boilers using gaseous fuels;
- CEN/TC 113: Heat pump and air-conditioners;
- CEN/TC 130: Space heating appliances without integral heat sources;
- CEN/TC 179: Gas-fired air heaters;
- CEN/TC 182: Refrigerating systems, safety and environmental requirements;
- CEN/TC 312: Thermal Solar Systems and Components.

The whole target results complex and large, mainly with reference to the harmonization of many different tools and calculation approaches.

During the 2008, all the technical standards have been approved, with reference to the whole energy calculation procedures, the evaluation of different kind of energy estimations (*e.g. the methodologies to analyze the monitored/calculated data*) and as regards organization and characteristics of the inspections of boilers and air-conditioning systems.

Totally, around 40 technical standards have been released and published: among these, about 30 are new, while the remaining ones consist in upgrade of old procedures or simply transpositions of previous set of technical documents. The relation and combined use, as regards this complex system of new calculation methods, is expressed by the CEN Technical Report CEN/BT WG 173 EPBD N 15 [2], well-known as "*Umbrella Document*" [2], that explains the main relations among the standards and represents a necessary document in order to understand how to use and coordinate these.

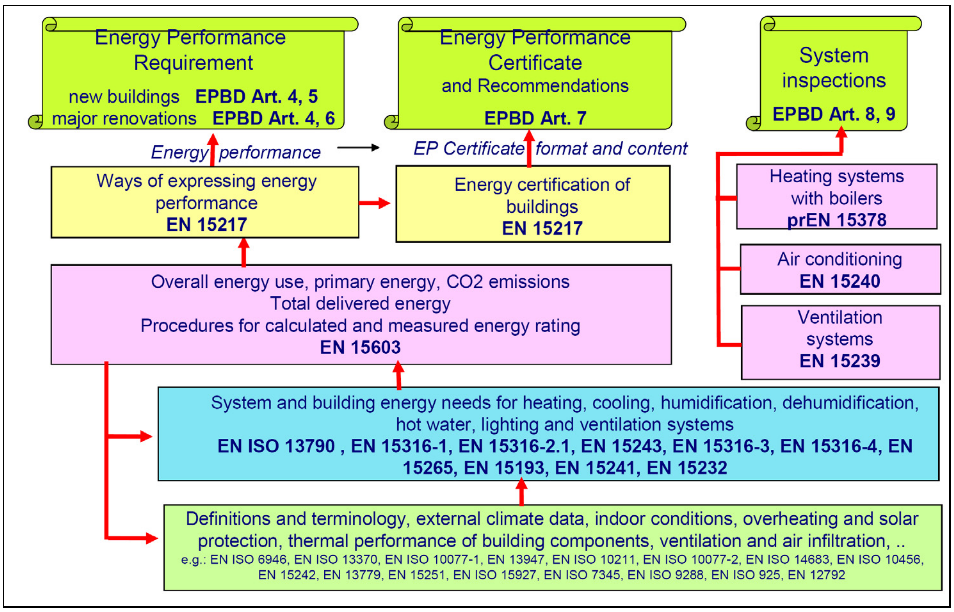


*Figure 2.1.2 – Calculation of the building energy performances, according to the EPBD [2]*

Presently, after the release of all the European technical standards, each EU national standard body (*for example, in Italy, the UNI*) is involved in transposing these into the specific national context. During the national implementation, of course, the standards can be modified and harmonize to the specific national consolidated methodologies, also considering that the local peculiarities can suggest simplifier adjustments of the methods. For example, specific climate conditions, technical building traditions, user behaviours can induce modifications to the European methodologies when transposed into the specific EU member legislations. Because of this, many of the various set of standards developed by the CEN committees suggest alternative evaluation procedures, more or less detailed, in order to obtain the most useful transpositions according to the specific national peculiarities.

For the same reason, many CEN standards make possible the elaboration of specific (national) annexes too, establishing that simpler methods can be adopt at regional level. Furthermore, considering that until the EPBD the energy legislations, in the different European countries, were very different, a minimum flexibility results absolutely necessary in order to provide a general and common European framework. In particular, the European traditions, competences and experiences as regards the evaluation of the building and relative system energy performances are not homogenous. Some countries have only a very limited experience about this, so that a gradual approach is necessary also to begin a process of homogenization; then, with fixed time step, gradually upgrading feedbacks will be useful to fully harmonize all the national methodologies.

On the other hand, reasoning on a larger scale, also the relationship among these new European methodologies and the ISO [3] ones represents another key-point. Presently, the most important standards (*for example, the EN 13790 and the other standards related to the building thermal transmission properties*) have been developed together by the CEN and the ISO, so that, at least as regards the main Guidelines, the building energy regulation and calculation methodologies could be worldwide uniformed. In particular, the ISO committee TC 163 – *Thermal Performance in energy use in the built environment* – is involved in a common work with the CEN, so that various EN standards today are also official ISO documents or drafts.

Of course, this approach cannot be extended to all the methodologies, often too much related to the specific culture and previous experiences. Anyway, a global sharing and spread of methodologies could result very useful, in order to increase the consensus around evaluation procedures and to carry out transparent comparisons between present performances and possible improvements. This with the aim to diffuse, as much as possible, a conscious participation of the different involved parties, so that the energy, environmental and climate problems can be undertaken by means of shared methodologies and common technical languages [3].

### 2.1.2 THE "UMBRELLA DOCUMENT" AND THE MAIN ROLE OF THE EN ISO 13790

The document CEN/BT WG 173 EPBD N 15 [2] then became the standard CEN/TR 15615/2008 "*Explanation of the general relationship between various European Standards and the Energy Performance of Buildings Directive (EPBD)*" [4], that contains Guidelines to use the other several documents, such as elaborated during the last 4 years, for a full application of the EPBD. Substantially, this is not a standard, but a technical report containing coordination instructions for a harmonic use of the calculation procedures [5].

The so-called "*Umbrella Document*" immediately identifies four main technical standards, necessary to implement the EPBD prescriptions, above all as regards the building energy certification:

- EN 15603: Energy performance of buildings - Overall energy use, $CO_2$ emissions and definition of ratings [6];
- EN 15217: Energy performance of buildings - Methods for expressing energy performance and for energy certification of buildings [7];
- EN ISO 13790: Energy performance of buildings - Calculation of energy use for space heating and cooling [8];
- EN ISO 15316: Energy performance of buildings - Heating systems in buildings [9-21].

In particular, the first two represent the key standards necessary to express the building energy performances, the overall energy use, primary energy and $CO_2$ emissions, assessment of energy use and definition of energy performance ratings; the same standards are also necessary to provide the energy certification of buildings. On the other hand, the EN 13790 represents the main standard to evaluate the building performances, describing the calculation procedures for the thermal needs related to both the space heating and cooling, taking into account several heat transfer phenomena and thermal contributes, such as:

- the energy gains/losses due to transmission and ventilation;
- opaque components thermal transmittances and transparent surface solar transmittance;
- radiative heat exchanges and various endogenous gains;
- utilization factors of the free energy gains in winter and free energy losses in summer.

Furthermore, the EN 15316, on the other hand, provides the calculation of the heating system efficiency ratios; this standard is divided in several parts, containing calculation methods related to the various systems and different devices, both for the space heating and for the production of domestic hot water.

As better explained in the Chapter 1, the EPBD main aspects concern the energy calculation methodology, the minimum energy performance requirements, the energy performance certificate and the inspections of boilers and air-conditioning systems.

About the calculation methodology, the Umbrella Document explains that several kind of approach can be possible, depending on the necessary accuracy of the calculation. In particular, as will be shown in the next paragraph, the EN 13790 presents hourly, monthly and annual calculation procedures, as well as different kind of energy ratings, more or less simplified or detailed. The chosen level of deepening depends on the scope of calculation (*energy certification or technical-economical evaluation of possible improvements*) and by the complexity of the building and relative plants.

The EN 13790 contains the general procedure for the building energy calculation, even if the full-described characteristics of the technical building systems are defined in other several standards, among which:

- EN 15316 (various parts) for the full descriptions of the heating system efficiencies;
- EN 15243 for the full definition of cooling systems [22];

- EN 15241 [23] and EN 15193 [24] respectively for ventilation and artificial lighting;
- EN 15232 for the building automation and control [25].

As regards the minimum energy efficiency requirements, no limits or minimum values are contained in the CEN standards, being these defined at regional levels, depending on the specific construction traditions, applied technologies, and, above all, the climatic contexts.

About the energy certificate, a draft model, containing some advices and suggestions to prepare this, is contained in the EN 15217 [7], where the energy label is schematised reporting the different performance classes, achieved comparing and relating the minimum performance requirements (Rr) and the reference value of the existing building stock (Rs). The EN 15217 adopted criterion, as regard the class construction, is reported in figure 2.1.3.

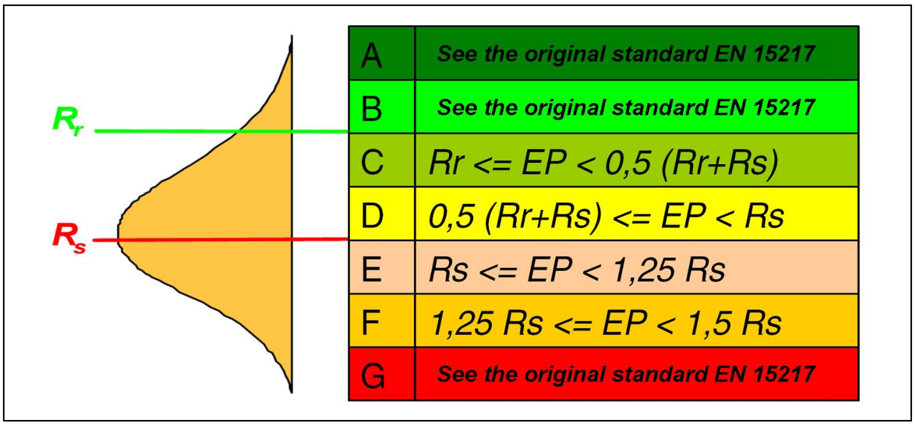


*Figure 2.1.3 – Method of expressing the energy performances for the energy certificate (source: EN 15217)*

As regards the criterion to build the performance classes, some different national specifications can be applied, in particular being sometimes too difficult finding a reference value for Rs in specific contexts characterized by a high variability of the construction methods, under not uniform climate conditions. The Italy represents a quite good example of this, being characterized by very different climatic zones and, as regards the building techniques, various and very different technologies are present and stratified, so that a singular value of Rs cannot be identified without very large approximations. For these reasons, the Italian certification scheme, recently introduced (*July 2009, Ministerial Decree 26.06.2009 [26]*) adopts a different approach, entirely based on the Rr value. About this, in the Chapter 3 a full description will be reported.

As regards the inspections of the building technical systems, the following standards have been released by the CEN:

- EN 15378: inspection of boiler, gas heaters and heating systems [27];
- EN 15239: inspection of ventilation systems [28];
- EN 15240: inspection of air-conditioning systems [29].

Quite all the EU countries already received or are transposing into the national legislations the methods contained in the above-cited technical documents.

Finally, even if it will be better described in the followings, some citations about the energy calculation methodologies will be here reported.

As already mentioned, the most important CEN standard, as regards the energy evaluation and calculation methodologies, is the EN 13790 [8]. This standard has been several time upgraded (*2001, 2005, 2008*) and presently provides calculation methods both as regards the heating and cooling seasons, with reference to both residential and non-residential buildings.

Even if the EN 13790 contains the whole general method (*as regards the building heating and cooling needs*), actually this standard is not autonomous and exhaustive for the overall energy evaluation, being necessary, such as understandable by means of figure 2.1.2 other input/output data evaluated by means other methodologies, contained in other CEN technical documents.

The CEN methodologies for the EPBD application base the energy performance evaluation structuring the calculation on three different levels, starting by the building envelope and arriving at the energy indicator [30]. In particular, the logical steps are:

a) calculation of the building energy needs for heating and cooling;
b) calculation of the delivered energy for heating, cooling, ventilation, domestic hot water and lighting, due to the active energy system inefficiencies;
c) calculation of the overall energy performance indicators (*primary energy, $CO_2$ emissions*).

The first part of calculation only evaluates the building envelope characteristics and behaviours, so that the result is the net energy required by the building, without considering the efficiencies of the technical equipments. The required data are related to:

- the building envelope (*i.e. component definitions, $U_{VALUES}$, thermal capacity, time constant*);
- the building use characteristics (*i.e. crowding, working time*);
- the imposed indoor conditions (*about the designed temperature and relative humidity*) and outdoor climate.

The second step, instead, is based on the evaluation of the active system efficiencies, in particular including the space heating, cooling, ventilation, domestic hot water and lighting equipments. The calculation is normally carried out taking into account the various different sub-system efficiency ratios, for example, about the heating systems, evaluating the heat emission, distribution, storage and generation; this second step includes the evaluation of the energy requirements for the running of the auxiliary devices, such as pumps or fans. Finally, the step c) combines the results of a) and b), in particular increasing the building envelope energy need by means of the consideration of the overall inefficiencies and delivered energy due to the use of active systems. In figure 2.1.2, the connections among the standards are represented [3].

Of course, the procedures, although these can be ideally schematized as above cited, actually are interested by several interconnections among the various steps. For example, an interrelation occurs between the steps a) and b), because the great part of the energy losses due to the technical equipments comes back to the building, representing a free heat gain (*in wintertime*) or a further penalizing endogenous thermal load (*in summertime*). About this point, generally, during the energy evaluation two different approaches can be considered:

- <u>*holistic approach*</u>*:* the heat gains associated with building and its technical systems are evaluated during the calculation of the energy needs for heating and cooling;
- <u>*simplified approach*</u>: the system heat losses are considered partially recovered (*by means of a conventional recovery factor*).

### 2.1.3 THE WHOLE SET OF NEW TECHNICAL STANDARDS

A brief description of the main standards elaborated or revisited in the last 5 years follows. In particular, only the main technical documents, inter-connected each-others, for the evaluation procedures before described, have bee shortly cited.

EN 13790: *Energy performance of buildings – Calculation of energy use for space heating and cooling*. This standard [8], better described in the next paragraph, is an extension of the earlier versions (*2005 and 2001*) referred only to non-residential building and to the energy evaluation of the energy demanded for the space heating. The final version, approved and published during the 2008, gives calculation methods for the assessment of the annual energy use for space heating and cooling, with reference to both residential or a non-residential building. The suggested procedures include the calculation of heat transfer by transmission and ventilation, both when the building is heated or cooled.

In the evaluation, the endogenous and external thermal gains are also considered. The calculated energy indicators consist in the annual energy needs for heating and cooling, without considering the annual energy required by the heating, cooling and ventilation systems, as well as the additional annual energy required by the auxiliaries; these energy uses are evaluated, in fact, adopting other standards in the following described.

The methods are applicable also for buildings characterized by several thermal zones, both when intermittent or continuous space heating and cooling are adopted. As regards the calculation period, this can be hourly or monthly. Furthermore, the EN 13790 annexes provide several common boundary conditions, when not available other apt input data; these boundary conditions are diversified depending on the kind of rating (*tailored, asset or design*).

EN 15217: *Energy performance of buildings – Methods of expressing energy performance and for energy certification of buildings*. The standard [7] defines the global indicators implemented to express the energy performances of the whole building, including heating, ventilation, air-conditioning, domestic hot water and lighting systems. The document includes different possible parameters and also methods to normalize these. The standard defines also the ways to express energy requirements for the design of new buildings or existing building renovations, as well as procedures to define the reference values, benchmark and kind of energy certification schemes.

EN 15603: *Energy performance of buildings – Overall energy use, primary energy and $CO_2$ emissions*. The standard [6] reunites the results from the other standards, specifying the global energy consumption within the building, the calculation of primary energy consumption and the related carbon dioxide emissions; furthermore, the general principles for the calculation of primary energy factors and greenhouse gas emissions factors are also provided.

EN 15378: *Energy performance of buildings – Inspection of boilers and heating systems*. The standard [27] contains explanations regarding the inspection procedures and the related calculation methods. At the same time, details about the connection with the other CEN standards about the heating system are also provided. The standard includes evaluation procedures regarding boilers, domestic hot water generators, gas, liquid or solid fuel heaters (*including biomasses*); also heat distribution network, emitters and accessories, control system are contemplated.

EN 15240: *Ventilation for Buildings - Energy performance of buildings – Guidelines for the inspection of air-conditioning systems*. The standard [29] describes the common methodologies for inspection of air-conditioning systems in buildings, both for space cooling and/or heating. The purpose is to assess the energy performances of the active energy equipments and to properly size these. The verification of conformity with respect to the design system, the correct system functioning, running and settings of various controls, as well as the function and fitting of the various components are also provided.

EN 15316-1: *Heating systems in buildings - Method for calculation of system energy requirements and system efficiencies – Part 1: General.* The standard [9] defines the required inputs, outputs and structure of the calculation method for the heating system energy evaluations. The energy performance can be evaluated through the values of the system efficiencies or considering the values of the system losses; the evaluated sub-system energy performances (*and relative controls*) are: emission, distribution, storage and heat generation.

EN 15316-2.1: *Heating systems in buildings - Method for calculation of system energy requirements and system efficiencies – Part 2.1: Space heating emission systems*. The energy performances of the emission systems are evaluated. The standard [10] establishes the use of two different methodologies, basing the calculation methods on the emission system performance factor or on the values of the heat emission system losses. Different strategies of heating use are considered (*continued or intermitted*).

EN 15316-2.3: *Heating systems in buildings - Method for calculation of system energy requirements and system efficiencies – Part 2.3: Space heating distribution systems*. This part of the EN 15316 [11] provides a methodology to calculate the heat emission and the energy losses related to the space heating distribution systems. In addition, the energy required for the running of the auxiliary pumps is considered.

EN 15316-3: *Heating systems in buildings - Method for calculation of system energy requirements and system efficiencies – Part 3. Domestic hot water systems*. Actually, this part is further divided in 3 sub-standards [12, 13, 14], all referred to the energy requirements for domestic hot water heating systems (including control and with reference to all kinds of buildings). The efficiencies (or losses) of distribution, storage and generation sub-systems are considered.

EN 15316-4: *Heating systems in buildings - Method for calculation of system energy requirements and system efficiencies – Part 4: Space heating generation systems*. This part of the standard is very complex, regarding the heat generation. In particular, various sub-parts are defined: Part 4.1, combustion systems; Part 4.2: heat pump systems, Part 4.3: thermal solar systems (*including DHW*), Part 4.4: electrical and thermal performances of CHP; Part 4.5: the energy performances of district heating and large volume systems, Part 4.6: performances of other energy systems by renewable sources; Part 4.7: evaluation of the efficiencies of biomass combustion systems. For each of these, methods for the evaluation of the system efficiencies and/or losses are offered [15-21].

EN 15243: *Ventilation for Buildings - Calculation of room temperatures and of load and energy for buildings with room conditioning systems*. The standard [22] defines procedures to evaluate the building energy demands, explaining methods for the evaluations of sensible and latent loads, heating and cooling, humidification and dehumidification requirements. The purposed methodologies consist into a general hourly calculation procedure as well as other alternative simplified evaluations.

EN 15193: *Energy performance of buildings – Energy requirements for lighting*. Also about the artificial lighting, the EPBD imposes the evaluation of the annual demanded energy. The standard [24] specifies the calculation methodology for the evaluation of the amount of used energy and provides numerical indicators for the lighting energy requirements.

EN 15255: *Thermal performance of buildings – Sensible room cooling load calculation - General criteria and validation procedures*. The standard [31] sets out the level of input and output data, prescribing the boundary conditions required for the sensible cooling load calculation method, characterizing a single room under constant or/and floating indoor temperatures. It includes also methodologies used to evaluate the maximum cooling load for the HVAC sizing. The temperature profile, when the cooling capacity of the system is reduced, is also provided, as well as apt strategies for the cooling load reductions.

EN 15265: *Thermal performance of buildings – Calculation of energy use for space heating and cooling – General criteria and validation procedures*. The standard [32] reports assumptions, boundary conditions and validation for the calculation procedure of the annual energy use for space heating and cooling. The standard does not specify calculation methodologies, but only energy data and inputs for the system performance analysis.

EN 15242: *Ventilation for buildings – Calculation methods for the determination of airflow rates in buildings including infiltration*. The technical document [33] describes methods to calculate the ventilation airflow rates for buildings. These data can be used for the required energy calculations, heat and cooling load estimations, summer comfort and indoor air quality evaluations. Both air-conditioned and naturally ventilated buildings are considered.

EN 15241: *Ventilation for buildings – Calculation methods for energy requirements due to ventilation systems in buildings*. The document [23] describes the methodologies used to weight the energy impact of ventilation systems, which should be used for the energy (heating and cooling) calculations. Methods to calculate the physical characteristics of the air entering into the building are provided too.

EN 15232: *Energy performance of buildings - Impact of Building Automation, Controls and Building Management*. A structured list of control (*building automation and technical building management functions that influence the energy performance of buildings*) is provided by this technical document [25]. The document contains methods to define minimum requirements regarding the control (*i.e. building automation and technical building management functions to implement*) according to several building typologies, each one characterized by a different level of complexities. These methods are apt to introduce the impact of these functions in the calculations of energy performance ratings and indicators. The standard provides also a simplified method for preliminary investigations.

Beside the above-cited new standards, a set of pre-existing technical documents has been also revised by the CEN during the last years, with some minor modifications. In particular, with reference to the heat transmission in buildings, the following documents have been upgraded:

EN 13786: *Thermal performance of building components. Dynamic thermal characteristics – Calculation methods*. The document [34] specifies the characteristics related to dynamic thermal behaviour of building components, by means of the parameters attenuation factor ($f_a$), time lag effect (S) and periodic thermal transmittance ($Y_{12}$), establishing also methods for their calculation.

EN 13789: *Thermal performance of buildings – Transmission and ventilation heat transfer coefficients – Calculation method*. The standard [35] specifies methodologies for the calculation of the steady-state transmission and ventilation heat transfer coefficients of the whole buildings and/or its parts.

EN 10077-1: *Thermal performance of windows, doors and shutters – calculation of transmittance.* This document includes [36] methods for the calculation of the thermal transmittance of windows, glazed doors, opaque panels fitted in a frame, with and without shutters. Another standard, the EN 10077-2, suggests, furthermore, more complex numerical methods (*based on thermal-fluid-dynamics algorithms*) in order to evaluate the same parameters regarding the heat transfer through transparent building surfaces.

Finally, another set of standards, also this related to the calculation of heat transmission in buildings, is been significantly revisited. In particular:

EN-ISO 10456: *Building material and products - Hygrothermal properties – Tabulated design thermal values and procedures for determining declared and design values*. The document [37] specifies methods for the determination of the thermal-physical properties of homogeneous building materials and products.

EN 13370: *Heat transfer via the ground – calculation methods.* The standard [38] gives methods of calculation of heat transfer coefficients and heat flow rates for building opaque component in thermal contact with the ground, including the formulation of calculation methods, in steady-state conditions, for the conductive heat transfer.

EN 10211: *Thermal bridges in building construction – Heat flows and surface temperatures – detailed calculations*. The standard [39] sets out the specifications for 3-D and 2-D geometrical thermal bridges, in order to carry out the numerical calculation of the heat flows and the temperatures of the interested surface. The document includes specifications about the geometrical, thermal and other typical design boundary conditions of common thermal bridges.

EN 14683: *Thermal bridges in building constructions – Linear transmittance – simplified methods and default values*. The document [40] contains simplified methods for determining heat flows through linear thermal bridges which occur at the junctions of building elements.

EN 6946: *Building components and building elements - Thermal resistance and thermal transmittance*. The standard [41] upgrades the previous and retired document, providing the calculation method for the evaluation of the thermal resistance and thermal transmittances of several building components.

EN 13779: *Ventilation for non-residential buildings – Performance requirements for ventilation and room conditioning systems*. The standard is a revision of the 2003 version; it gives [42] performance requirements for ventilation systems, above all as regards non-residential buildings. Instead, as regards the dwellings, the CEN/TR 14788 [43] includes the same information.

EN 15377: *Design of embedded water based surface heating and cooling systems*. The standard is divided in 3 parts: Part 1: *Determination of the design heating and cooling capacity* [44], Part 2: *Design, Dimensioning and Installation* [45], Part 3: *Optimizing for use of renewable energy sources* [46]. This technical document applies, for all kinds of buildings (*residential, commercial and industrial*), the criteria for the design of water based surfaces for heating and cooling; systems integrated inside the wall, floor or ceiling construction (*without any open-air gaps*) are considered too.

EN-ISO 13791: *Thermal performance of buildings – Calculation of internal temperatures of a room in summer without mechanical cooling – Simplified methods*. The standard [47] specifies the necessary input data for simplified calculation methods, in order to determine maximum, average and minimum daily values of the indoor operative temperature in summertime.

EN 15459: *Energy performance of buildings - Economic evaluation procedure for energy systems in buildings*. The document [48] provides data and calculation methods for economic issues of heating systems and other plant involved in the energy demand and energy consumption of the building.

EN 15239: *Ventilation for buildings – Energy performance of buildings - Guidelines for inspection of ventilation systems*. The technical document [28] refers methodology for the inspection of mechanical and natural ventilation systems, depending on their energy consumption. The standard also includes recommendations as regards possible energy improvements.

EN 15251: *Criteria for the indoor environment, including thermal, indoor air quality, light and noise*. The standard specifies the parameters and criteria to evaluate indoor comfort conditions. Methods for long-term evaluation are reported. The standard [49] is above all referred to non-industrial buildings (*residential, tertiary, educational…*) i.e. where the criteria for indoor environment are mainly referred to human occupancy. Both air-conditioned and naturally ventilated buildings are contemplated.

## 2.2 CALCULATION OF THE BUILDING ENERGY PERFORMANCES

### 2.2.1 DESCRIPTION OF THE CALCULATION METHODS

In this paragraph, the methodologies to evaluate the energy performances of building are briefly reported, simply describing the procedures contained in the new set of CEN technical standards.

First of all, several calculations methods are purposed by the CEN, in order to provide more or less accurate procedures, depending on the energy evaluation purpose. The EN 15603, in fact, suggests various rating methodologies; immediately, these can be classified in:

a. calculated ratings;
b. measured ratings.

Both the methodology kinds evaluate the building energy performances as of the sum of the different energy uses, such as the heating, cooling, ventilation, lighting, domestic hot water production services. The measured ratings are based, obviously, on the energetic bills, thus carrying out evaluations by means of the real energy needs and requests of the building. Contrariwise, the calculated ratings are based on numerical-physical evaluations, starting by typical boundary conditions, diversified for building typologies; these methodologies can adopt different levels of deepening, depending on the scope of the energy audit.

In particular, the European Standard 15603 defines, with reference to the building energy evaluations, the following kinds of estimations (table II.1):

- calculated energy ratings:
  - design energy rating;
  - standard energy rating;
  - tailored energy rating.
- measured energy ratings.

Obviously, the higher level of accuracy is achieved adopting the last two approaches, *i.e. the tailored rating, based on detailed boundary conditions, and the measured data evaluation*.

These kinds of evaluations are necessary when optimization analyses must be carried out, above all in order to exactly estimate the technical-economical convenience of a possible energy improvement solution.

On the other hand, when the final purpose in a standard evaluation of the building energy performances, e.g. in order to obtain a building permit or to compare the energy performances of a particular building compared to benchmark values, respectively design rating or standard methods should be used.

In fact, in order to make possible a coherent comparison, the same boundary conditions (*above all as regards the use of the building, the occupancy, the installed equipment, the amount of ventilation, the required indoor conditions*) should be adopted.

Table II.1: different calculation approaches on varying of the energy audit purpose *(source: CTI)*

| | Name | Input data | | | Purpose |
|---|---|---|---|---|---|
| | | Use | Climate | Building | |
| Calculated | Design | Standard | Standard | Design | Building permit, Certificate under condition |
| | Standard | Standard | Standard | Actual | Energy Certificate, compliance with building regulations |
| | Tailored | Actual (*) | Actual (*) | Actual | Optimisation, retrofit planning (EE measures) |
| Measured | Operational | Actual | Actual | Actual | Energy Certificate, regulations |

Definitively, the asset ratings (*design or standard*) are recommended during the design process or for the existing building energy certification, while, when a higher accuracy is needed, measured or detailed calculation procedures (*tailored rating*) have to be used.

Of course, as already before explained, the energy certification requires universal calculation procedures, applicable to both new and existing buildings, so that the connection to specific boundary conditions, related only to this building, cannot be contemplate. For this reason, the CEN standards (*in particular the EN 13790*) provide typical building characteristics (*about the management*) released with the intention to make possible and reliable the comparison under the same boundary conditions.

Some confusion around the meaning of "rating" usually happens, being this indistinctly used for the building energy classification (*the rating system*) as well as for the application of the procedure *(the action of rating*).

In this Thesis, the definition of rating will intend, as specified by Stein and Meier [50, 51], "*a method for the assessment of predicted energy use under standard conditions and its potential for improvement*''. The usual inputs are well-defined standard boundary conditions, while the required outputs are related to the energy use predictions, useful when compared with a reference building.

In addition, the EPBD uses the "*rating*" as expression to identify the building energy performances. Before the description of the different calculation procedures, some definitions can be useful, in order to better understand the following methodology explanations:

- *energy need for heating and cooling*; heat to be delivered or extracted from a conditioned space in order to maintain the desired temperature;
- *energy need for domestic hot water*; heat to be delivered to obtain the domestic hot temperature water, starting from the cold temperature of the sink;
- *energy use*; energy need summed to the not recovered technical system losses and to the energy required for the auxiliary running;
- *delivered energy*; energy, expressed per energy carrier, supplied to the technical building systems, through the system boundaries, in order to satisfy the considered energy uses;
- *primary energy*; energy that has not been subject to any conversion or transformation process.
- *energy performance of a building*; calculated or measured amount of delivered energy used or calculated to meet the needs associated with a standardised use of a building (heating, ventilation, domestic hot water, cooling and lighting);
- *energy rating*; evaluation of the energy performance of a building, based on weighted sum of calculated/measured uses.

As before cited in the previous paragraphs of this chapter, the main CEN standard, developed with the intention of providing fixed calculation methodologies, is the EN 13790/2008, referred to the evaluation of both the energy required for the winter heating and the summer cooling of the indoor space. The same standard contains various calculation approaches, in order to carry out the different evaluations above described.

In particular, also as regards the calculation (*i.e. the energy balances*) time steps, different levels of deepening are provided, being suggested methods for the seasonal, monthly and hourly calculations, as well as more complex algorithms for detailed evaluation procedures.

Independently by the adopted methodology, figure 2.1.1 reports the calculation scheme in order to calculate the energy required for the space heating and cooling, linking the different main standards developed by the CEN during the last years.

In figure 2.1.2, the central role of the EN 13790 emerges, such as the interconnections with the other necessary technical standards.

First of all, the definitions of the building envelope characteristics and uses are necessary in order to evaluate the two first parameters that affect the heat gains and losses, due to the energy transfers through the building shell:

- the energy transferred for transmission (*diffusive heat exchange*);
- the energy transferred for ventilation (*convective heat exchange*).

Then, other contributes can raise or reduce the sum of the two above-reported energy exchanges; about it, in the followings, a light description of the evaluation procedure will be reported.

The application of the methodologies requires, obviously, a set of input, among which the most important are:

- the parameters governing the transmission and ventilation heat exchanges;
- the parameters necessary to estimate the solar gains and the endogenous ones;
- the set of data connected with the climate conditions;
- definition of the building behaviour and thermal properties of the opaque and transparent components of the building shell;
- established indoor conditions, about the thermal level imposed in a fully air-conditioned building;
- parameters connected to the active energy plants, as well as the main characteristics of heating, cooling, hot water, ventilation and lighting systems,
- diversification of the building in different thermal zones, identified depending on their characteristics (*about the use, the exposure, the kind of applied systems…*);
- the energy losses due to the installed system inefficiencies, and the recoverable fractions of these;
- energy uses due to the auxiliaries and the complementary operations, such as the air-circulation, the pre-heating and pre-cooling functions;
- kind of heating/cooling systems, supplied airflow (*and relative thermo-dynamic state*), kind of distribution, emission, storage and control sub-systems.

On the other hand, the main outputs can be simply defined:

- the annual energy needs for space heating and cooling;
- the annual energy use for space heating and cooling, considering the system losses due to several phenomena;
- the lengths of the winter (*heating season*) and of the summer (*cooling time*), that affect the energy consumptions, both in terms of used energy and energy required by the auxiliaries.

In particular, as expressed in the scope of the standard, the calculation methods include [8]:

a) the heat transfer by transmission and ventilation of the building zone when heated or cooled;
b) the contribution of internal and solar heat gains to the building heat balance;
c) the annual energy needs for heating and cooling, in order to maintain a fixed (comfortable) value of the indoor temperature (*latent loads are not included*);
d) the annual energy use for the building eating and cooling, adopting inputs from the relevant system standards;

In the preface, the EN 13790 underlines that the division in several thermal zones should be considered when the building presents various homogeneous spaces, characterized by different set-point temperatures, or interested by intermittent heating and cooling diversifications.

The standard bases the calculation time step on the month, even if hourly energy balances are possible for most detailed annual simulations or for particular energy analyses. Finally, the technical document includes common rules for the boundary conditions and physical input data, establishing diversified approaches depending on the adopted calculation methodology.

Starting by the first point above-reported, and considering the monthly/seasonal calculation methods, for each building zone and calculation period, the total heat transfer interesting the building envelope has to be calculated as expressed in the equation 1:

$$Q_{ht} = Q_{transmission} + Q_{ventilation} \qquad (1)$$

where $Q_{tr}$ and $Q_{ve}$ are the heat losses or gains due to the energy transmission (eq. 2) and ventilation (eq. 3):

$$Q_{transmission} = H_{transmission}\left(\Theta_{int,set(HEAT-COOL)} - \Theta_{e}\right)t \qquad (2)$$

$$Q_{ventilation} = H_{ventilation}\left(\Theta_{int,set(HEAT-COOL)} - \Theta_{e}\right)t \qquad (3)$$

In the reported equations, the $\Theta_{int,set}$ are the set-point temperatures for heating or cooling, $\Theta_e$ is the ambient air temperature, t is the duration of the calculation step, $H_{tr}$ and $H_{ve}$ are the overall heat transfer coefficients respectively for transmission and ventilation.

As regards the values of the heating and cooling set point temperatures, the EN 13790 doesn't specify absolute values, establishing that, about this, national technical standard should be propose specific reference values. For example, in Italy the standards UNI TS 11300-1 (*as described in the next paragraph*) [52], at the same way of the big part of the European countries, imposes the following internal thermal conditions, with reference to air-conditioned buildings:

- wintertime: indoor set-point temperature = 20 °C ± 1;
- summertime: indoor set-point temperature = 26 °C ± 1.

In the evaluation of the building thermal energy need, the next step is the determination of the free gains in wintertime (*in summertime, these, represent further energy penalties*).

In particular, with reference to both the climatic seasons, the free entering thermal gains are represented by the solar gains due to the solar radiation entering into the space (eq. 4) and the endogenous gains due to the people presence and the installed equipments (eq. 5):

$$Q_{solar} = \left\{\sum_{k}\Phi_{FREE-SOLAR,CONSIDERED-ZONE}\right\}\cdot t + \left\{\sum_{l}\left(1-b_{tr,l}\right)\cdot\Phi_{FREE-SOLAR,ADJACENT-ZONES}\right\}\cdot t$$

(4)

$$Q_{internal} = \left\{ \sum_k \Phi_{FREE-INTERNAL,CONSIDERED-ZONE} \right\} \cdot t + \left\{ \sum_l \left(1 - b_{tr,l}\right) \cdot \Phi_{FREE-INTERNAL,ADJACENT-ZONES} \right\} \cdot t$$

(5)

where the various physical terms represent:

- $\Phi_{FREE-SOLAR,\ CONSIDERED\ ZONE}$ = time averaged heat flow from the solar sources, placed in the considered building zone;
- $\Phi_{FREE-SOLAR,\ ADJACENT-ZONE}$ = the time averaged heat flow from the various solar sources placed in adjacent unconditioned spaces;
- $\Phi_{FREE-INTERNAL,\ CONSIDERED\ ZONE}$ = time averaged heat flow from the various endogenous sources, placed in the considered building zone;
- $\Phi_{FREE-INTERNAL,\ ADJACENT-ZONE}$ = the time averaged heat flow from the various endogenous sources, placed in adjacent unconditioned spaces;
- $b_{tr,l}$ = the reduction factor due to the presence of adjacent unconditioned space.
- t = the length of the considered calculation period.

The main terms referred to the building energy balances have been so defined. Therefore, the whole energy balances can be presented, by means of the equations 6 (*refereed to the wintertime*) and 7 (*related to the summer season*):

$$Q_{HEATING,nd} = \left(Q_{H,trasmission} + Q_{H,ventilation}\right) - \left(Q_{H,internal} + Q_{H,solar}\right) \cdot \eta_{HEATING,gn}$$

(6)

$$Q_{COOLING,nd} = \left(Q_{C,internal} + Q_{C,solar}\right) - \left(Q_{C,transmission} + Q_{C,ventilation}\right) \cdot \eta_{COOLING,ls}$$

(7)

With reference to the equations 6 and 7, of course $Q_{HEATING,,nd}$ and $Q_{COOLING,,nd}$ represent respectively the building total thermal energy needs, in heating mode and for cooling.

### 2.2.2 CALCULATION METHODOLOGIES FOR THE UTILIZATION FACTORS IN WINTER AND SUMMER

In the equations 6 and 7, the terms $\eta_{HEATING,gn}$ and $\eta_{COOLING,ls}$ appear, and these respectively are defined as the gain utilization factor and the loss utilization factor. These definitions express a different approach applied for the winter and the summer times. In fact, while during the heating period the energy need of the building is related above all to the heat losses from the building to the external ambient (*due to the higher indoor temperatures*), in summertime, contrariwise, the main responsible of the required cooling energy are the endogenous heat sources (*placed at the first term of the equation 7*).

In winter, the indoor gains (*placed at the second terms of the equation 6*) reduce the heating need of the building, even if these have to be multiplied for a reduction factor

($\eta_{HEATING,nd}$) related to the real utilization amount of the free gains. It is quite obvious underlining that, in fact, the direction of these heat fluxes goes in the same way of that realized by the heating system (→ *indoor*), so that solar and endogenous gains represent a positive contribute.

On the other hand, in summer, the amount of the cooling energy need can be reduced through the transmission and ventilation losses from the indoor to the outdoor environments, of course when the mean outdoor temperature results lower than the indoor one. Thus, also in this case, an utilization factor must be considered ($\eta_{COOLING,ls}$), in order to operate under safety boundary conditions.

In both the seasons, according to the calculation methods proposed in the equations 6 and 7, high utilization factors contribute to reduce the thermal energy need of the building.

As regards the calculation criteria, the utilization factors are related to the building thermal inertia and to the relation between *heat losses* and *energy gains*, as expressed in the following sections.

*a) HEATING MODE: UTILIZATION FACTOR OF THE THERMAL GAINS*

Several formulas are provided by the standard EN 13790 in order to calculate the utilization factor of the free heat gains, related, as before cited, to: building thermal inertia, amount of free heat gains and lost energy (equation 8).

$$\eta_{HEATING,nd} = f\left(\gamma, \text{building inertia, kind of calculation}\right) \quad (8)$$

In particular, depending on the value assumed by the term $\gamma_H$ (*expressive of the "energy losses" to "free gains" ratio*), it is possible the selection of the appropriate equation 8.

$$\gamma_H = \frac{Q_{H,gn}}{Q_{H,ht}} = \frac{\text{total energy loss}}{\text{total energy gain}} \quad (9)$$

As expressed in the Annex I of the standard EN 13790, in this way the not-used gains are omitted from the heat balance equation.

*b) COOLING MODE: UTILIZATION FACTOR OF THE THERMAL LOSSES*

The loss utilization factor, at the same way, is related to the *heat losses* to *energy gains ratio,* in summertime (i.e. the ratio $\gamma_C$ ) and to the parameter $a_C$, dimensionless, also in this case connected to the thermal inertia of the building envelope. In particular, analogously to the procedure already shown for the wintertime, it results:

$$\eta_{COOLING,ls} = f\left(\gamma, \text{building inertia, kind of calculation}\right) \quad (10)$$

The term $\gamma_C$ represents, in this case, the ratio "losses" to "gains", i.e. the "total heat gains for the cooling mode" *to* "the total heat (loss) transferred by transmission and ventilation" ratio (eq. 11).

$$\gamma_C = \frac{Q_{C,gn}}{Q_{C,ht}} = \frac{\text{total energy gains}}{\text{total energy trasm.} + \text{vent.}} \quad (11)$$

Also in this case, only 1 among the 3 alternative forms assumable by the equation 10 has to be used, depending on the value assumed by $\gamma_C$

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Under a "*thermodynamic*" point of view, it is quite clear that, in both the climatic seasons, a high thermal inertia induces a higher utilization factor of the useful heat transfer phenomena (*free thermal contributes in wintertime, free losses/dissipation in summer*).

Therefore, a first design indication consists in the use of a great thermal capacity of the building envelope, in order to reduce the wintertime energy need (*equation 6*) and the summertime cooling energy requests (*equation 7*).

The equations 6 and 7 report the final relations to evaluate the building total heating need ($Q_{HEATING,nd}$) and the summer one ($Q_{COOLING,nd}$). The solar and endogenous gains (*favourable contributes to reduce the winter heating need and further penalizing effects during the cooling season*) have been already described in the equations 4 and 5.

The heat transfer phenomena, due to the energy transmission through the building envelope, and those related to the indoor space ventilation are reported, instead, in the equations 2 and 3.

In the followings, the main terms reported in these relations 2, 3, 4 and 5 will be better defined.

### 2.2.3 TRANSMISSION, VENTILATION, SOLAR GAINS AND ENDOGENOUS ENERGY TRANSFERS: SINGLE CONTRIBUTE EVALUATION

#### a) HEAT TRANSFERRED FOR TRANSMISSION THROUGH THE BUILDING ENVELOPE

In the equation 2 appears $H_{tr,adj}$, that represents the overall transmission heat transfer coefficient. In particular, the term is evaluated as reported into the equation 12.

$$H_{transmission} = H_D + H_g + H_U + H_A \quad (12)$$

where, the reported terms represent: $H_D$ = transmission heat transfer to the external environment; $H_g$ = transmission steady-state heat transfer to the ground; $H_U$ = transmission heat transfer to unconditioned spaces; $H_A$ = transmission heat transfer to other buildings.

Each of the these parameters can be easy calculated by means the equation 13, where the thermal transmittance of the building component ($U_{generic}$), the area of the dispersing surface ($A_{generic}$), the linear thermal bridges characteristic ($\Psi_{generic}$) and length ($l_{generic}$), as well as the punctual thermal bridges incidence ($\chi_{generic}$) are present.

$$H_{generic} = b_{tr,k} \cdot \left( \sum U_{generic} A_{generic} + \sum l_{generic} \Psi_{generic} + \sum {}_{generic} \chi_{generic} \right) \tag{13}$$

In the equation 13, $b_{tr,k}$ represents the correction factor that should be used when the temperature of the outer side of the building component is not the same of the outdoor environment (*only if these are coincident → $b_{tr,x}$ = 1*). Thus, the technical standard provides a method that, in case of dispersions directed to adjacent unconditioned spaces or toward the ground, the equation 2 continues with the same outdoor T (*the temperature of the outdoor ambient*), but considering a reduction coefficient.

b) HEAT TRANSFERRED FOR VENTILATION

In the equation 3, $H_{ventilation,}$ represents the overall ventilation heat transfer coefficient. It depends, of course, on the volumetric flow rate entering into the conditioned space ($q_{ventilation}$), the air density ($\rho_a$), the fluid specific heat capacity ($c_a$), and, at the same way of the dispersion for transmission, also in this case a reduction factor is considered in case of ventilation from another ambient ($b_{ve,k}$), different with respect to the external one.

$$H_{ventilation} = \rho_a \cdot c_a \left( \sum b_{ve,k} \cdot q_{ventilation} \right) \tag{14}$$

The term $q_{ventilation}$ is achieved multiplying the airflow rate, typical for the building use (*standard EN 13790 Annex G*), and the typical time period in which the ventilation is realized; The EN 13790 provides common boundary conditions, with reference to occupancy, installed electrical power and indoor set point temperatures are reported, depending on the building use. In particular, as specified in the Annex G of the European standard, this value can be used when no national one are available.

Finally, a last note about the $b_{ve,k}$ factor. At the same way of the $b_{tr,k}$, this coefficient varies between 0 and 1. In particular, the value 1 is used when the outdoor environment is the external one, while, if less critical conditions are considered (*in presence of ventilation or transmission through an unconditioned space or from the ground*), a lower value should be provided. *Obviously, when both transmission and ventilation come from the same adjacent space, then $b_{ve,k}$ and $b_{tr,k}$ assume the same value.*

As regards $b_{ve,k}$, the temperature adjustment factor can be converted, in presence of heat recovery system, into a number expressing the efficiency of this device; in this way, in the determination of heat losses due to the space ventilation, the presence and the efficiency of the heat recovery system can be easily contemplated.

c) SOLAR HEAT GAINS

In the equation 3, the method for the calculation of the solar gains is reported. In this section, a description of each element of the equation is provided, in order to give easily some explanations about the main parameters influencing the amount of energy transferred into the building, because of the solar radiative phenomena.

First of all, it is important to underline that the radiation heat transfer phenomena, although these result higher for the transparent building surfaces, interest the opaque components of the building too, both in form of higher outdoor surface temperature of walls and roofs, and in form of nighttime radiation between the building shell and the cool sky. About the sky temperature, this induces a free radiative cooling, being the sky characterized by a thermal level usually in the range 10 - 15 °C.

In the explanation of the equation 4, two terms regarding the solar flux have been reported, considering the analysed zone and adjacent spaces; moreover, the two terms can be summed (*i.e. the parameter $\Phi_{solar}$*), such as reported in the equation 18:

$$\Phi_{sol} = \sum_{k} \Phi_{FREE-SOLAR,CONSIDERED-ZONE} + \sum_{l} \left(1 - b_{tr,l}\right) \cdot \Phi_{FREE-SOLAR,ADJACENT-ZONE}$$

(15)

In this way, the incidence of the solar gains can be easily expressed as

$$Q_{solar} = \Phi_{solar} \cdot t \qquad (16)$$

In the equation 15, the following elements are present:

- $b_{tr,l}$ is the adjustment factor, that has to be considered when the solar heat sources interest not the space but adjacent unconditioned rooms;
- $\Phi_{FREE\text{-}SOLAR,\ CONSIDERED\text{-}ZONE}$ is the hourly heat flow rate from the solar heat source into the considered environment.
- $\Phi_{FREE\text{-}SOLAR,\ ADJACENT\text{-}ZONE}$ is the hourly heat flow rate from the solar heat source into adjacent and not conditioned spaces;

Analyzing the equations 15 and 16, it becomes quite clear that the main responsible term, as regards the energy entering into the conditioned environment by means the solar radiation, is the parameter $\Phi_{FREE\text{-}SOLAR,\ CONSIDERED\ ZONE}$. In the equation 17, this term has been better defined.

$$\Phi_{FREE-SOLAR,CONSIDERED-ZONE} = \left(F_{shading} \cdot A_{sol} \cdot I_{sol}\right) - \left(F_{r,k} \Phi_{r,k}\right)$$

(17)

In particular, the terms $\Phi_{FREE\text{-}SOLAR,\ CONSIDERED\text{-}ZONE}$ depends on the collecting area ($A_{sol}$), the solar irradiance ($I_{sol}$) and the shading reduction factor ($F_{shading}$).

Furthermore, with reference to the equation 17, the product of $F_{r,k}$ and $\Phi_{r,k}$ obviously reduces the global amount of solar energy entering into the environment, because this multiplication represents a radiative heat loss. In fact, $F_{r,k}$ is the form factor between the building element and the sky (*the value assumed by this factor is equal to 1 for horizontal roof, 0.5 for not-shaded vertical walls*) and $\Phi_{r,k}$ represents the hourly extra heat flow due to thermal radiation from the building generic element toward the sky.

Each one of the above-defined parameters can be calculated adopting the relations contained in the standard. In particular, the equation 17 is composed by two terms, closed by parentheses:

1. a first terms that represents a solar gain, useful in wintertime, penalizing in summer;
2. a second one representing a heat loss (*so that this second term is preceded by the minus sign*).

For a complete description of all the algorithms, reported in order to evaluate each member of the equation 17, the paragraph 11 of the standard EN 13790 should be used; here, only the main responsible terms, with reference to the building-outdoor environment energy balances, are briefly described.

Still with reference to the equation 17, $A_{sol}$ is the surface area that has to be evaluated during the calculation; it can be calculated in 2 different ways, depending on its transparent or opaque characteristics.

In case of *transparent surfaces*, this area depends, obviously, by the amount of glazed area of the building, multiplied by the solar energy transmittance of the transparent surfaces and by the shading reduction factor due to the presence of movable window blinds.

Typical values of the total solar energy transmittance ($g_{gl}$), at normal incidence and for common types of glazing, are reported into the technical standard (*e.g. usually, a single glass has a solar transmission factor around 0.85, while a double glass with selective low-emissive coating has a "$g_{gl}$" factor around 0.65*).

On the other hand, in case of *opaque surface*, $A_{sol}$ depends on the area of the considered component, on the solar absorption coefficient of the opaque element, on the external heat resistance of the sun-exposed surface and on the thermal transmittance of this building component.

The solar gains, through the building opaque envelope, during the heating season represent a very low part of the total solar contribute (*quite completely compensated by the radiative losses from the building to the cold sky*). On the other hand, the penalizing effect due to the solar radiation of the opaque shell effect becomes very significant in summertime.

In the second parenthesis of the equation 17, the term $\Phi_{r,k}$ appears; this is defined as the extra heat flow due to thermal radiation from building element to the sky. The sky varies its temperature significantly throughout the year, but its thermal levels never reaches values above the 15 ° C (*i.e. always, the net radiative flux is directed form the building toward the sky*).

This means that the second parenthesis of the equation 17 represents, in both winter and summer, a heat loss. In particular, the entity $\Phi_{r,k}$ depends on:

- the external radiative heat transfer coefficient;
- the average difference between the external air temperature and the apparent sky temperature;
- the thermal transmittance of the building component;

- the external surface heat resistance of the element.

As regards the average difference between the external air temperature and the apparent sky temperature, the standard provides three values, to use when better data are available. In particular this difference is in this way expressed: *tropical areas* → $\Delta T = 13$ *°C, sub-polar areas* → $\Delta T = 9$ *°C, intermediate situations* → $\Delta T = 11$ *°C.*

However, as regards the thermal extra flow between building envelope and sky, the EN 13790 makes possible, at national level, the adoption of different values with respect to those here proposed, also on varying of the building use. At the same way, the standard makes possible also the neglecting of this term (*extra heat transfer by radiation toward the sky*). The same possibility regards also the solar energy absorbed by opaque construction elements.

d) ENDOGENOUS GAINS

In the equation 5, the procedure for the calculation of the endogenous heat gains, both in summer and winter times, has been reported. This term of the building energy balance has been expressed as function of the time averaged heat flows from internal sources, placed in the conditioned environment and also when located in adjacent spaces (*in this last case, it is multiplied for a reduction factor* $b_{tr,l}$).

The equation 5 establishes a base formula $Q_{internal} = \Phi_{internal} * time$; the time averaged heat flow from the various sources can be expressed as reported into the equation 18.

$$\Phi_{internal} = \sum_k \Phi_{FREE-INTERNAL,CONSIDERED-ZONE} + \sum_l \left(1 - b_{tr,l}\right) \Phi_{FREE-INTERNAL,ADJACENT-ZONE} \tag{18}$$

where $b_{tr,l}$ is the already cited adjustment factor for the adjacent unconditioned space with internal heat sources.

As regards the internal thermal sources, these consider all the heat generation sinks placed in the conditioned space, excluding the energy intentionally used for space heating, space cooling or hot water preparation. In particular, the internal gains include:

- metabolic heat from occupants and dissipated heat from energy appliances;
- heat flows released from the lighting devices;
- thermal energy dissipated from, or absorbed by, hot water and sewage systems;
- thermal energy dissipated from, or absorbed by heating, cooling and ventilation systems;
- thermal energy from or to processes and goods.

Each one of the above cited heat sources can be consider as $\Phi_{internal}$. In the followings, the methodologies to calculate the single contribute are briefly described.

METABOLIC HEAT FROM OCCUPANTS. The occupants release heat, both in the form of sensible and latent generations; the EN 13790 standard considers only the heat flow acting on the space temperature, so only the sensible part is considered. The same standard specifies that hourly and weekly schedules of heat flow rate for metabolic heat from occupants should be defined at national level, during the transposition of the methodologies into the local technical documents, depending on the building use, the kind of crowding and occupancy, and on varying the value depending on the purposes of calculation (*kind of rating*).

HEAT DISSIPATED FROM LIGHTING DEVICES. The indoor spaces are interested, of course, by the presence of lighting equipments; these release a heat flow rate associated to the electric installed power. In particular, the heat contribute can be expressed as the sum of main lighting systems and the local ones, as well as the decorative lighting, removable lighting, special-task lighting, building-grounds lighting, process-related lighting. The amount of released thermal energy can be calculated as fraction of the installed electric power, while a further reduction can be considered when a ventilation extraction system, via luminaries, is provided.

HEAT DISSIPATED FROM, OR ABSORBED BY, HOT WATER AND SEWAGE SYSTEMS. Even if this contribute doesn't play a strong influent role, anyway, the hot water production, distribution and sewage determine an amount of internal gains that should be considered. In particular, the main heat flows considered are represented by the internal heat flow rate due to recoverable losses from the hot water production systems, permanent or time-controlled hot water circulation equipments, the internal heat flow rate due to recoverable losses from mains water and sewage. The standard EN 13790 provides all the relations and terms necessary for the calculation, even if the use of normalized values is suggested (*for example adopting international or national technical specifications*). Furthermore, it is clearly specified that also the neglecting of this term can be decided, above all when the building use makes not so significant these contributes.

HEAT DISSIPATED FROM, OR ABSORBED BY HEATING, COOLING AND VENTILATION SYSTEMS. This endogenous heat gains can be divided in the sum of three terms, the internal heat flow rate due to recoverable losses from the space heating system, the one due to recoverable losses from the space cooling devices, the heat recoverable from the ventilation equipments. These heat flows are obviously evaluated as positive (*i.e. from the system to the indoor environment*) both in summer and in winter. The EN 13790 establishes that the recoverable losses from the heating and cooling system should be calculated after the evaluation of the energy needs for heating and cooling (without these heat gains) because their amount is strongly related to the required thermal energy of the building.

The space heating system dissipates thermal energy in the building, by means the auxiliary energy sources (*pumps, fans, electronics*), but also due to the circulation, distribution, storage and generation losses. The standard provides typical values of the recoverable part of these losses, diversified for hourly, monthly or whole heating season average values. However, also the neglecting of these contributes is admitted, when, at national level, a not significant entity of the heat dissipated in the space heating system and actually recoverable is evaluated.

At the same way, also the cooling system requires the use of auxiliary devices, such as the ones for the air circulation and the thermal-hygrometric regulations; these installed equipments release a heat gains, increasing the cooling energy required to keep the indoor space at a comfortable temperature. Also in this case, the considered technical standard suggests the adoption of the typical values reported in its annexes. Alternatively, for reasons of simplification, this contribute can be neglected, even if, contrariwise with respect to the wintertime, in this case ignoring this further significant load can induce an underestimation of the cooling energy required by the building.

Finally, the last one internal heat flow rate, in the considered building zone due to the HVAC system, consists into the thermal losses of the ventilation system, released into the building and so representing a positive energy contribute. This value includes the heat dissipated for the air supply and circulation, so that a fraction of the installed power fan should be considered as endogenous positive gain. The EN 13790 specifies that these values should be derived, preferably, from authoritative technical documents.

HEAT FROM OR TO PROCESSES AND GOODS. The standard 13790 is quite vague about this thermal energy contribute, providing only a general definition, so that this can be intended as a further generic gain to be considered for the thermal energy evaluation, both in summer and wintertime.

### 2.2.4 LENGTH OF THE HEATING AND COOLING SEASONS

The European technical standards, derived by the EPBD emanation, provide also methodologies to identify the length of the heating and cooling seasons, which could be used in absence of specific national evaluation procedures. In particular, both as regards the heating and cooling procedures, in order to identify the extension of the period, two calculation methodologies are proposed, the first one based on the energy needs for heating, cooling and for the ventilation air pre-heating or pre-cooling, the second one based on the heat balance ratios, respectively, for the heating or cooling mode. In the followings, the evaluation methods are described.

The length of the seasons ($L_{H/C}$) is determined applying different equations, with reference to the considered used of the air-conditioning system (*i.e. heating or cooling functions*).

The heating period length can be evaluated applying two different procedures: the method A (*simplified*) and the method B (*more detailed*). The first one considers the "*energy need for heating*" to "*the energy need for cooling*" ratio, while the second one operates on the basis of the monthly values of the heat-balance ratio. At the same way, the length of the cooling season adopts quite similar procedures.

However, the technical standard EN ISO 13790 provides, also in this case at national level, different evaluation methods for the evaluation of the season length. In particular, in the following paragraph, with reference to the Italian procedures (*UNI TS 11300 part 1 and part 2, [52, 53]*), it will be show another criterion adopted to identify the length of the heating and cooling seasons.

### 2.2.5 TOTAL ENERGY USED FOR SPACE HEATING AND COOLING

Until now, only the thermal energy required to induce comfort conditions inside the indoor spaces has been considered, diversifying procedures, contribution and influential parameters, with reference to the heating or cooling climatic season. In this way, only the net demanded energy has been considered, without evaluating the losses due to the various system inefficiencies.

Actually, the EPBD and its transposition into the European national legislations require the evaluation of the primary energy demand, at least for the winter heating and the summer cooling. Of course, in order to do this, before the conversion between thermal and primary energy, the losses due to the installed heating and cooling systems have to be considered, in particular determining an adequate increment of the building thermal energy need.

The EN 13790 doesn't provides methodologies for the calculation of the heating/cooling system efficiency ratios, even if the criteria to identify the total energy entering into the complex system building-HVAC is provided, such as expressed in the equations 19 and 20, respectively referred to the heating season and to the cooling one.

$$Q_{HEATING} = \left(Q_{HEATING,nd}\right) / \left(\eta_{SYS-HEATING}\right) \tag{19}$$

$$Q_{COOLING} = \left(Q_{COOLING,nd}\right) / \left(\eta_{SYS-COOLING}\right) \tag{20}$$

where

- $Q_{HEATING}$ is energy required by the heating system in order to heat the indoor environment for achieving the desired temperature in wintertime. The term includes the losses due to the system inefficiencies;
- $Q_{COOLING}$ is energy required by the cooling system in order to cool the indoor environment until the desired temperature in summertime. The term includes the losses due to the system inefficiencies;
- $\eta_{SYS-HEATING}$ and $\eta_{SYS-COOLING}$ are, respectively, the overall heating and cooling system efficiencies, evaluated seasonally, and inclusive of all the sub-system losses (*due to the generation, distribution, emission, storage and control devices*).

This, above described, is the EN 13790 option C. In fact, the standard reports also two further alternative methods in order to evaluate the overall energy uses, based on the direct evaluation of the total energy requirements (*option A*) or on a direct balance among energy needs and energy losses, considering, at the same time, building and technical system (*option B*).

In the followings, we will refer exclusively to the method C above briefly cited. In fact, this is not only quite intuitive but also included in the Italian official technical standards.

About the evaluation of the active system energy efficiencies and energy losses, briefly another European standard should be cited: the EN 15316/2008 [9 → 21]. This technical document (*divided in several parts*) provides the determination of performances and energy losses of the heating and hot water production systems. On the other hand, when the energy performances and losses of a cooling system should be quantified, the EN 15243/2007 [22 has to be used.

For the evaluation of the total energy required for the space heating, the logical scheme of the calculation procedure is presented in figure 2.2.1, where, starting by the net energy necessary to keep at the desired value the indoor temperature, all the systems losses are added, in terms of both dissipated thermal energy and electrical energy required by the auxiliaries.

Obviously, the same approach is referred to the hot water supply efficiency, as well as for combined systems.

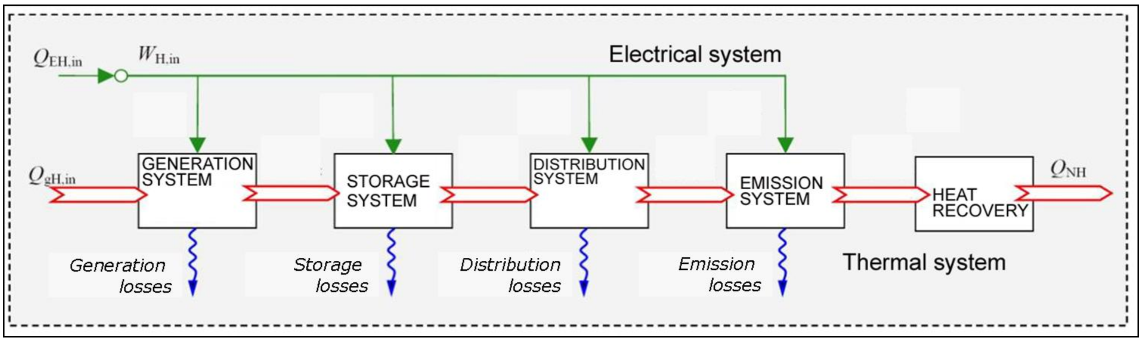


*Figure 2.2.1 – Energy losses due to the heating sub-system inefficiencies (source: the graph has been elaborated simplifying the CEN methods)*

In this section, further explanations are not provided. This because, in the next paragraph (*within the description of the Italian transposition of this European standards*) all the procedures can be better described and understood by means a calculation sample referred to a case-study.

## 2.3 The Italian calculation procedures: description through a case-study

Several times, in this chapter, the derivation of the Italian standards from the CEN ones has been underlined. In particular, during the last year, the Italian Thermal-technical Committee (CTI) and the Italian Committee for Standardization (UNI) developed and released the UNI TS 11300, inside which all the main prescriptions and calculation procedures adopted by the CEN were transposed.

Also the Italian mandatory regulations, i.e. the Legislative Decree 115/2008 [54], the Presidential Decree 59/2009 [55], as well as, in July 2009, also the new Guidelines for the Energy Certification of Buildings, Decree 26/06/09 [26], explicitly define these standards as official national instruments.

In particular, as specified in the Chapter 1, the following standards have been prepared by the Italian official technical institutions:

1. UNI TS 11300 part 1: *Energy performance of buildings. Evaluation of energy need for space heating and cooling* [52];

2. UNI TS 11300 part 2: *Energy performance of buildings. Evaluation of the primary energy needs and energy efficiency ratios for the winter space heating and the domestic hot water production* [53];
3. UNI TS 11300 part 3: *Energy performance of buildings. Evaluation of the primary energy needs and energy efficiency ratios for the summer space cooling* [56];
4. UNI TS 11300 part 4: *Energy performance of buildings. Use of renewable energy sources and other methods of energy generation for the space heating and domestic hot water production* [57].

The first two parts were published in the spring 2008, while the third and fourth are today quite complete even if not yet into force (*i.e. not yet officially published*).

The UNI TS 11300 part 1 and 2 derive respectively from the EN 13790 and the EN 15316 [58]. In particular, most algorithms and calculation methods have been only translated in Italian, while, several others, contain simplified procedures in order to provide an easy application and in order to harmonize the European criteria to the consolidated Italian ones.

As regards the UNI TS 11300 part 1, this technical specification defines the procedures for the national implementation of the CEN methods, with reference to the methodologies for the monthly energy calculation. In particular, three types of evaluations are possible, depending on:

- the type of building (*existing or new construction*);
- purpose of the energy audit (*design, energy certification, energy optimization and possible improvements*);
- boundary conditions (*climatic data and data related to the conditions of actual use or project*).

Table II.2 - Several calculation methodologies depending on kind of buildings and audit purposes (Italian Ministerial Decree 26.06.2009 [26])

| | BUILDING DESIGN CALCULATION PROCEDURE | BUILDING SURVEY CALCULATION PROCEDURE – OPTION 1 | BUILDING SURVEY CALCULATION PROCEDURE – OPTION 2 | BUILDING SURVEY CALCULATION PROCEDURE – OPTION 3 |
|---|---|---|---|---|
| *Interested Buildings* | All kinds of buildings, new and existing | All kinds of existing buildings | Existing buildings with useful surface lower than 3000 $m^2$ | Existing buildings with useful surface lower than 1000 $m^2$ |
| *Thermal performance of the building envelope in wintertime* | Italian Technical Standards UNI TS 11300 | Italian Technical Standards UNI TS 11300 | Software DOCET (by CNR and ENEA) | Simplified methods (annex 2 of the National Guidelines for the building energy certification) |
| *wintertime, primary energy performance* | Italian Technical Standards UNI TS 11300 | Italian Technical Standards UNI TS 11300 | Software DOCET (by CNR and ENEA) | Simplified methods (annex 2 of the National Guidelines for the building energy certification) |
| *Domestic hot water production, primary energy performance* | Italian Technical Standards UNI TS 11300 | Italian Technical Standards UNI TS 11300 | Software DOCET (by CNR and ENEA) | Italian Technical Standards UNI TS 11300 |
| *Thermal performance of the building envelope in summertime* | Italian Technical Standards UNI TS 11300 | Italian Technical Standards UNI TS 11300 | Software DOCET (by CNR and ENEA) | Technical Standards UNI TS 11300 or DOCET |

At the same way of the methodologies reported in the EN 13790, the UNI TS 11300 part 1 diversifies the calculation algorithms depending on the energy evaluation purposes, providing calculation of the building project (*design rating*), energy assessment of buildings through the calculation under standard uses (*asset rating*) or under specific climatic/operational conditions (*tailored rating*). An explicative scheme is reported in table II.2 [26].

With respect to the old and abrogated standards (*among which, the UNI 832, UNI 13790, UNI 10379*), the main new topic is the evaluation of the energy demand during the cooling season. Furthermore, other new features are:

- the great attention to the natural ventilation;
- the thermal effects due to various endogenous sources and the sun;
- the revision of the correct criteria for the building zoning.

The second part of the technical specification [53] makes possible the evaluation of the heating technical system performances, in particular as regards the energy efficiency ratios. This standard can be applied during the design of new systems, but also for the analysis of existing or renovated ones. In particular, various configurations of the heating systems can be considered: only for the space heating; combined heating and domestic hot water (DHW), exclusively deputed to the hot water production. Therefore, the UNI TS 11300-2 provides all data and methods for the determination of the primary energy needs for the winter heating and for the production of DHW. This new standard, derived from the 15316-2-3:2008, substitutes and cancels the old technical documents, i.e. the UNI 10348:1993, "*Heating of buildings - Performances of heating systems - Method of calculation*".

Similarly to the first part, the UNI TS 11300-2 concerns both new and existing buildings, even if the technical systems provided and partially powered by renewable energy sources are not considered; about this, the fourth part of the UNI TS 11300 (*not yet available*) should be used.

In the followings, a "*practical*" description of these new evaluation procedures will be provided. In fact, being a direct derivation of the already cited European technical documents (*developed inside the Mandate M/343 and enacted to support Directive 2002/91/EC*) in this Thesis has been considered not useful another simple algorithm description (*being this quite similar to the already mentioned ones, as regards the EN 13790 and EN 15316*).

On the other hand, the application of the calculation methodologies to an example building has been considered more useful in order to better understand the evaluation methods. The energy audit, in the following proposed, has been carried out as regards both the building envelope energy balances and the energy needs for space heating *(in terms of primary energy*) and cooling (*only with reference to the final energy required to keep the space, in summertime, at a comfortable thermal level*).

The application of the calculation methodologies will referred to the energy certification of an existing building, considering the prescriptions of the Italian legislation into force at the present moment (*i.e. Legislative Decree 192/2005 [59], Presidential Decree 59/2009 [55], Ministerial Decree 26/06/2009 [33]*).

### 2.3.1 ENERGY EVALUATIONS AND PRESENTATION OF THE CASE STUDY

The UNI TS 11300 part 1 defines, as already cited, several kinds of building energy evaluations, depending on the target and the required level of deepening. In particular, as expressed in table II.2, the energy audit can be carried out according to the following approaches:

- STANDARDIZED (ASSET OR DESIGN) CALCULATION. The standard evaluation of the building energy performances starts from the input data provided in the technical documentation of the building design, and from the characteristics of the designed technical systems. This method is suitable for new constructions and the integral renovations, and it is applied in order to realize the building energy certificate and the technical report according introduced by the Italian Law 10/91.
- CALCULATION FROM SURVEY ON BUILDING AND SYSTEMS. Also in this case, a standard evaluation of the building/HVAC performance has been carried out. The input data are achieved by means a real inspection and survey of the architecture, both as regards the building envelope and the technical systems. The method is suitable for the energy qualification/certification of existing buildings. The following procedures can be adopted: a) direct measures of the data; b) analogy with similar buildings and systems.
- TAILORED RATING EVALUATION. In this last case, the scope is not the energy certification but the evaluation of the real performances of the buildings. The input data are not fixed or typological, but selected accurately in order to approximate, in the better way, the true performances of the building and it operational conditions. Thus, specific data and not conventional calculation methods can be used, also adopting numerical procedures more complexes (*dynamic analysis*). The method is suitable in order to estimate the efficiency of various design solutions or the convenience of possible energy improvements.

In this section, an application of the calculation methodologies based on the survey data will be shown. This because this method is very well expressive of the actual necessities of the Italian building activity (*the energy certifications are much more numerically significant compared to the feasibility investigations.*). Moreover, in the paragraph 4 of this chapter (*paragraph 2.4*) more complex dynamic numerical methods will be described, and, in the following chapter (*Chapters 3, 4, 5*) these will be applied to different building categories.

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With reference to a residential existing building, three aspects of the building energy performances will be in this section described and, step by step, explained:

- wintertime space heating: evaluation of the primary energy needs;
- summertime space cooling: evaluation of the thermal energy needs;
- summertime cooling: evaluation of the building envelope dynamic behaviours.

The analyzed building is located in Naples (Italy), Italian climatic zone C, used as residential architecture. As regards the typological characteristics, the building presents several apartments, consisting in a three floors construction with two houses on each level. Under the constructive point of view, the building is realized as typical in Italy during the last 40 years: a main structure in reinforced concrete with vertical walls in double layers of hollow bricks and air gap interposed. The building is represented in figure 2.3.1 (*plan*) and 2.3.2 (*façade*).

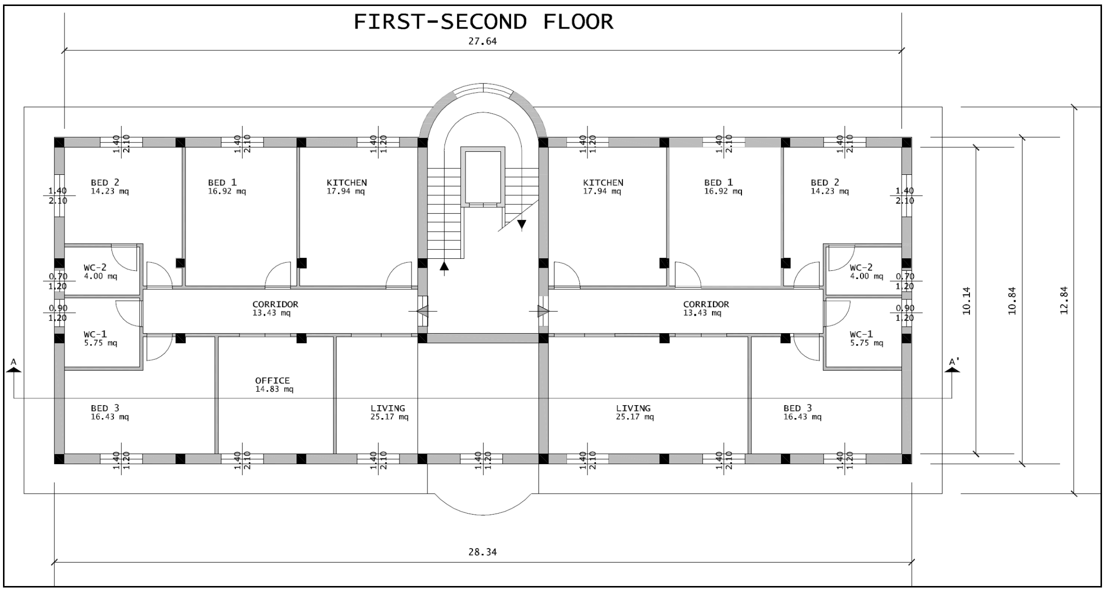



*Figure 2.3.1 – Example building: typological floor plan*

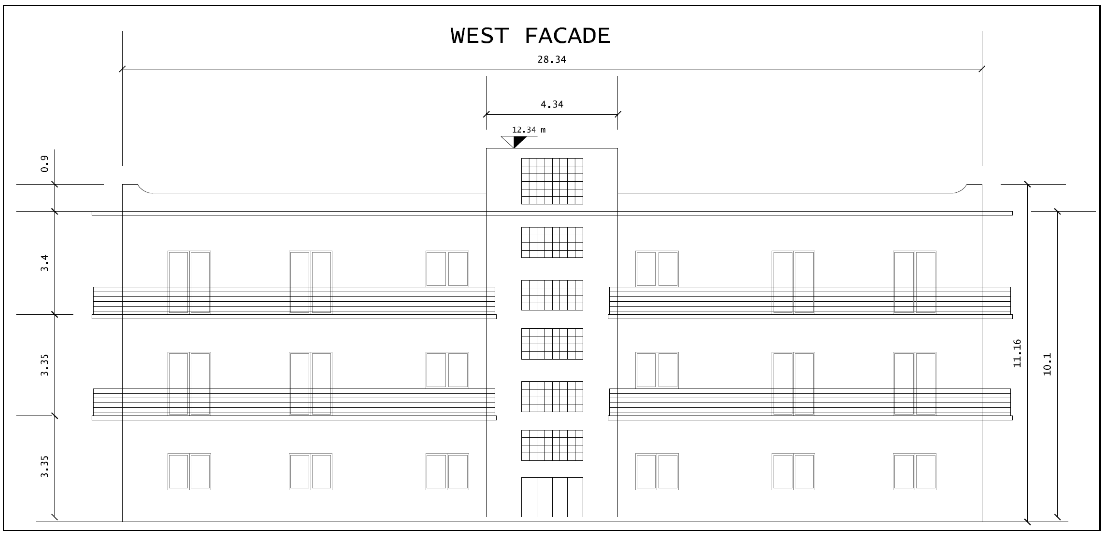



*Figure 2.3.2 – Example building: the main prospect*

Table II.3: Heating period and mean ambient thermal levels (UNI 10349)

| NAPOLI | January | February | March | November | December |
|---|---|---|---|---|---|
| Length (*days*) | 31 | 28 | 31 | 15 days | 31 |
| Length (*mega seconds*) | 2.6784 | 2.4192 | 2.6784 | 1.2960 | 2.6784 |
| Mean Temperature (°*C*) | 10.5 | 10.6 | 13.2 | 15.5 | 12.1 |

The gross heated volume is equal to 3162 $m^3$, the net surface area, considering all the three floors, is around 800 $m^2$. The surface-to volume ratio (S/V) is 0.44 $m^{-1}$, the total dispersing surface (*opaque walls + roof + basement + windows*) consists in 1435 $m^2$.

Considering the specific climatic region, the Italian Law (*i.e. Presidential Decree 412/93* [60]) admits a heating period in the temporary range 15 November ÷ 31 March. In table II.3, the monthly lengths and the average temperatures have been reported.

### 2.3.2 THE ENERGY REQUIREMENTS IN WINTERTIME: BUILDING THERMAL NEEDS, HEATING SYSTEM EFFICIENCIES, PRIMARY ENERGY DEMAND

First, a difference with respect to the European standard EN 13790 has to be immediately underlined. In fact, the Italian UNI TS 11300 imposes two boundary conditions not so clearly defined by the CEN, as regards the length of the heating season and the considered indoor temperature during the winter period.

About the first point, the EN 13790 establishes the determination of the heating season considering the relations between external climates and free gains. On the contrary, the Italian standard imposes a length of the season such as established by the Italian Presidential Decree 412/93 [60] (*for Naples, starting by the second half of November, until the end of March*).

Furthermore, as regards the indoor temperature in wintertime, no specifications are reported in the European standard, while the Italian UNI TS 11300 imposes the consideration an indoor air set point temperature equal to 20 °C.

#### a) ENERGY LOSSES DUE TO THE THERMAL DISPERSIONS FOR TRANSMISSION AND VENTILATION

With reference to this example, the absence of surely defined data imposes the adoption of typical building structures, such as provided in the Annex A of the UNI TS 11300, in which the thermal transmittances of typological building components are defined and reported depending on constructive traditions and thicknesses of the opaque and the transparent building elements. In figure 2.3.3, the structure of the prospect A1 of the UNI TS 11300 has been represented.

Analogues tables are available also for the basement, the roofs, and the transparent surfaces.

In this application, the following values as regards the building envelope thermal transmittances have been considered:

- Vertical walls → $U_{VALUE}$ = 1.10 W/m$^2$K (*wall realized in two layers of hollow bricks and included air gap, overall thickness equal to 35 cm*); in these conditions and for this kind of structure, the considered increment for the thermal bridge evaluation is around 10%, as suggested by the same standard UNI TES 11300-1;
- Basement → $U_{VALUE}$ = 1.80 W/m$^2$K (*concrete structure directly posed on the ground, overall thickness equal to 25 cm*);

- Roof → $U_{VALUE}$ = 1.80 W/m²K (*mixed structure in concrete and hollow bricks, overall thickness equal to 30 cm*);
- Window → $U_{VALUE}$ = 6.00 W/m²K (*single glass: 80%; and metallic frame 20%*); solar transmittance = 0.85.

| Thermal Transmittances of the vertical walls (W/m²K) | | | | | |
|---|---|---|---|---|---|
| Thickness (m) | Stones + plaster | Filled bricks + plaster | Semi-filled bricks or tuff | Concrete panels | Hollow bricks and air gap |
| 0,15 | | | | | - |
| 0,20 | | | | | - |
| 0,25 | | | | | 1,20 |
| 0,30 | | | | | 1,15 |
| 0,35 | *See the original technical standard* | | *See the original technical standard* | | 1,10 |
| 0,40 | | | | | 1,10 |
| 0,45 | | | | | 1,10 |
| 0,50 | | | | | 1,10 |
| 0,55 | | | | | - |
| 0,60 | | | | | - |

*Figure 2.3.3 – Thermal transmittance of the vertical wall, on varying thickness and composition*

The first calculation phase consists in the evaluation of the total heat transfer interesting the building envelope, using the same equations already defined in the description of the EN 13790. In particular, as reported in the equation 1, the evaluation of the total losses is carried out summing the energy exchanges for transmission and ventilation.

| | | °C | °C | Ms |
|---|---|---|---|---|
| month | Ti | 20 | Ti-Te | |
| 1 | Te | 10.5 | 9.5 | 2.6784 |
| 2 | | 10.6 | 9.4 | 2.4192 |
| 3 | | 13.2 | 6.8 | 2.6784 |
| 11 | | 15.5 | 4.5 | 1.296 |
| 12 | | 12.1 | 7.9 | 2.6784 |

| W/K | MJ | kWh | kWh/m² |
|---|---|---|---|
| $H_{Tr}$ | $Q_{hT}$ | $Q_{hT}$ | |
| 2209.7 | 56224.4 | 15617.9 | 19.5 |
| 2209.7 | 50248.7 | 13958.0 | 17.4 |
| 2209.7 | 40244.8 | 11179.1 | 14.0 |
| 2209.7 | 12886.7 | 3579.6 | 4.5 |
| 2209.7 | 46755.0 | 12987.5 | 16.2 |
| TOTALs | 206360 | 57322 | 71.61 |

| | | | |
|---|---|---|---|
| S gross | m² | 938.79 | 0.85 |
| S net | m² | 800.52 | |
| V gross | m³ | 3161.3 | |
| V net | m³ | 2401.56 | |
| n | h⁻¹ | 0.3 | |
| Qve | m³/s | 0.20013 | |

| | | |
|---|---|---|
| Degrees-day | Kd | 1034 |
| S/V | 1/m | 0.44 |
| $EPi_{lim}$ | kWh/m² | 28.19 |

| $H_{Tr}$ | Roof | Windows | Walls | Basement |
|---|---|---|---|---|
| Surface (m²) | 313 | 106 | 703 | 313 |
| U (W/m²K) | 1.5 | 6 | 1.21 | 1.8 |
| $f_{corr}$ | 1 | 1 | 1 | 0.45 |
| | 469.5 | 636 | 850.63 | 253.53 |

$$H_T = \sum_i (A_i\ U_i\ f_{T,i})$$

$H_T$ = 2209.7 W/K

*Figure 2.3.4 – Wintertime: calculation of the heat losses for transmission*

In the above-reported equation 2, the method for the evaluation of the transmission losses through the building envelope is expressed. With reference to the case-study here analysed, the application of the method determines the results represented in figure 2.3.4, where, by means of a simple self-made calculation tool (*a quite simple data sheet*), the transmission heat transfer coefficient has been evaluated. The equations adopted by the Italian standards are quite the same of the EN 13790 ones (*equations 12 and 13*).

At the same way, by means of the equation 14 before reported, the energy losses due to the building ventilation have been calculated, establishing, as suggested by the Italian Standard UNI 10339, a mean air change equal to 0.3 Vol/h. Input data and results are reported in figure 2.3.5.

| | | °C | °C | Ms |
|---|---|---|---|---|
| month | Ti | 20 | Ti-Te | |
| 1 | Te | 10.5 | 9.5 | 2.6784 |
| 2 | | 10.6 | 9.4 | 2.4192 |
| 3 | | 13.2 | 6.8 | 2.6784 |
| 11 | | 15.5 | 4.5 | 1.296 |
| 12 | | 12.1 | 7.9 | 2.6784 |

| $H_V = \rho * C * q_{VE}$ | $\rho * C =$ | 1200 | J(/m Kg) |
|---|---|---|---|

| Hv | $Q_{hve}$ | $Q_{hve}$ | | |
|---|---|---|---|---|
| W/K | MJ | kWh | kWh/m$^2$ | |
| 240.156 | | | | |
| | 6111 | 1697 | 2.12 | |
| | 5461 | 1517 | 1.90 | |
| | 4374 | 1215 | 1.52 | |
| | 1401 | 389 | 0.49 | |
| | 5082 | 1412 | 1.76 | |
| TOTALs | 22428 | 6230 | 7.78 | kWh/m$^2$ |
| | | | 28.02 | MJ/m$^2$ |

| | | | |
|---|---|---|---|
| S gross | m$^2$ | 938.79 | 0.85 |
| S net | m$^2$ | 800.52 | |
| V gross | m$^3$ | 3161.3 | |
| V net | m$^3$ | 2401.56 | |
| n | h$^{-1}$ | 0.3 | |
| $q_{ve}$ | m$^3$/s | 0.20013 | |
| | | | |
| Degrees Da | Kd | 1034 | |
| S/V | 1/m | 0.44 | |
| EPilim | kWh/m$^2$ | 28.19 | |

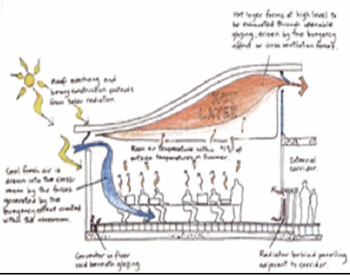


*Figure 2.3.5 – Wintertime: calculation of the heat losses for ventilation*

Reading the main results reported in the figures 2.3.4 and 2.3.5, immediately it can be seen that, with reference to both the global heating season and with respect to each month, the energy losses for transmission are around ten times higher than the losses for ventilation.

At the same way provided by the EN 13790, the next step, such as established by the UNI TS 11300 in order to carry out the overall energy balance *(equation 6*), is the calculation of the positive contributes (*endogenous and solar gains*). These should be opportunely reduced in order to operate in safety conditions and to take into account the dynamic behaviours of the building envelope.

In particular, a reduction factor ($\eta_{HEATINGgn}$) is considered for the computation of the winter energy free gains ($Q_{solar}$ + $Q_{internal}$) in order to avoid an over-estimation of the overall thermal energy need. $Q_{solar}$ and $Q_{internal}$ are respectively calculated by means of the equations 4 and 5 already described.

b) SOLAR HEAT GAINS AND RADIATION LOSSES.

The equation 17 (*again, below reported*) considers all the energy exchanges due to radiative phenomena among the building, the sky and the sun.

$$\Phi_{\text{FREE-SOLAR,CONSIDERED-ZONE}} = \left(F_{\text{shading}} \cdot A_{\text{sol}} \cdot I_{\text{sol}}\right) - \left(F_{r,k}\Phi_{r,k}\right) \qquad (17)$$

The amount of the total solar gains is determined, at the same way of the method provided by the EN 13790, by means of the above-reported equation 4.

SOLAR HEAT GAINS THROUGH THE WINDOWS. With reference to the calculation procedure, the window area has to be considered differently depending on the exposure (*figure 2.3.6*) and on the kind of glass. In this case-study, with reference to each month, considering the radiation data reported in the UNI 10349 [61] (*table II.4*), the gross gains have been evaluated.

Table II.4: Monthly global solar radiation on vertical oriented surfaces for Naples in wintertime

| NAPOLI | SOUTH | EAST | NORTH | WEST |
|---|---|---|---|---|
| Month | $MJ/m^2$ | $MJ/m^2$ | $MJ/m^2$ | $MJ/m^2$ |
| January | 11.1 | 5.2 | 2.2 | 5.2 |
| February | 12.2 | 7.2 | 3.3 | 7.2 |
| March | 12.5 | 9.8 | 4.1 | 9.8 |
| November | 11.,9 | 5.9 | 2.4 | 5.9 |
| December | 9.8 | 4.5 | 1.9 | 4.5 |
| Totals | 57.5 | 32.6 | 13.6 | 32.6 |

In figure 2.3.6, as regards to the south-exposed windows, the terms $g_{gl}$, and $(1\text{-}F_f)$ appear. These parameters represent, respectively, the solar transmittance of the glasses and the frame factor of the window. Adopting the methodologies before cited, then the $A_{sol}$ has been evaluated. As can be seen in the figure 2.3.6, even considering a gross window surface of 13 $m^2$, the effective collecting area is lower than 8.0 $m^2$. The same procedure has been carried out also for all the other exposures (*i.e. the east-, west-, north-exposed windows*).

**Windows, single glass, south exposure**

| | $MJ/m^2d$ | $MJ/m^2$ | $kWh/m^2$ | |
|---|---|---|---|---|
| month | H | | | days |
| 1 | 11.1 | 344.1 | 95.58 | 31 |
| 2 | 12.2 | 341.6 | 94.89 | 28 |
| 3 | 12.5 | 387.5 | 107.64 | 31 |
| 11 | 11.9 | 190.4 | 52.89 | 16 |
| 12 | 9.8 | 303.8 | 84.39 | 31 |
| totals | 57.5 | 1567.4 | 435.39 | 137 |

| | | | |
|---|---|---|---|
| S gross | $m^2$ | 13 | $F_W$ = 0.9 |
| $g_{gl}$ | | 0.765 | |
| $1\text{-}F_f$ | | 0.8 | |
| Asol | $m^2$ | 7.96 | |
| $Fi_{sol}$ | kWh | 3464 | |
| | TOTALs | 4.33 | $kWh/m^2$ |

*Figure 2.3.6 – UNI TS 11300 application: calculation of the solar gains through the windows*

In presence of shading elements, due to each kind of screen that reduces the amount of solar radiation on the collecting surface, the UNI TS 11300 operates multiplying the radiation by a reduction factor ($F_{sh,ob}$), variable within the range 0 (*i.e. full shade*) ÷ 1 (*i.e. no shadings*), according to the logic already defined as regards the EN 13790.

In particular, $F_{sh,ob}$ depends on $F_{hor}$ (*the reduction factor due to each kind of shading*), on $F_{ov}$ (*the reduction factor due to horizontal external overhangs*) and on $F_{fin}$ (*the reduction factor due to vertical external fins*).

It is important to underline that, while the presence of internal shadings reduce the effective collecting area, the external obstructions reduce directly the heat gains.

As regards the window screens, the reduction factor depends on the solar transmittance of the window with and without the use of the shading devices, and also on the time fraction that identifies the time use of the screen. The standard UNI TS 11300 reports all the prospects necessary to calculate the incidence, as regards the solar gains, of shadings and external obstructions.

It the example here analysed, no shadings have been considered. Extending the procedure reported in the figure 2.3.6 to the windows facing toward other directions (i.e. *east, west, north*), the total solar gains through the transparent surfaces have been evaluated. Until now, only the first term of the equation 17 has been considered (*i.e. no consideration of adjacent spaces*), and only with reference to the transparent surfaces.

SOLAR HEAT GAINS THROUGH THE OPAQUE ENVELOPE. By means of the equation 17, the solar gains due to the growth of the external envelope surface temperatures (*because of the solar radiation*) are evaluated. In fact, even if, obviously, the radiative gains are higher when these interest directly the transparent surfaces, also as regards the opaque components these have a significant incidence, above all when the surfaces are characterized by high $\alpha_{SOLAR}$ and/or low $\varepsilon_{INFRARED}$ (*see figure 2.3.7*). About this, in the Chapter 3 several studies about the radiative characteristics of the sun-exposed surfaces are reported.

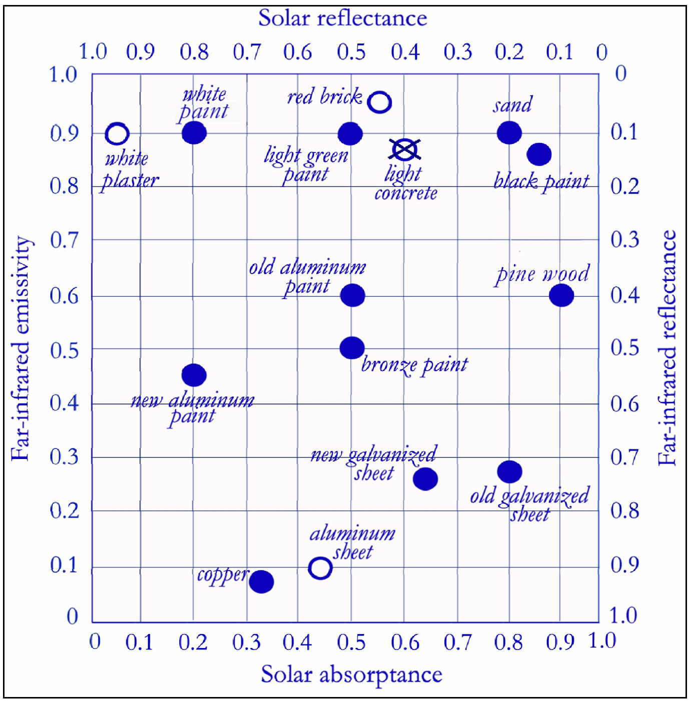



*Figure 2.3.7 – Spectral characteristics of several building materials*

As regards the solar absorptance of the sun-exposed surfaces, when real data are not available, the following ones can be used:

- clear colour of the external surfaces: $\alpha_{SOLAR} = 0.3$;
- medium colour of the external surfaces: $\alpha_{SOLAR} = 0.6$ (*this value has been considered*);
- dark colour of the external surfaces: $\alpha_{SOLAR} = 0.9$.

This is the criterion suggested by the UNI TS 11300. *Actually, as it will be shown in the next chapter, also the thermal (infrared) emissivity plays a significant role.*

In this example, applying the equation 4 (*only with reference to the opaque surfaces*) and then the methods before described, the results reported in table II.5 have been calculated.

In the use of the equation 4, the second part of the formula, related to the presence of adjacent spaces with radiative energy sources, has been not considered, as well as the presence of external obstructions.

Table II.5: Energy gains, in wintertime, due to the solar radiation on the opaque envelope surfaces

| | south-wall | east-wall | west-wall | north-wall | roof | $\Phi_{sol}$ | t | $Q_{sol}$ |
|---|---|---|---|---|---|---|---|---|
| | *Thermal flux due to the solar radiation (W)* | | | | | (W) | t (Ms) | kWh |
| January | 347 | 451 | 451 | 69 | 1047 | 2365 | 2.678 | 1759.8 |
| February | 381 | 625 | 625 | 94 | 1500 | 3225 | 2.419 | 2167.2 |
| March | 391 | 851 | 851 | 128 | 2172 | 4392 | 2.678 | 3267.7 |
| November | 372 | 512 | 512 | 75 | 1188 | 2659 | 1.296 | 957.1 |
| December | 306 | 391 | 391 | 59 | 906 | 2053 | 2.678 | 1527.5 |
| | | | | | | | Total (kWh) | 9679.3 |

Until now, the positive gains in wintertime, due to the radiative exchange between the building and the environment, have been considered. Actually, the sky temperature, in this season, determines a further heat losses, as in the followings shown. This term has been already cited in the previous paragraph and appears in the second member of the equation 17.

Moreover, this energy penalty, that reduces the net energy gain due to the solar radiation, depends on the view factors among the various building surfaces and the sky and on the related radiative heat flow.

With reference to the examined case-study, the total energy loss due to this thermal phenomenon results equal to 8048 kWh (*the partial values are reported in the table II.6*).

Table II.6: Energy losses, in winter, due to the radiative extra flows between building and sky

| Radiative extra flows (kWh) | January | February | March | November | December |
|---|---|---|---|---|---|
| *Roof* | *830* | *750* | *830* | *402* | *830* |
| *Vertical Walls* | *570* | *515* | *570* | *276* | *570* |
| *Windows* | *434* | *392* | *434* | *210* | *434* |

Considering that the energy lost for transmission (*figure 2.3.4*) is around 57300 kWh and the energy lost for ventilation is equal to 6230 kWh (figure 2.3.5), globally the radiative extra-flow toward the sky represents around the 11% of the energy globally dispersed by the building.

c) ENDOGENOUS HEAT GAINS

The simulated building is a residential dwelling. The Italian standard UNI TS 11300 provides several specifications in order to define properly the endogenous gains due to the people presence and to the indoor installed equipments. The evaluation methods are diversified on the basis of the kind of energy analysis (*design, asset or tailored rating*).

As regards the calculation here presented, referred to a quite typical case-study, the asset rating has been considered, in order to provide the energy certification of an existing construction. Therefore, conventional data related to the building use are adopted.

In particular, the Italian standard imposes that, for residential building, the mean internal gains (*people and installed equipments*) must be calculated considering the mean heat gains (*provided by the standard and expressed in watt*) and the net surface area of the building. When this area results higher than 170 m$^2$, the proposed method is no more apt.

Actually, in the presented example, even if the building total area is around 800 m$^2$ (*and, thus, >> than 170 m$^2$*) the same methodology has been adopted: this because the whole building is formed by several apartments, each one lower that 170 m$^2$.

In particular, the calculation has been carried out separately for each one of the six flats, and then the results have been summed. The standard UNI TS 11300-1 reports also an approximate determination of the net floor area starting by the gross one. In fact, knowing the mean thickness of the walls, a reduction factor (here called $F_{net/gross}$) is provided to convert the gross area into the useful one, according to the equation 21.

$$A_{net} = A_{gross} \cdot F_{net/gross} \qquad (21)$$

Imposing a mean thickness of the walls equal to 35 cm, in the reported example, the endogenous loads result equal to:

- each apartment: $\Phi_{int}$ 0.412 kW;
- whole building $\Phi_{int}$ 2.47 kW.

Moreover, adopting the calculation parameters reported in table II.7, the evaluated data are extended to each month and to the whole winter period, considering the permanence time of the people and the use of the other installed equipments; about this, the UNI TS 11300 establishes that the calculation should be carried out considering a heating period of 24h/day.

Table II.7: Energy gains, in wintertime, due to the endogenous heat sources.

| S gross | m$^2$ | 938.79 | | | | |
|---|---|---|---|---|---|---|
| | $Q_{int}$ | Time | $Q_{int\text{-}month}$ | $Q_{int\text{-}month}$ | | |
| Months | W | Ms | MJ | kWh | | |
| January | 2470 | 2.6784 | 6615.6 | 1837.68 | 2.30 | kWh/m$^2$ |
| February | 2470 | 2.4192 | 5975.4 | 1659.84 | 2.07 | kWh/m$^2$ |
| March | 2470 | 2.6784 | 6615.6 | 1837.68 | 2.30 | kWh/m$^2$ |
| November | 2470 | 1.296 | 3201.1 | 889.20 | 1.11 | kWh/m$^2$ |
| December | 2470 | 2.6784 | 6615.6 | 1837.68 | 2.30 | kWh/m$^2$ |
| | | TOTALs | 29023 | 8062 | kWh/m$^2$ | |
| | | TOTALs | | 10.07 | kWh/m$^2$ | |

| Monthly heat gains (kWh) | January | February | March | November | December |
|---|---|---|---|---|---|
| | 1838 | 1660 | 1838 | 889 | 1838 |

For other kinds of buildings, the technical document reports the mean endogenous gains (*for examples, museums ≈ 8 W/m$^2$, schools ≈ 4 W/m$^2$, offices ≈ 6 W/m$^2$*).

The endogenous thermal gains are evaluated in a different way when the tailored rating is applied. In fact, in this case, a better approximation is required, so that, both in summer and in winter, other values of the internal heat sources are considered. About this, the UNI TS 11300 provides a set of tables in which, depending on the day of the week, the kind of building, the indoor density and scheduling of the real presence, the thermal contributes due to the people, electrical equipment and any other kind of thermal sources are reported.

### d) UTILIZATION FACTOR OF THE FREE HEAT GAINS AND OVERALL BUILDING ENERGY BALANCE

Once calculated the free gains, considering both those related to the sun radiation and the endogenous ones, these should be computed only partially in the overall energy balance referred to the building. This because a prudential under-estimation is preferable and, furthermore, in this way it can be taken into account also the dynamic behaviour (*i.e. the time constant*) of the building. Therefore, on the basis of the building use, envelope characteristics, "weight" of the free gains and of the energy losses, the reduction parameter $\eta_{HEATING,gn}$ is in the followings calculated.

Table II.8: Wintertime – overall energy balances referred to the building

| | Months | | | January | February | March | November | December |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | |
| Input | transmission + ventilation losses | $Q_{ls}$ (kWh) | | 17509.0 | 15664.9 | 13021.6 | 4451.9 | 14849.8 |
| Input | total gains | $Q_{gn}$ (kWh) | | 6972.8 | 7831.7 | 10835.6 | 3792.2 | 6300.4 |
| | | | | | | | | |
| Calculation | gains / losses | $\gamma_H$ | | 0.398 | 0.500 | 0.832 | 0.852 | 0.424 |
| | | | | | | | | |
| Provided | internal heat capacity per area | kJ/m$^2$K | | 165 | 165 | 165 | 165 | 165 |
| | | | | | | | | |
| Input | total area | m$^2$ | | 1435 | 1435 | 1435 | 1435 | 1435 |
| Calculation | internal heat capacity | (kJ/K) | | 236775 | 236775 | 236775 | 236775 | 236775 |
| Input | heat exchange coefficient | (kW/K) | | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 |
| Calculation | building thermal constant | $\tau$ (h) | | 29.3 | 29.3 | 29.3 | 29.3 | 29.3 |
| Calculation | $a_H$ | | | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 |
| Calculation | utilization Factor | $\eta_{H,gn}$ | | 0.959 | 0.931 | 0.811 | 0.803 | 0.953 |
| Calculation | used free Gains | $Q_{H,gn}$ x $\eta_{H,gn}$ (kWh) | | 6688.8 | 7291.5 | 8788.7 | 3047.0 | 6002.1 |
| Calculation | Net thermal need $Q_{H,nd}$ (kWh) | | | 10820 | 8373 | 4233 | 1405 | 8848 |

TOTAL THERMAL NEEDS IN WINTERTIME = 33679 kWh/year

The procedure is quite the same of the one already described previously, about the homologous factor introduced by the European standard EN 13790. With reference to the case-study here presented, the results are reported, monthly and with reference to the whole season, in table II.8.

In table II.8, it can be noted that the utilization factor of the free gains is progressively smaller when the gains/losses ratio becomes higher. This approach is adopted in order to evaluate, prudentially, the incidence of the positive and free thermal contributes.

As regards the results, of course the higher free gains are achieved in March and November, when the solar contributes, through both the windows and the opaque walls, are significant. Then, applying the formula reported in the equation 6, the building total heating need has been evaluated.

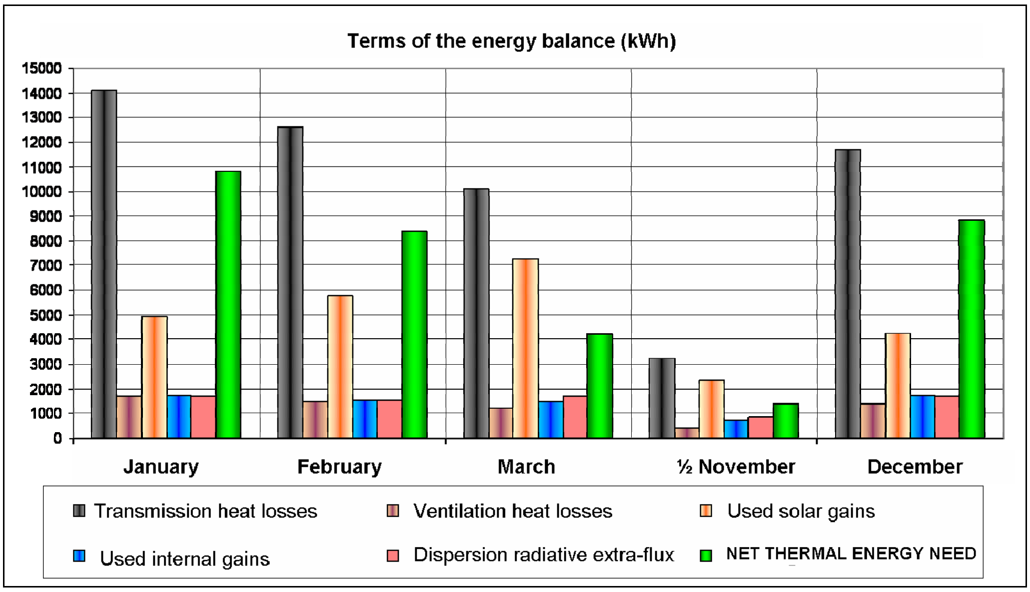



*Figure 2.3.8 – UNI TS 11300: building overall energy balance*

In figure 2.3.8, each energy flux has been represented. Annually, the thermal request of the building is around 33'700 kWh ($\approx$ *42 kWh/m²a*). Until now, the heat losses due to the heating systems have been not yet considered, therefore the expressed value represents the net energy that the heating systems has to provide and not the total delivered energy demand.

After the evaluation of this energy need ($Q_{HEATING,nd}$ - *the energy requirement for the winter heating*), it is necessary to estimate also the energy losses and recoveries of the heating system, in order to quantify the building energy performance index $EP_i$ (*i.e. the primary energy request for the winter air-conditioning*).

Depending on the $EP_i$ value, not only the respect of the present law can be shown (*for new buildings*) but also the energy class characterizing the building is clarified, such as established by the contents of the energy certificate.

e) EVALUATION OF THE PRIMARY ENERGY NEED FOR THE WINTERTIME AIR-CONDITIONING

In order to evaluate the heating system efficiencies, as well as the energy losses, the layout scheme represented in figure 2.2.1 has been used. In fact, also about the energy performances of the heating appliance, the Italian standard (UNI TS 11300 part 2) transposes the European methods (EN 15316) into the national legislation. Thus, the heating system has been divided in several sub-systems:

- generation equipments;
- distribution of the heated fluid devices;
- equipments for the heat emission into the indoor environment;
- control devices;

Each one of these equipments determines energy losses, so that the transferred energy is progressively reduced. The global system efficiency can be defined as the product of the efficiency ratios characterizing each of these sub-systems, even if this represents a simplified way to evaluate the global efficiency, being the losses (*above all the generation ones*) related to the amount of the building thermal energy need.

$$\eta_g = \eta_{GENERATION} \cdot \eta_{REGULATION} \cdot \eta_{DISTRIBUTION} \cdot \eta_{EMISSION} \quad (22)$$

The standard UNI TS 11300-2 establishes the calculation methodologies for each one of these energy efficiency ratios. Actually, the evaluation of each energy loss and the next multiplication of the single energy efficiency ratio in order to achieve the overall seasonal energy efficiency of the heating systems is applicable only under a closely theoretical point of view. In this way, once determined $\eta_g$, the determination of the primary energy need for the winter air conditioning would be a simple operation, carried out applying the equation 23:

$$EP_i = Q_{HEATING,nd} / \left( A_f \cdot \eta_g \right) \quad (23)$$

Actually, the determination of the overall energy efficiency ratio cannot be carried out monthly, being this operation rather muddled, even if not significantly complex. In the following pages, the definitions of all the sub-system energy efficiency ratios will be reported.

EMISSION SYSTEM $\eta_{eH}$: this is the ratio between the useful energy requirement necessary in order to heat the indoor space using a reference system of emission (*apt to the achievement of a perfectly uniform and equal room air temperature*) and the energy requirements deriving from the use of the real system. The two systems, real and ideal, are compared in the same operational conditions, as regards the indoor temperature and the external thermal level.

The evaluation of the losses due to the emission system is influenced by the characteristics of the heated space, among which, the most significant parameter is the indoor height.

For heated environments characterized by various inner height (*lower than 4 m, higher than 4 m and higher than 10 m*), the UNI TS 11300-2 reports various simplified prospects, in which $\eta_{eH}$ is evaluated depending on:

- the real height of the rooms;

- the annual mean thermal loads;
- the kind of emitters;
- the modalities of installation;
- the characteristics of the building.

The emission system energy efficiency ratios are referred to a perfect installation, and, about this, the Italian standard suggests also best practices.

In the example here proposed, a net inner height equal to 3.3 is imposed, being this value quite typical with reference to the Italian existing concrete buildings.

In order to use the UNI TS 11300-2 prospect (*figure 2.3.8*), the mean annual thermal load has to be determined. The annual thermal needs of the simulated building is equal to 33700 kWh. It means that, operating the necessary operations and dividing this value for the gross heated volume and for the number of hours characterizing the winter period (*10 hours/day, 15 November → 31 March: 1360 hours*), the mean annual thermal load is equal to 7.8 W/m$^3$.

Now, the method schematized inside the Italian standard can be applied: the resulting $\eta_{eH}$ corresponds to 0.95

| Heat Emitters | Mean Annual Thermal Load (W/m$^3$) | | |
|---|---|---|---|
| | <4 | 4-10 | >10 |
| | $\eta_e$ | | |
| Radiators on external insulated wall | 0,95 | 0,94 | 0,92 |
| Radiator on internal wall | | | |
| Fan coils ($T_{mean}$ = 45°C) | | | |
| Thermal Convector | | | |
| Wall grilles | ***See the original technical standard*** | | |
| Floor Radiant Panels (insulated) | | | |
| Floor Radiant Panels | | | |
| Ceiling Radiant Panels | | | |
| Wall Radiant Panels | | | |

*Figure 2.3.8 – Values of the energy efficiency ratio of the emission sub-system, depending on the kind of emitters and the mean annual thermal load*

REGULATION SYSTEM $\eta_{rH}$: this parameter expresses the deviation between the energy amount demanded in real conditions compared to the energy demanded under an ideal situation. Numerically, it is given from the ratio between the useful energy requirement for heating the indoor air using a perfect (*i.e. theoretical*) regulation device and the energy need necessary in real conditions, adopting the designed control equipments.

The UNI TS 11300-2 reports some prospects relative to the typical value of the energy efficiency ratio of regulation systems. In particular, depending on the control strategy, the energy losses / free gains ratio, the gain utilization factor and the kind of plant and emitters, the prospects reported by the standards give the value of $\eta_{rH}$.

Moreover, the standard specifies that, acting frequently on the systems, by means programmed maintenance actions, the reported values can be improved.

About the control strategy for the winter heating in the simulated case-study, a simple system with radiators equipped with thermostatic valves (*single room regulation*) has been simulated. The calculation of gains, losses and utilization does possible the determination of $\eta_{rH}$, in this case equal to 0.95.

DISTRIBUTION SYSTEM $\eta_{dH}$: this represents the "*real useful energy requirement of the zones*" *to* the "*effective thermal energy supplied from the production system*" ratio. The determination of the distribution system losses can be carried out:

1. by means of pre-calculated values, schematizing the main characteristics and behaviours of the distribution systems, such as reported in the prospects of the UNI TS 11300-2;
2. by means of the methods described in the standard annex A;
3. by means of other more complex methods, described in other specific standards.

According to the present Italian law, the energy calculation in standard conditions (*asset or design ratings*) should be carried out adopting the methodologies 1 or 2.

The use of the method 1 makes not possible the estimation of the thermally recoverable energy losses. The pre-calculated values, reported by the prospects of the standards, are very useful when, during the energy audit of an existing building, no data are available about the real distribution net, so that generic hypotheses must be considered. In this case, none thermal loss can be considered recovered.

When the thermal vector fluid is warm air, other specific methodologies reported in other standards should be considered. For the evaluation of the efficiency of the distribution systems, the prospects 21 (*reported in the standard UNI TS 11300-2*) are so structured:

- 21a → single house heating systems;
- 21b → centralized multi-family heating system: horizontal distribution;
- 21c → centralized multi-family heating system: distribution inside internal walls (*period of construction afterward the 1993*);
- 21d → centralized multi-family heating system: distribution inside internal walls or within the air-gaps (*period of construction between 1977 - 1993*);
- 21e → centralized multi-family heating system: distribution inside internal walls or within the air-gaps, no insulation (*period of construction before the 1977*).

The values of the distribution sub-system energy efficiency ratios are referred to typological systems, with a supply temperature of the hot water equal to 80 °C and a return thermal level of 60 °C. The standard UNI TS 11300-2 contains, within other sections and prospects, also some correction factors based on other temperatures (*and related* $\Delta$) of the thermal vector fluid, depending on the kind of emitters (*radiators, fan coils, radiant panels*).

In this case-study, considering a multi-family house realized around the 1965, equipped with a quite typical heating system with hot water radiators, the value of the energy efficiency ratio of the distribution system has been estimated, using the UNI 11300-2 methods, equal to 0.913.

GENERATION SYSTEM $\eta_P$: this energy efficiency ratio is calculated on the basis of the equation 24 and represents the "thermal energy supplied by the generation system ($Q_P$)" *to* the "overall monthly primary energy request" *ratio*.

$$\eta_p = \frac{Q_{p,H}}{EP} \qquad (24)$$

The generation subsystem can be destined to supply thermal energy not only for the space heating needs, but also for different other applications (*commonly, the production of the domestic hot water*). In this case, the total thermal energy that should be provided is calculated by means of the equation 25:

$$Q_{p\ HEATING+WATER} = Q_{p,HEATING} + Q_{p,WATER} \qquad (25)$$

where $Q_{p,HEATING}$ is the thermal energy need for the indoor space heating, while $Q_{p,WATER}$ represents the thermal energy need for the sanitary domestic hot water.

In the equation 25, of course, $Q_{p\ HEATING+WATER}$ is the total energy that should be provided by the generation system; about this, the production losses not only depend from the characteristics of the heat generator, but these are also strongly related to the kind of installation of the boiler inside the complex heating plant.

In particular, the selection of the heater size, with respect to the real thermal energy requirements, plays a significant role as regards the efficiency of the generation system, as well as the water temperature (*supply and return*) during the operational exercise. For these reasons, the overall seasonal energy efficiency varies strongly (*because the main work is realized under part load conditions*) compared to the design values, measured in different operational conditions and during the manufacture tests.

The UNI TS 11300-2 provides various methods to determine the monthly energy efficiency ratio of the generation sub-system, in particular adopting:

- pre-calculated values for common solutions (prospects realized on varying type and working modalities of boilers and heat pumps);
- analytical correlations and calculation methodologies.

The prospects reported in the UNI TS 11300-2 evidence a great variability, depending on the size of the heat generator and the installation conditions.

When the real characteristics and behaviours of the generator system are different compared to those reported in the prospects, analytical evaluation procedures should be used; these methodologies are reported in the annex B of the standard. In particular, the proposed calculation methodologies consist in two usable methods for the evaluation of the generation energy losses:

- method of calculation based on the declared efficiency ratios, such as reported by the manufacturer according to the European Directive 92/42/CEE (*with apt corrections based on the specific operational conditions*);
- analytical calculations.

When standard ratings are applied (*asset or design ratings*) the proposed simplified methods should be used, while, if the operative conditions are not traditional, a calculation by means of specific and more complex methodologies has to be carried out.

In case of more detailed analyses (*the operational rating*), a specific calculation has to be adopted. The reference values, such as reported in the standard, are calculated with the analytical method, assuming medium values of the input boundary conditions, above all with reference to nominal thermal power, the characteristics of the generators, the installation conditions. In the technical document accompanying the energy audit, the adopted calculation methodologies have to be clearly specified.

In particular, the pre-calculated values depend on several F-factors, such as defined by the UNI 11300-2:

- F1 = nominal power of the heat generator / design thermal load ratio;
- F2 = installation in outdoor position;
- F3 = smokestack with height > 10 m;
- F4 = mean heater temperature (water side) > 65 °C;
- F5 = mono-stadium generator;
- F6 = smokestack with height > 10 m and absence of the combustive air when the heater is turned off;
- F7 = temperature of the return water with reference to the coldest month.

In order to provide an easy understandable example and simply show the procedure, in this case-study no evaluation of the electrical energy required by the auxiliaries has been considered. At the same way, the energy losses due to the various sub-system inefficiencies have been considered not recoverable. Therefore, in this simplified calculation, the equation 49 has been used:

$$\eta_p = \text{base value} + F1 + F2 + F3 + F4 + F5 + F6 + F7 = 0.795 \tag{26}$$

Collecting all the results, such as above singularly calculated, and simplifying the procedure reported in the UNI TS 11300-2, it results:

1. $\eta_p \rightarrow 0.795$;
2. $\eta_{e,H} \rightarrow 0.950$;
3. $\eta_{r,H} \rightarrow 0.950$;
4. $\eta_{d,H} \rightarrow 0.913$.

Then, applying the method reported by the equation 26, the overall seasonal energy efficiency ratio of the heating system has been calculated:

$$\eta_{g,H} = \eta_{SYS\text{-}HEATING} = 0.66$$

It can be easily understood that the evaluation of the energy efficiency ratios of the heating system is not fast or easy, above all when the pre-calculated values are not applicable so that the methodologies reported in the annex B of the UNI TS 11300-2 should be used.

This complexity induced the Italian national legislator, in the emanation of the “National Guidelines for the Energy Certification of Buildings” (*Ministerial Decree 26.06.2009* [26]), to adopt a more simple scheme (*with reference to the asset rating)* when the building is characterized by a surface lower than 1000 $m^2$.

Actually, the calculations have been already carried out using the extended methodology, so that, only as example, in the following lines the simplified method is considered, in order to verify how much significant is the change in the resulting values of $\eta_{g,H}$ .

The useful winter thermal need has been already determined, so that only the second part of the Annex 2 of the Italian Law [26] is here applied: "*Determination of the partial energy efficiency ratios for the determination of the overall seasonal energy efficiency of the heating system*". The logical sequence is simpler, but similar to that above described. In fact, the overall energy efficiency ratio is determined as product of the four partial efficiency ratios described in the equation 22.

The pre-calculated values for $\eta_p$, $\eta_{e,H}$, $\eta_{r,H}$, $\eta_{d,H}$ are reported in table II.9 (*the selected values have been grey-evidenced*).

Table II.9: Energy efficiency ratios of the heating plant sub-systems (Italian Guidelines)

| *Gas or oil Heat generators, type B, air-blown or pre-mixed, modulating, classified *** | | | | | |
|---|---|---|---|---|---|
| Base value | F1 | F2 | F3 | F4 | F5 |
| 0.90 | -0.02 | -0.01 | -0.02 | -0.02 | -0.02 |

| *Energy efficiency ratio of the emission sub-system ($\eta_{e,H}$)* | |
|---|---|
| Radiators | 0.94 |
| Fan coils | 0.95 |
| Grilles for warm air | 0.92 |
| Floor radiant panels | 0.96 |
| Ceiling or wall radiant panels | 0.95 |
| Others | 0.92 |

| *Energy efficiency ratio of the regulation sub-system ($\eta_{r,H}$)* | |
|---|---|
| On-Off regulation | 0.94 |
| Others | 0.96 |

| *Energy efficiency ratio of the distribution sub-system ($\eta_{d,H}$)* | |
|---|---|
| Centralized systems with vertical main pipes | 0.92 |
| Centralized systems with vertical main pipes | 0.94 |
| Heating systems for single apartment | 0.96 |
| Other typologies | 0.92 |

Attributing the apt value to each sub-system, the final result determines an overall seasonal energy efficiency ratio of the heating system equal to 0.67; considering that the more complex procedure provided in the standard UNI TS 11300-2 determined a value equal to 0.66, the Italian law simplified method can be considered, at least in this case, well correspondent. However, in the following the more rigours result for $\eta_g$ will be considered.

Applying the equation 23, i.e. $EP_i = Q_{HEATING,nd} / \left( A_f \cdot \eta_g \right)$, the energy performance of the integrated system building envelope-heating plant can be calculated.

In particular, remembering the above calculated parameters (*$Q_{HEATING,nd}$ = 33679 kWh, $A_f$ = 800.5 $m^2$, $\eta_g$ = 0.66*), the $EP_i$, expressed in terms of primary energy, results equal to 63.7 $kWh/m^2a$.

As several time already cited, in July 2009 the Italian Government has enacted the Italian Guidelines for the Building Energy Certification [26]. This new legal document imposes, after the determination of the primary energy performance index, the use of a graduate scale in order to make more understandable the goodness of the calculated energy performance.

Starting by the Italian scheme, that builds the different classes starting by the limit admitted value of the $EP_i$ (*see figure 1.4.4, Chapter 1*), the energy certification of this building has been prepared and shown in figure 2.3.9.

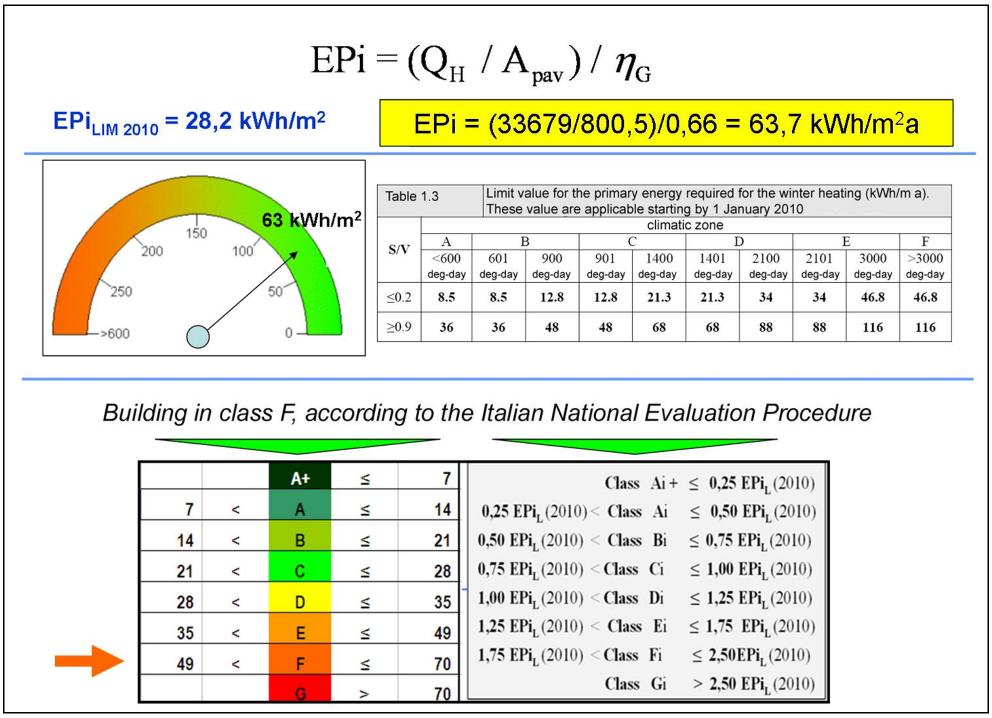



*Figure 2.3.9 – Energy certification of the building, based on the winter heating primary energy performances, according to the Italian procedure*

With reference to the case-study building here presented, a energy label expressing an energy <u>*class F*</u> has been obtained.

The value of 63 $kWh/m^2a$ is typical for the buildings located in the southern Italy context. With the same constructive characteristics, an analogous building situated in less favourable climatic zones (*e.g. Zone E or F according to the Decree 412/93*) approximately can requires around 150 - 200 $kWh/m^2a$ for the space heating.

Therefore, as it has already explained in the Chapter 1 of the Thesis, the Italy is meanly characterized by a building stock quite unsatisfactory under the energy efficiency point of view.

### 2.3.3 THE ENERGY REQUIREMENTS IN SUMMERTIME: BUILDING THERMAL NEEDS AND COOLING PERFORMANCES

The present Italian legislation imposes only the evaluation, in summertime, of the thermal energy required by the building in order to keep, during the cooling season, an indoor air temperature equal to 26 °C. As before cited, at the present moment is not yet fully available the standard UNI TS 11300-3 (*referred to the air-cooling system energy performances*). Thus, the evaluation of the primary energy requirement cannot be carried out by means of national standards.

In the following pages, the evaluation of $Q_{COOLING,nd}$ will be described, at the same way already shown as regards the winter performances. Also in this case, the applied methodologies are reported in the UNI TS 11300-1, directly derived from the EN 13790.

The EN 13790 doesn't provide calculation procedures that consider the latent heat transfer, so that, as regards the evaluation of the cooling energy required by the building in summertime, the energy necessary to control the humidity inside the conditioned space is not considered. On the other hand, when simple procedures are necessary to calculate the total energy needs for a complete building air-conditioning, other standard have to be used, such as the EN 15241 and the EN 15243.

a) SUMMER COOLING: INPUT DATA FOR THE EVALUATION OF ENERGY NEEDS

Previously, it has been shown the set of equations applicable in order to evaluate the energy transfers in summer regime (equation 7), according to the EN 13790. The UNI TS 11300-1 provides exactly the same formula.

With reference to the equation 7, immediately it can be seen that, contrarily to the common idea, globally in summertime the energy fluxes due to transmission and ventilation are useful in reducing the cooling energy need. The air-conditioning necessity, instead, is related to the thermal heat gains due to the solar radiation (*both through the transparent surfaces and on the opaque walls*) and to the endogenous heat production.

Also in this case, the thermal energy need for cooling is calculated with reference to each thermal zone of the building and with a monthly time step. At the same way before shown as regards the wintertime, the total heat exchange coefficient must be determined, both with reference to the heat transfers for transmission ($H_{transmission}$) and ventilation ($H_{ventilation}$); about these, the same procedures already used for the wintertime has to be used.

As regards the utilization factor of the heat losses ($\eta_{COOLING,ls}$), the calculation method is obviously quite different compared to the winter homologous parameter, even if the adopted logic results quite similar.

As regards the extra-flow between building and sky, as well as the heat gains endogenous and due to the solar radiation, the calculation algorithms are almost the same of those already expressed previously as regards the winter heating energy evaluation.

The Italian standard fixes the indoor temperature, in summertime, in the following way:

- residential buildings and all the others: 26 °C;
- swimming pools and similar: 28 °C;
- sport, gymnasiums and similar: 24 °C.

In wintertime, the heating season length is nationally fixed. In fact, as before cited, the Presidential Decree 412/93 [60] assigns, depending on the specific winter degrees-day of the examined location, a climatic zone, and on the basis of this, a fixed period for the winter heating is established, such as the number of hours/day admitted for the heating system use.

In summertime, instead, there is not a legal time for the use of air-conditioners, so that, also with reference to the energy evaluation, a simple procedure to evaluate the limits of the cooling period is provided by the standard UNI TS 11300, by means of the equation 27.

$$\theta_{e,day} > \theta_{i,set,C} - Q_{gn,day} / \left(H \cdot t_{day}\right) \tag{27}$$

The cooling season starts when the first term of the equation 50, $\theta_{e,day}$ (*the mean outdoor air temperature*) is at least equal to the second term of the equation (*i.e.* $\theta_{i,day} - Q_{gn,day} / H{*}t_{day}$), and finishes when this event is not anymore verified. In order to evaluate the limits of the cooing season, the outdoor ambient temperature, such as reported in the standard UNI 10349, are used and assigned to the 15$^{th}$ day of the month. Then, operating by means of a simple linear interpolation, each other day of the month is characterized by a mean thermal level.

This method is much simpler than that proposed at European level, reported in the standard EN 13790 and previously cited.

As regards passive techniques useful to discharge the building mass, the UNI TS 11300 is not so exhaustively, and only the effects and the achievable benefits deriving from the nighttime ventilation are very briefly described. In particular (*and this is a great limit of the present Italian legislation*), not enough “weight” is attributed to the nocturnal possible free cooling.

The UNI TS 11300 establishes that, as regards the nighttime ventilation, the benefits achievable can be considered only in presence of mechanical ventilation systems, during the energy audit in standard conditions (*asset or design ratings*). In these circumstances, nighttime ventilation during the 23.00 and 7.00 o’clock is established, and, consequentially, the mean daily ventilation should be calculated averaging the different amounts of air supplied during the diurnal and nocturnal hours.

In the case-study here presented, the building is not equipped with a mechanical ventilation system, so that no free-cooling can be considered. Therefore, a constant air change of 0.3 Vol/h is considered, both with reference to the night and day hours.

As regards the utilization factor of energy losses, the method described with reference to the European standard EN 13790 is completely confirmed. Actually, the thermal loss utilization factor, as before explained, depends on the building envelope thermal inertia. About this, the Italian procedure is a little bit different. In fact, the UNI TS 11300 considers, in the evaluation of the building attitude to store energy, also the term “window area ($A_w$) / useful floor surface ($A_f$)”.

This improvement of the Italian methodologies is not negligible, determining a more reliable evaluation.

As regards the operational period of the cooling system, above all with reference to possible different temperature set points during the day/night alternation and as regards the intermittent functioning, when the tailored rating is applied, the most useful strategy and scheduling in order to better simulate the energy performances can be applied.

On the other hand, as regards the standard ratings (*asset or design*), only a fixed indoor thermal level has to be selected (*depending on the kind of building*). For example, with reference to residential buildings, the energy necessary in order to keep at 26 °C the indoor environment, 24 hours/day for the duration of the whole summer season, has to be considered.

b) EVALUATION OF THE COOLING SEASON LENGTH

As easily visible in the equation 27, the evaluation of the cooling season length requires the calculation of the whole heat gains, both solar and endogenous. About these, the calculation procedures and algorithms are quite the same of those proposed by the EN 13790, in particular adopting the same equations 4 and 5.

In order to provide a clear description, in the case-study here analysed, in a first moment the final results, with reference to the overall $Q_{FREE\text{-}CONTRIBUTE}$ (*i.e. the sum of $Q_{solar}$ and $Q_{internal}$*) will be directly reported, in order to identify immediately the cooling season length (*Table II.10*).

Table II.10: Calculation sheet for the determination of the cooling season length

| | $T_{out}$ | $T_{int}$ | $H_{TRAS}$ | $H_{VENT}$ | $H_{TOT}$ | H * t | $Q_{FREE}$ | $Q_{FREE}$ / ($H_{TOT}$ * t) | $T_{INT}$ – $Q_{FREE}$ / ($H_{TOT}$ * t) | cool |
|---|---|---|---|---|---|---|---|---|---|---|
| | (°C) | (°C) | (W/K) | (W/K) | (W/K) | (kWh/K) | (kWh/d) | (K) | (K) | |
| Apr | 16.0 | 26 | 2209.7 | 240 | 2450 | 58.8 | 360.9 | 6.1 | 19.9 | No |
| May | 19.5 | 26 | 2209.7 | 240 | 2450 | 58.8 | 416.0 | 7.1 | 18.9 | yes |
| June | 24.1 | 26 | 2209.7 | 240 | 2450 | 58.8 | 451.6 | 7.7 | 18.3 | yes |
| July | 26.7 | 26 | 2209.7 | 240 | 2450 | 58.8 | 465.0 | 7.9 | 18.1 | yes |
| Aug | 26.5 | 26 | 2209.7 | 240 | 2450 | 58.8 | 423.0 | 7.2 | 18.8 | yes |
| Sept | 23.8 | 26 | 2209.7 | 240 | 2450 | 58.8 | 344.4 | 5.9 | 20.1 | yes |
| Oct | 19.6 | 26 | 2209.7 | 240 | 2450 | 58.8 | 281.7 | 4.8 | 21.2 | No |
| Nov | 15.5 | 26 | 2209.7 | 240 | 2450 | 58.8 | 200.3 | 3.4 | 22.6 | No |

Then, in the followings, each single term will be properly described. This choice derives from the intention about a non-fragmentation of the explanation of the calculation method.

The calculation should be carried out day by day, determining the external medium temperature by means of interpolation of the UNI 10349 data, and attributing the mean value here reported to the 15$^{th}$ day of the month. Here, in order to make possible a faster calculation, the evaluations have been done assuming homogenous conditions within the same month (*for example, no differences as regards the outdoor environment temperature between 20 - 25 April or 18 - 27 May have been considered*).

In the evaluations of $Q_{internal}$ and $Q_{solar}$, also in this case the second terms of the equations 4 and 5 (*related to energy sources in adjacent spaces*) have been neglected. In table II.10 all the results, month by month, are reported.

When the last calculated column of the table II.12 $\left[\theta_{i,set,C} - Q_{gn,day} / \left(H \cdot t_{day}\right)\right]$ reports values lower than the first column $\left[\theta_{e,day}\right]$ then the environmental cooling is required. Thus, a cooling season in the period 15 April – 15 October has been individuated.

c) THERMAL GAINS DUE TO THE SOLAR RADIATION AND ENDOGENOUS THERMAL SOURCES

The calculation procedure is quite the same of that already described for the heating season. Starting by the solar radiation heat gains, also in this case both the following contributes have to be considered: the solar radiation on the external surfaces of the building envelope, that rises up the wall temperatures (*determining a further thermal energy transmission through the building shell*); the solar radiation entering through the transparent surfaces, such as windows, glassed facades, skylights.

Table II.11: Net area ($A_{sol}$) collecting, in summertime, the solar radiation

| | α | $R_{se}$ | U | A | $A_{sol}$ |
|---|---|---|---|---|---|
| Roof | ---- | $m^2$ K / W | W / $m^2$ K | $m^2$ | $m^2$ |
| East Wall | 0.6 | 0.04 | 1.21 | 94.5 | 2.7 |
| West Wall | 0.6 | 0.04 | 1.21 | 257 | 7.5 |
| South Wall | 0.6 | 0.04 | 1.21 | 257 | 7.5 |
| North Wall | 0.6 | 0.04 | 1.21 | 94.5 | 2.7 |
| Roof | 0.6 | 0.04 | 1.8 | 313 | 13.5 |

Table II.12: Monthly solar irradiance, in summertime, on oriented surfaces for Naples (UNI 10349)

| | south-wall | east-wall | west-wall | north-wall | roof |
|---|---|---|---|---|---|
| Month | W/$m^2$ | W/$m^2$ | W/$m^2$ | W/$m^2$ | W/$m^2$ |
| April | 132 | 147 | 147 | 66 | 219 |
| May | 120 | 177 | 177 | 96 | 274 |
| June | 113 | 193 | 193 | 117 | 304 |
| July | 122 | 203 | 203 | 110 | 315 |
| August | 142 | 185 | 185 | 78 | 277 |
| September | 162 | 145 | 145 | 52 | 206 |
| October | 179 | 111 | 111 | 38 | 148 |

Table II.13: Energy gains, in summertime, due to the solar radiation on the opaque envelope surfaces

| | south-wall | east-wall | west-wall | north-wall | roof | $\Phi_{sol}$ | t | $Q_{solar}$ |
|---|---|---|---|---|---|---|---|---|
| | *Thermal flux due to the solar radiation (W)* | | | | | (W) | t (Ms) | kWh |
| April | 356 | 1102 | 1102 | 178 | 2953 | 5692 | 1.382 | 2185.2 |
| May | 325 | 1328 | 1328 | 259 | 3703 | 6944 | 2.678 | 5165.4 |
| June | 306 | 1450 | 1450 | 316 | 4109 | 7631 | 2.592 | 5494.0 |
| July | 328 | 1519 | 1519 | 297 | 4250 | 7913 | 2.678 | 5887.4 |
| August | 384 | 1389 | 1389 | 209 | 3734 | 7106 | 2.678 | 5286.8 |
| September | 438 | 1085 | 1085 | 141 | 2781 | 5530 | 2.592 | 3981.3 |
| October | 484 | 833 | 833 | 103 | 2000 | 4254 | 1.296 | 1531.5 |
| | | | | | | Total (kWh) | | 29531.6 |

In order to evaluate the solar gains through the opaque building envelope, the solar absorption coefficient of the external wall surface must be evaluated. In figure 2.3.7 for several building material this coefficient has been represented.

Alternatively, the following values can be used: clear colour of the external surfaces: $\alpha_{SOLAR}$ = 0.3; medium colour of the external surfaces: $\alpha_{SOLAR}$ = 0.6; dark colour of the external surfaces: $\alpha_{SOLAR}$ = 0.9.

Adopting, the value $\alpha_{SOLAR}$ = 0.6, the equation 17 has been applied; the results are reported in table II.11 (*evaluation of the collecting area*), II.12 (*mean monthly solar irradiances*) and, above all, II.13 (*energy gains due to the solar effect*).

In the application of the equation 17, $F_{shading}$ has been posed equal to 1 (*i.e. no shadings considered*) and the second term of the equation 4, related to the solar gains in adjacent non-conditioned rooms, has been not considered.

At the same way already applied for the wintertime, the next step is the calculation of the solar radiation through the building transparent envelope. Also in this case, the effective collecting area, the window frame factor, the solar transmittance of the transparent surfaces ($g_{gl}$) and all the reduction factors due to shading systems have been opportunely evaluated. As example, for the windows placed on the south-wall, the calculation results have been reported in figure 2.3.10.

Analogues evaluations have been carried out also for all the other window exposures.

**Windows, single glass, south exposure**

| | MJ/m²d | MJ/m² | kWh/m² | |
|---|---|---|---|---|
| Month | H | | | Days |
| April | 11.4 | 182.4 | 403.10 | 16 |
| May | 10.4 | 322.4 | 89.56 | 31 |
| June | 9.8 | 294 | 81.67 | 30 |
| July | 10.5 | 325.5 | 90.42 | 31 |
| August | 12.3 | 381.3 | 105.92 | 31 |
| September | 14 | 420 | 116.67 | 30 |
| October | 15.5 | 232.5 | 64.58 | 15 |
| totals | 54.4 | 1505.6 | 770.66 | 184 |

| | | | |
|---|---|---|---|
| S gross | $m^2$ | 13 | $F_W$ = 0.9 |
| $g_{gl}$ | | 0.765 | |
| $1-F_f$ | | 0.8 | |
| $A_{sol}$ | $m^2$ | 7.96 | |
| $Fi_{sol}$ | kWh | 6131 | |
| | **TOTALs** | **7.66** | **kWh/m²** |

*Figure 2.3.10 – UNI TS 11300 application: calculation of the solar gains through the windows*

Table II.14: Energy gains, in summertime, due to the endogenous heat sources.

| S gross | M² | 938.79 | | | | |
|---|---|---|---|---|---|---|
| | $Q_{internal}$ | Time | $Q_{internal-month}$ | $Q_{internal-month}$ | | |
| Months | W | Ms | MJ | kWh | | |
| April | 2470 | 1.382 | 3413.5 | 948.21 | 1.18 | kWh/m² |
| May | 2470 | 2.678 | 6614.7 | 1837.41 | 2.30 | |
| June | 2470 | 2.592 | 6402.2 | 1778.40 | 2.22 | |
| July | 2470 | 2.6784 | 6615.6 | 1837.68 | 2.30 | kWh/m² |
| August | 2470 | 2.6784 | 6615.6 | 1837.68 | 2.30 | kWh/m² |
| September | 2470 | 2.592 | 6402.2 | 1778.40 | 2.22 | kWh/m² |
| October | 2470 | 1.296 | 3201.1 | 889.20 | 1.11 | kWh/m² |
| | | TOTALs | 39265 | 10907 | kWh/m² | = 13.62 kWh/m² |

| Monthly heat gains (kWh) | April | May | June | July | August | September | October |
|---|---|---|---|---|---|---|---|
| | 948 | 1837 | 1778 | 1838 | 1838 | 1778 | 889 |

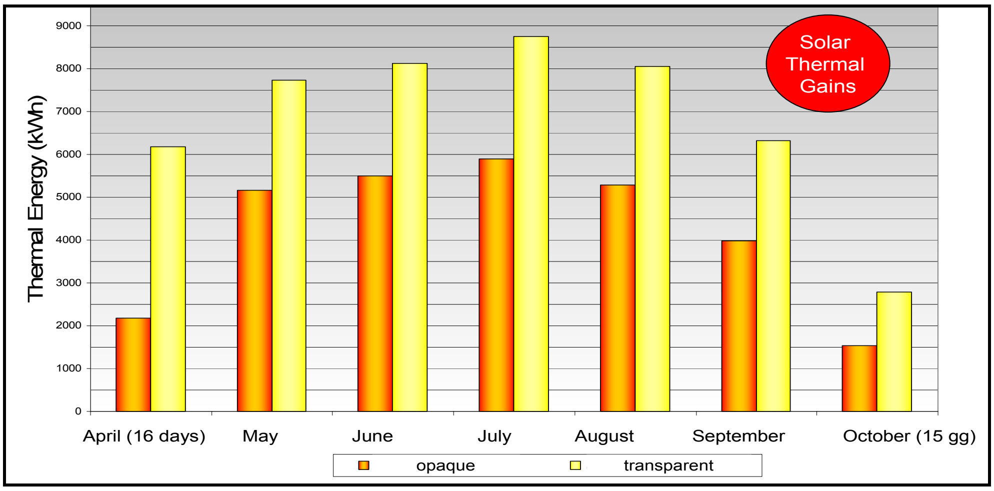



*Figure 2.3.11 – Thermal gains, in summertime, due to the solar radiation*

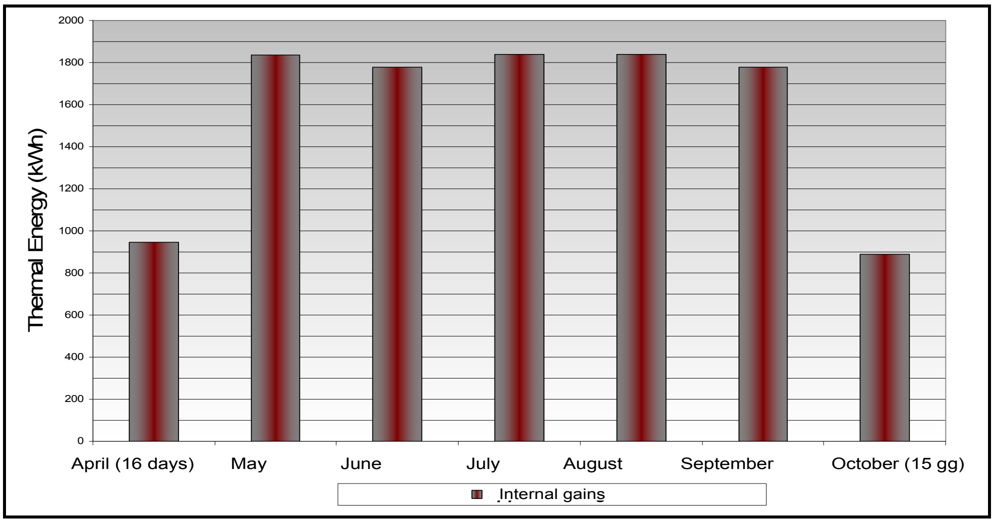



*Figure 2.3.12 – Endogenous heat gains, in summertime, due to internal heat sources*

Also as regards the endogenous heat gains, the calculation procedure is the same of that already described in the equations above-reported and applied, in this case study, for the winter season.

Appling the methods before described, and extended the results to the all summer months, the results presented in table II.14 have been calculated. Also now, the second term of the equations 18 has been neglected.

d) ENERGY LOSSES DUE TO THE THERMAL DISPERSIONS FOR TRANSMISSION AND VENTILATION

Obviously, in the evaluations, the same building component characteristics of those described for the wintertime calculations have been considered. In particular, the thermal transmittances of typological building component have been evaluated with reference to typical constructive traditions and thicknesses of opaque and transparent component, considering common structures such as reported by the annexes of UNI TS 11300-1.

Note that, considering the whole summer season, the energy exchanges due to the transmission and ventilation represent, globally, thermal losses. In fact, adopting the procedures included in the new European and Italian standards, these thermal exchanges are determined by the temperature differences between the indoor and outdoor environment, while the radiative phenomena are calculated in a different way.

Therefore, meanly considering the whole season, the outdoor temperature is lower than the indoor ones, so that the diffusive heat transfer phenomena (*energy lost for transmission*) and the convective ones (*energy lost for ventilation*) globally are directed from the building to the outdoor ambient. The same direction characterizes the heat exchange between the building and the sky, being the sky temperature lower than the building shell one.

About this last point, the UNI TS 11300-1 does not diversify the temperature difference between the building shell and the sky thermal level depending on the season, proposing an only one ΔT reference value of 11 °C.

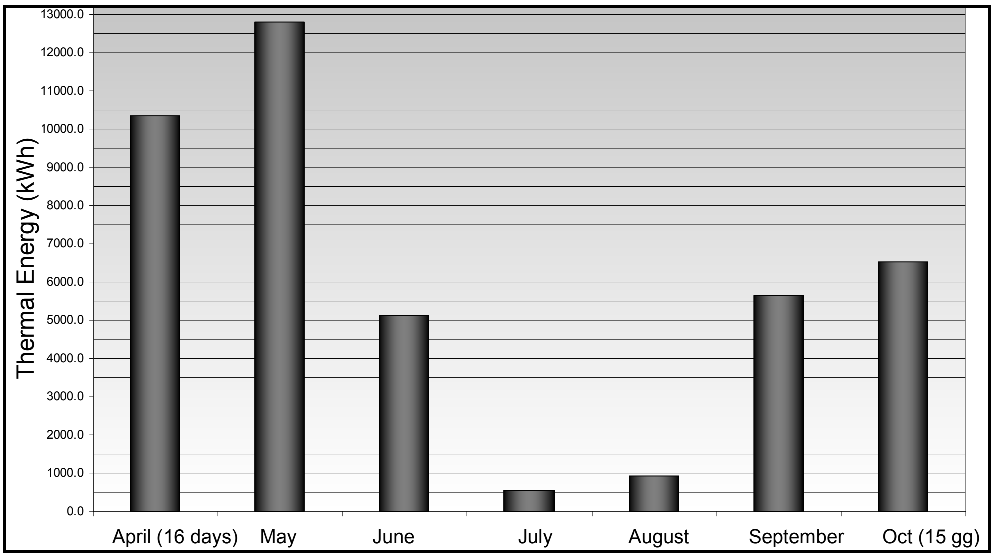



*Figure 2.3.13 – Energy losses for ventilation, transmission and radiation*

The same procedure already explained during the wintertime calculations has been carried out with reference to the summer season, calculating every one of these energy transfer contributes. As already before described, the utilization factor calculation is a little bit different, as regards the Italian standard, compared to the algorithm provided at European level, being taken into account also the amount of the windows as regards the determination of the building attitude in storing the thermal energy.

For the considered period, the calculated values of the utilization factor of energy losses ($\eta_{COOLING,ls}$) always result equal to 1. Only with reference to April, $\eta_{COOLING,ls}$ results around 0.936. It means that, globally, the energy losses are much lower than the energy gains, so that also under precautionary conditions, these could be entirely considered (table II.15).

In the followings, it will be shown that, actually, in April and October no cooling is required.

Once completed the evaluation procedure for the energy loss estimation, than the overall energy balance, in summertime and referred to the whole building, can be calculated. The final results are reported in table II.15 and figure 2.3.14.

Table II.15: Summertime – overall energy balances referred to the building

| | Months | | April | May | June | July | August | September | October |
|---|---|---|---|---|---|---|---|---|---|
| Input | Transmission + ventilation losses | $Q_{ls}$ (kWh) | 10350.6 | 13679.5 | 5125.3 | 558.1 | 922.7 | 5654.5 | 6532.4 |
| Input | total gains | $Q_{gn}$ (kWh) | 9305.4 | 14734.0 | 15405.0 | 16473.6 | 15172.1 | 12085.8 | 5211.0 |
| | | | | | | | | | |
| calculation | gains / losses | $\gamma_C$ | 0.899 | 1.077 | 3.006 | 29.515 | 16.444 | 2.137 | 0.798 |
| | | | | | | | | | |
| provided | internal heat capacity per area | kJ/m$^2$K | 165 | 165 | 165 | 165 | 165 | 165 | 165 |
| | | | | | | | | | |
| Input | total area | m$^2$ | 1435 | 1435 | 1435 | 1435 | 1435 | 1435 | 1435 |
| calculation | internal heat capacity | (kJ/K) | 236775 | 236775 | 236775 | 236775 | 236775 | 236775 | 236775 |
| Input | Heat exchange coefficient | (kW/K) | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 |
| calculation | Building thermal constant | T (h) | 29.3 | 29.3 | 29.3 | 29.3 | 29.3 | 29.3 | 29.3 |
| calculation | $a_C$ | | 9.7 | 9.7 | 9.7 | 9.7 | 9.7 | 9.7 | 9.7 |
| calculation | Utilization factor | $\eta_{C,ls}$ | 1.000 | 0.936 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| calculation | used free losses | $Q_{ls}$ x $\eta_{C,ls}$ (kWh) | 10350.6 | 12809.5 | 5125.3 | 558.1 | 922.7 | 5652.6 | 6532.4 |
| calculation | Net cooling need $Q_{C,nd}$ (kWh) | | **-1045** | **1924** | **10280** | **15915** | **14249** | **6433** | **-1321** |

TOTAL THERMAL NEEDS IN SUMMERTIME = 48802 kWh/year

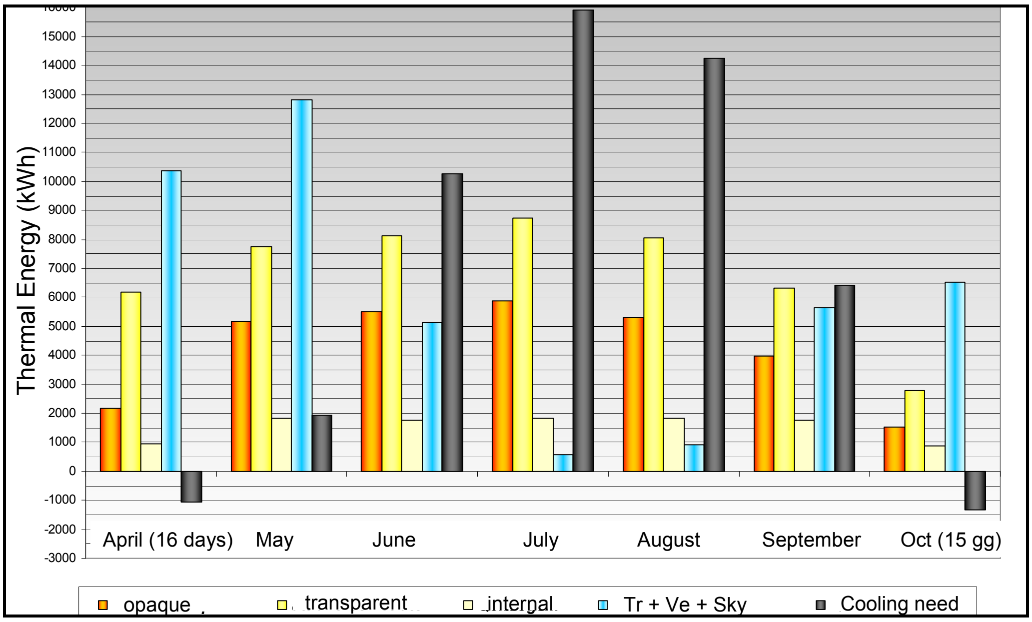



*Figure 2.3.14 – Cooling season: single energy exchange and overall energy balances*

As regards the negative values of the cooling needs, achieved with reference to April and October, this result suggests that in these months no cooling is necessary. This results can be explained considering that, in the evaluation of the length of the cooling season, no interpolation of climatic data has been carried out, while the same value of the mean daily outdoor temperature has been attributed to the all days of the same month. In the followings, of course the corrected results, such as reported in table II.15, will be considered, in order to adjust the previous approximation.

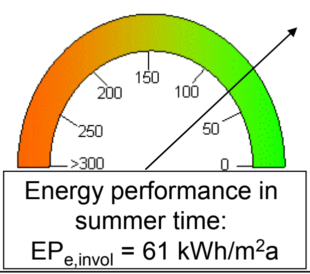
Presently, the Italian Presidential Decree 59/2009 establishes limits to the building envelope thermal energy needs in summertime (*i.e.* $EP_{e,invol}$). In fact, with reference to the only thermal requirements (*no consideration of the cooling system efficiencies and no conversion in primary energy*), the following maximum values must be respected:

- Italian climatic zones A and B → maximum value = 40 $kWh/m^2a$;
- Italian climatic zones C, D, E and F → maximum value = 30 $kWh/m^2a$.

In order to calculate the $EP_{e,invol}$ characterizing this building, the equation 28 has been then applied, starting by the dimension of the building useful area and the total net energy demand to keep the building at 26 °C during the considered period.

$$EP_{e,invol} = Q_{COOLING,nd} / A_f \tag{28}$$

Considering a net area of the building equal to 800.5 $m^2$, and the thermal need calculated in table II.15 (*i.e. a thermal energy need of 48802 kWh*), an $EP_{e,invol}$ equal to 61 $kWh/m^2a$ has been estimated. According to the recent Italian legislation (*Ministerial Decree 26/06/2009, the so-called National Guidelines for the Building Energy Certification*), the performances of this building, as regards the thermal performances in summertime, are considered "*bad*", because the behaviours are not satisfactory with reference to the indoor over-heating limitation during the cooling season.




| EPe,inv ($kWh/m^2anno$) | Performances | Building quality |
|---|---|---|
| $EP_{e,inv} \leq 10$ | Optimal | I |
| $10 < EP_{e,inv} \leq 20$ | Good | II |
| $20 <$ E $EP_{e,inv} \leq 30$ | Sufficient | III |
| $30 < EP_{e,inv} \leq 40$ | Poor | IV |
| $EP_{e,inv} > 40$ | Bad | V |

*Figure 2.3.15 – Cooling season: evaluation of the $EP_{e,invol}$ and attribution of a performance Class*

In figure 2.3.15, the evaluation of the $EP_{e,invol}$ has been transposed into the national scheme for the building energy certification, and also the table to define the energy performances of the building during the summer season has been reported in the same graph [26].

The unsatisfactory achieved performances are quite evident.

### 2.3.4 THE DYNAMIC BEHAVIOURS OF THE BUILDING ENVELOPE COMPONENTS

In the Chapter 1 of the Thesis, the Italian Legislative Decree 192/2005 has been described also as regards the Annex I, reporting the transient regime for the evaluation of the building energy performances. In particular, in the climatic zones characterized by high value of the summer solar radiation (*mean daily irradiance, on the horizontal plane, higher than 290 W/m$^2$*), the Decree 192/2005 imposes high thermal mass for the building envelope component (*at least equal to 230 kg/m$^2$*).

This measure was enacted in order to guarantee an effective thermal capacity of the building shell, imposing an apt attenuation and time lag of the summer cooling loads. In the Chapter 3, the effectiveness of this kind of regulation will be deeply analysed. In this section, instead, the new regulations about the dynamic characteristics of the building envelope are discussed.

Alternatively to the determination of the $EP_{e,invol}$, the Ministerial Decree 26/06/2009 makes possible, in some cases, the determination and verification of qualitative parameters regarding the building envelope: the time lag effect achieved by the building component in summertime (S) and the attenuation factor of the summer cooling loads ($f_a$).

In particular, adopting definitions and methodologies contained in the European standard EN 13786/2008 [34] "*Thermal performances of the building components: dynamic thermal characteristics, calculation methods*", these two parameters can be so described:

- attenuation factor ($f_a$) o decrement factor: this represent the "module of the dynamic thermal transmittance" *to* the "thermal transmittance value evaluated in steady-state conditions" ratio.
- time lag effect (S): is the time delay between the maximum of the thermal flux entering into the indoor environment and the maximum of the external ambient room temperature.

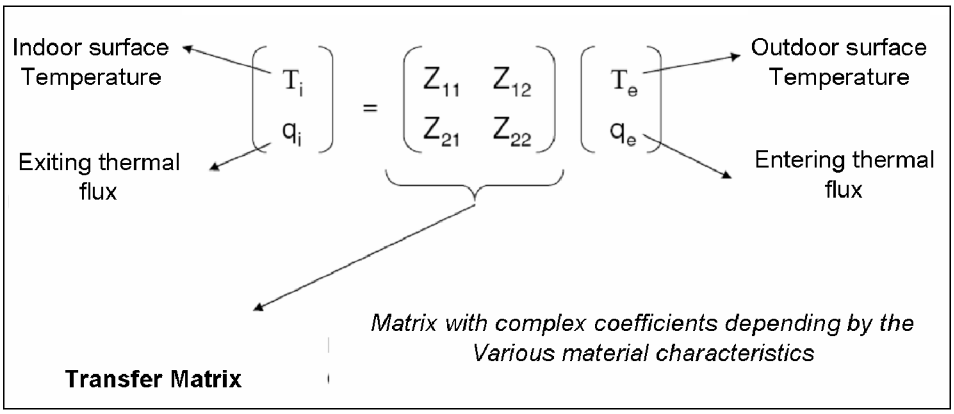



*Figure 2.3.16 – Scheme of the transfer matrix*

The cited Standard EN ISO 13786 provides the whole calculation procedure useful do evaluate also the periodic thermal transmittance ($Y_{12}$), defined as the ratio between the thermal flux that crosses the building component surface on a side and the thermal stress induced on the other side. Of course, the calculation of this parameter adopts the methodologies already applied for the evaluations of the decrement factor and the time lag effect. In particular, the whole calculation procedure is based on a transfer matrix built starting by the building component definition: (*layers, weight, specific thermal capacity, thermal conductivity, thickness*); all these characteristics make possible the construction of the transfer function, based on a matrix with complex coefficients (figure 2.3.16).

As regards a defined wall layer, under boundary conditions (*as regards temperatures and thermal fluxes*) variable during the day with a harmonic law, the unitary exchanged thermal flux $q_2$ and the temperature $\theta_2$ (*both referred to the same surface*) can be related to the thermal flux $q_1$ and the temperature $\theta_1$, characterizing the opposite face, through the relation 29:

$$\begin{bmatrix} \hat{\vartheta}_2 \\ \hat{q}_2 \end{bmatrix} = \begin{bmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{bmatrix} \cdot \begin{bmatrix} \hat{\vartheta}_1 \\ \hat{q}_1 \end{bmatrix} \tag{29}$$

where the $Z_{jk}$ are the complex coefficients of the matrix, related to the characteristics of the layer of the building opaque component.

The transfer matrix of a building component, constituted from several layers, is estimated as the product of the transfer matrixes that characterize the single layers. The calculation methods are not particularly complex to apply; anyway, a computer tool is necessary, being the procedure characterized by multiple interactions of algorithms based on calculations of heat transfer matrixes, each one of these constituted by several complex (*i.e. imaginary and real units*) coefficients.

For the case-study building, in this section analysed, also this procedure, alternative to the determination of the $EP_{e,invol}$, has been applied. Thus, with reference to only one apartment of the building, the attenuation factor ($f_a$) and the time lag effect (S), as well as the period thermal transmittance ($Y_{12}$) have been calculated.

The selected apartment is located at an intermediate floor, so that these dynamic thermal parameters must be evaluated only for the external vertical wall (*the only one building component thermal dispersing toward the exterior environment*).

In table II.16, the reference scale, in order to classify the building summer performances such as proposed by the Italian regulation (*Ministerial Decree 26/06/2009 [26]*), has been represented. When time lag and attenuation factor describe different quality categories, the value assumed by the time lag results the main one to be considered.

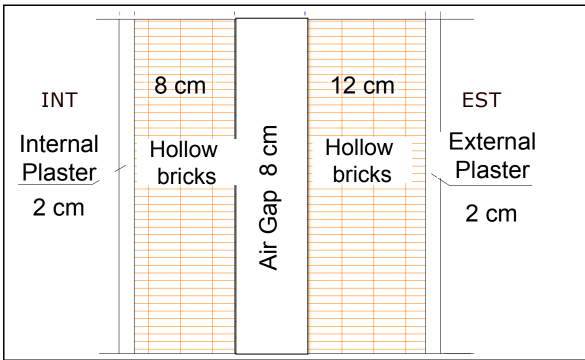
With reference to the base-case building in this paragraph analysed, three different possible walls have been considered:

1. in a first case, the building presents two layers of hollow bricks and none interposed insulation, being provided with a simple air gap.
2. in a second case, the air gap is substituted with a layer of extruded polystyrene;

3. in a third case, the wall presents two layers of filled bricks and a layer of interposed extruded polystyrene.

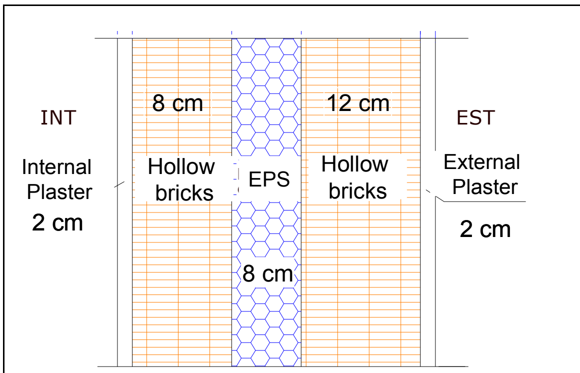
Table II.16: The Italian scheme (Decree 26.06.2009) applied to classify the building performances depending on the dynamic thermal parameters.

| Time Lag | Attenuation | Performances | Performance quality |
|---|---|---|---|
| **S** > 12 | $\mathbf{f_a} \leq 0,15$ | ***Optimal*** | **I** |
| 12 ≥ **S** > 10 | $0,15 < \mathbf{f_a} \leq 0,30$ | ***Good*** | **II** |
| 10 ≥ **S** > 8 | $0,30 < \mathbf{f_a} \leq 0,40$ | ***Sufficient*** | **III** |
| 8 ≥ **S** > 6 | $0,40 < \mathbf{f_a} \leq 0,60$ | ***Poor*** | **IV** |
| 6 ≥ **S** | $0,60 < \mathbf{f_a}$ | ***Bad*** | **V** |



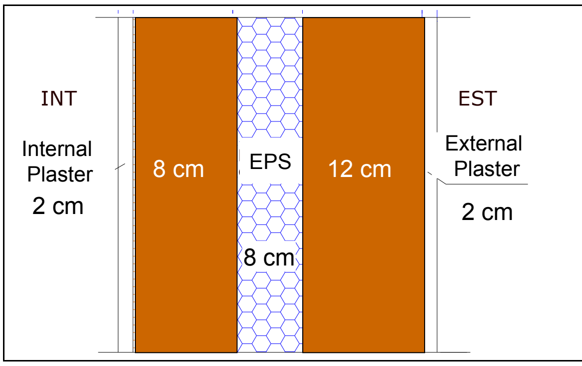

| | *Wall* |
|---|---|
| Transmittance U (W/m² K) | *1,13* |
| Thickness (m) | *0,32* |
| Mass (kg) | *160* |
| Periodic Transmittance (W/m² K) | *0,72* |
| Time Lag (h) | *6,17* |
| Attenuation Factor (---) | *0,63* |

*Figure 2.3.17 – The simulated building: dynamic thermal characteristics for the wall 1*




| | *Wall* |
|---|---|
| Transmittance U (W/m² K) | *0,34* |
| Thickness (m) | *0,32* |
| Mass (kg) | *162,4* |
| Periodic Transmittance (W/m² K) | *0,172* |
| Time Lag (h) | *8,04* |
| Decrement Factor (---) | *0,50* |

*Figure 2.3.18 – The simulated building: dynamic thermal characteristics for the wall 2*




| | *Wall* |
|---|---|
| Transmittance U (W/m² K) | *0,378* |
| Thickness (m) | *0,32* |
| Mass (kg) | *402,4* |
| Periodic Transmittance (W/m² K) | *0,096* |
| Time Lag (h) | *10,06* |
| Attenuation Factor (---) | *0,25* |

*Figure 2.3.19 – The simulated building: dynamic thermal characteristics for the wall 3*

For each one of these building opaque components, all the characteristics, geometrical, typological and relative to the obtained dynamic performances are represented respectively in the figures 2.3.17, 2.3.18 and 2.3.19.

Comparing the achieved results (*i.e. such as reported in the figures 2.3.17, 2.3.18 and 2.3.19*) with respect to those established by the Italian regulation (*table II.16*), the following notes can be inferred:

- both as regards time lag effect and decrement factor, the wall 1 presents poor/bad performances;
- rising up the thermal resistance of the wall, applying a thermal insulation (wall 2), the stationary thermal transmittance obviously goes down drastically. The same thing does not happen as regards the decrement factor, periodic thermal transmittance and time lag effect. In fact, even if the wall 2 (*figure 2.3.18*) presents better results compared to the wall 1 (*figure 2.3.17*), anyway the achieved performances are not at all satisfactory;
- the use of heavy materials (*filled bricks*), instead, makes possible much better summer performances. In fact, in this way, both the thermal mass and the thermal capacity rise, so that the thermal inertia of the opaque component improves and respectively an increase of the time lag and a decrease of the attenuation factor are achieved. Therefore, as regards the dynamic thermal characteristics of the building components, another approach has to be adopted with respect to the criterion applied for the wintertime (*simple thermal insulation, i.e. low thermal conductivity*).

*This entire topic will be also analysed in the Chapter 3, with much more complete investigations.*

## 2.4 ADVANCED TOOLS AND METHODS FOR THE BUILDING ENERGY EVALUATION

### 2.4.1 THE BEPS - BUILDING ENERGY PERFORMANCE SIMULATION

The numerical codes for the dynamic energy simulations of the integrated system building-HVAC plants determine the dynamic management of all the variables that influence the seasonal operation of the systems (*external climatic conditions, time-dependent crowding, lighting system, thermal inertia of the building envelope, performances of HVAC at the part load conditions, regulation…*).

The steady-state calculation, in fact, even if makes possible the sizing of the heating and cooling systems, is not enough in order to estimate the energy performances of the building and related HVAC plants, both in terms of microclimatic control performances and energy demands.

Various BEPS codes are used in the advanced energy simulations of buildings, structured in many ways and different also as regards the algorithms resolution methods, even if a common logical scheme can be identified. Commonly, the BEPS (*i.e. Building Energy*

*Performance Simulations*) codes provide the construction of the building (*its geometric and thermo-physical characterizations*), as well as the choice and the attribution to it of an air-conditioning system.

In the following chapters of this Thesis (*i.e. Chapters 3, 4 and 5*), various analyses carried out by means of these tools are proposed, in particular using the calculation engines DOE 2.2 (*Department of Energy of Berkley University*) [62] and EnergyPlus 2.0 [63] (*U.S. Department of Energy*). These two codes, particularly well-accredited according to the international scientific community, provide large possibilities as regards the energy performance evaluations, both as regards the definition of the building (*its characteristics, such as geometry, material, constructive typologies*) and also with reference to the air-conditioning systems.

In particular, EnergyPlus (*the main code used in the following studies*) consists in a complex system of various numerical modules and solvers, working together in order to evaluate the energy required for the building heating, ventilating and cooling, adopting traditional or quite innovative systems and energy sources (*figure 2.4.1*).

This code solves the energy balances when the complex system is exposed to different environmental and operating conditions. The central module of the code is the building and HVAC simulation manager.

As represented in figure 2.4.1, a detailed definition of all the necessary boundary conditions is necessary in order to obtain reliable results, being the architecture of the code quite complex and interactive.

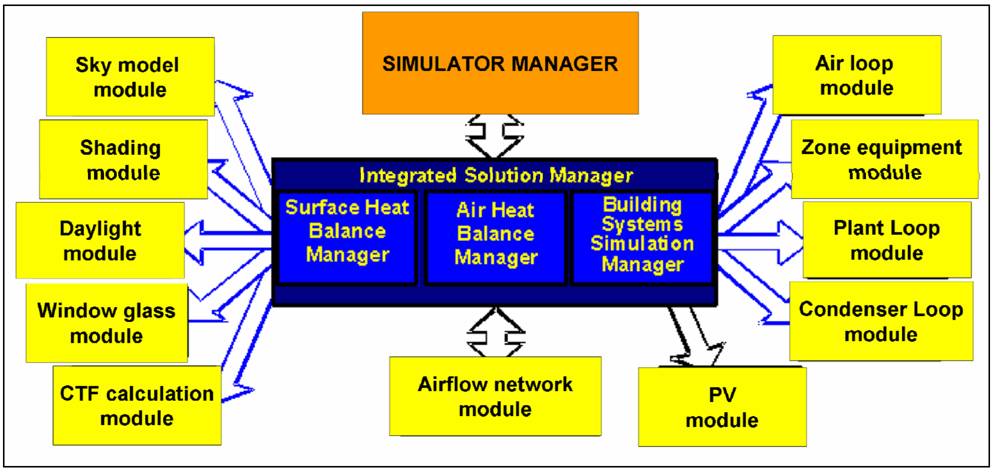



*Figure 2.4.1 - Building Energy Performance Simulator: E+: architecture of the code (source: Energy Plus Documentation)*

Actually, several codes and energy simulators are today available, even if quite all are organized more or less in similar architectures. Usually in a first section, the model editing is provided, being necessary the definition of the thermal-physical properties of the building, both as regards the opaque and transparent surfaces, as well as the definition of the component stratigraphies and the building geometrical characteristics. In the same section, the scheduling of endogenous loads (*persons, lights, and installed equipments*) and the construction of the system and relative components are usually fully defined.

In this phase, also the selection of the climatic data is carried out. Usually, about these, the most spread adopted data are the weather files TRY [64], IWEC [65] or TMY2 [66].

The most common resolution method, adopted in the BEPS code, is based on Conduction Transfer Functions (CTF), that make possible the evaluation of the thermal loads characterizing the building, the energy demand required by the HVAC, the achievable indoor conditions as regards the thermal-dynamic state of the indoor air. Other set of solution algorithms, based on the finite difference methods, are also available by some energy simulators.

Usually, the numerical codes evaluate the thermal loads solving the transfer functions, that describe, as regards each one of the building components, the physical phenomena such as an interrelation among the entering variables (*causes*) and the editing ones (*effects*). The heat and mass transfer phenomena charactering the physical model are described, in the time-domain, by a set of differential equations.

The thermal loads are calculated as sum of the sensible heat loads (*constituted from the radiative loads evaluated applying the coefficients of the transfer functions, with the aim to simulate the thermal inertia of the envelope, and from those characterized by a convective nature*) and the latent ones (*related to the moisture transfer phenomena inside the building*).

The numerical analysis represents an useful instrument in order to understand the effectiveness of several building envelope solutions or HVAC alternatives, as regards the energy efficiency of the integrated system, the achievable comfort conditions, the energy demand and the operating costs, the capability to maintain a temporal stability in the indoor conditions on varying suddenly the thermal loads conditions.

On the other hand, the limit of the codes for the building energy simulations consists in the representation, like a single node, of the whole environment, so that a strong hypothesis of perfect mixing ventilation is imposed (*i.e. zero-dimensional evaluation*). In particular applications, for example where the thermal stratifications phenomena are not negligible, this kind of numerical study cannot give exhaustive and reliable results. In particular, this happens, for example, simulating indoor spaces characterized by elevated inner heights, or when particular air diffusion strategies – *such as the displacement ventilation* – are designed, so that, intentionally, a lack of uniformity inside the indoor environment is assigned, with remarkable differences as regards the microclimatic conditions.

The codes for the building energy simulation are based on a set of mathematical equations, implemented in order to apply energy balances. Two main groups of equations are identifiable: the first one contains the resolution algorithms relative to the surfaces delimiting the building (*walls, roof, basement, windows, and, generally, all the surfaces that compose the building enevelope, equation 30*), the second relative to the indoor air (*equation 31*) [67]:

$$q_{i,cond} + q_{i,s-rad} = \sum_{k=1}^{N} q_{ik,rad} + q_{i,conv} \tag{30}$$

$$\sum_{i=1}^{N} q_{i,conv} \cdot A_i + Q_{other} - Q_{extract} = \left( \rho \cdot V_{room} \cdot c_p \cdot \Delta T_{room} \right) / \Delta t \tag{31}$$

where

- $q_{i,cond}$ = conduction thermal flux interesting the surface i;
- $q_{i,s\text{-}rad}$ = radiative thermal flux interesting the surface i, between the surface and an internal or solar heat source;
- $q_{ik,rad}$ = radiative thermal flux between the surface i and a surface k;
- $q_{i,conv}$ = convection thermal flux interesting the surface i;
- $\sum_{k=1}^{N} q_{i,conv} \cdot A_i$ = convective heat exchange between the surface i (*area* = $A_i$) and the indoor air;
- $Q_{other}$ = thermal gains due to the presence of people, installed equipments, artificial lightings, etc…;
- $Q_{extract}$ = total thermal loads that has to be balanced;
- $\left(\rho \cdot V_{room} \cdot c_p \cdot \Delta T_{room}\right) / \Delta t$ = energy exchange relative to the indoor air;
- $\rho$ = air density;
- $c_p$ = air specific heat capacity;
- $\Delta T$ = indoor air temperature difference;
- $\Delta t$ = time step reference period (usually 1 hour).

The solution of the equation 30 provides the indoor surface temperatures and the quantification of the convective energy exchanges involving these surfaces, through which, by means of the equations 31, the mean indoor air temperatures can be evaluated, as well as the total thermal load that should be balanced. In fact, it can be written:

$$q_{ik,rad} = h_{ik,rad} \cdot \left(T_i - T_k\right) \qquad (32)$$

$$q_{i,conv} = h_{i,conv} \cdot \left(T_i - T_{i,air}\right) \qquad (33)$$

where

- $h_{i,rad}$ = linearized radiative heat exchange coefficient;
- $T_{i,}$ = temperature of the inner surface i;
- $T_{k,}$ = temperature of the inner surface k;
- $T_{i,air}$ = temperature of the indoor air near the surface k;
- $h_{i,conv}$ = convective heat exchange coefficient;

Usually, the coefficient $h_{i,conv}$ isn't known, so that it was estimated through empirical equations or assumed as a constant. Also for these reasons, in the followings, the usefulness of a coupled analysis, by means dynamic building energy simulations and computational fluid-dynamic studies, will be clear (*the coupling of these two different mathematical resolution instruments will be described in the followings of this paragraph*).

In following lines, a little bit more exhaustively the structures, the features and the main characteristics of the mainly used BEPS code (*i.e. EnergyPlus*) will be described. As already said, in fact, several codes are presently available, so that a full description of the adopted methodologies cannot be carried out without focusing the attention on a specific simulator.

EnergyPlus [63] makes possible the simulation of heating, cooling, lighting, ventilation and all the other energy flows interesting the buildings; this code, originally based on the resolution methodologies of BLAST [68] and DOE-2 [62], in the last version has been totally restructured, including innovative simulation capabilities such as:

- reduced time steps for the energy balances;
- modular systems and plant integrated with heat balance-based zone simulation;
- multi-zone airflow;
- investigation of the achievable thermal comfort;
- analyses referred to the water use;
- natural ventilation and its effect on the cooling demand;
- integration and energy contributes of photovoltaic systems.

A scheme of the E+ architecture is represented in figure 2.4.1. EnergyPlus is above all a simulation engine [63], where both the input and the output data are provided as text files. Heat balance, indoor temperature and comfort condition predictions are obtained by means of a complex algorithm resolution procedures, based on an integrated and simultaneous analysis of the building and technical systems.

The iterative procedure provides a continuous information exchange among the several parallel modules, so that the calculated loads, referred to the user specified time-steps, are transferred to the simulation module of the building system, referred to the same temporary range.

The module for the building simulation, once achieved the minimum error established, calculates the heating and cooling system response, as well as the energy balances referred to the other plants (*e.g. the photovoltaic system*) and electrical appliances.

By means of this operative scheme, EnergyPlus provides (*and these data are confirmed by several literature sources [69, 70]*) temperature predictions and those referred to the plant sizing (*the indoor comfort, the energy needs and requirements in terms of primary sources*) more accurate compared to other simulation tools.

The approach of the integrated simulation makes possible, furthermore, also more reliable studies as regards better regulation solutions, the investigation of moisture adsorption or de-sorption with reference to the building components, potentialities of radiant heating and cooling and so on. The architecture of EnergyPlus establishes, above all, two modules for the system simulations:

- a heat and mass balance simulation module;
- a simulation tool to solve the building systems.

The simulation manager of the building systems manages the data exchange and the communication among the heat balance solver and the various sub-modules related to the HVAC system simulations (*i.e. coils, boilers, chillers, pumps, fan, and all the auxiliaries*). Even if the high compatibility to other simulation codes for the building energy simulations admits the implementation of several technical solutions, a great database of basic components is already provided in the code and modifiable by the users. In particular, all the HVAC solutions can be managed and further implemented.

The building system simulation tool is above all based on the HVAC air-side and the water (*water loops*) modules; these two represent the core of this code sections and are user-changeable, so that several kind of water pipes and air ducts, such as defined in the real building, can be varied and implemented.

The air-side sub-module includes and simulates the air transport phenomena, the air-conditioning and mixing of the airflows crossing the several HVAC equipments (*supply and return fans, central heating and cooling/heating coils, air-economizers, heat recovery devices, controls…*). Moreover, each one of these HVAC devices can be differently defined and modelled for each one of the building thermal zones (*that can be characterized also by several and contemporaneous active energy systems*).

About the heat and mass balance calculations, these are based on an evolved BLAST [68] procedures: *i.e. the IBLAST*, which provides the integration of the building-HVAC system simulations. The heat balance module manages the sub-modules for the energy balances referred to the indoor air and the building surfaces, acting as a bridge between the heat balance and the simulation manager of the building systems. The continuous feedbacks between the HVAC calculation modules and the loads evaluation sections do EnergyPlus much more accurate than DOE and BLAST singularly analysed, and also with respect to many other simulation codes [69].

Furthermore, the integrated simulations make possible many processes not possible for many other tools, such as:

- realistic system controls;
- moisture transfer phenomena;
- radiant heating and cooling;
- inter-zone airflows.

The surface heat balance module solves the energy transfer between the external and internal surfaces of the building envelope components, relating the calculation algorithms (*Conduction Transfer Functions CTF or Conduction Finite Difference CFD*) to the all assigned boundary conditions, considering the convection, conduction and radiative heat transfer contributes. An example of CTF is reported in the equations 34 and 35 in the most generic definition, respectively with reference to heat fluxes interesting the inside and outside surfaces of a building element.

$$q''_{ki}(t) = -Z_o T_{i,t} - \sum_{j=1}^{nz} Z_j T_{i,t-j\delta} + Y_o T_{o,t} + \sum_{j=1}^{nz} Y_j T_{o,t-j\delta} + \sum_{j=1}^{nq} \Phi_j q''_{ki,t-j\delta} \tag{34}$$

$$q''_{ko}(t) = -Y_o T_{i,t} - \sum_{j=1}^{nz} Y_j T_{i,t-j\delta} + X_o T_{o,t} + \sum_{j=1}^{nz} X_j T_{o,t-j\delta} + \sum_{j=1}^{nq} \Phi_j q''_{ko,t-j\delta} \tag{35}$$

where, the following terms are present:

- $q''_{ko}$ = the heat flux on the outside surface;
- $q''_{ki}$ = the heat flux on the inside surface;
- $T_i$ = the inside surface temperature;

- $T_o$ = the outside surface temperature;
- i = the inside of the building component;
- o = the outside of the building component;
- t = the current time-step;
- Z = inside CTF coefficient; X = outside CTF coefficient; Y = cross CTF coefficient;
- Φ = Flux CTF coefficient.

The Conduction Transfer Functions represent an efficient method to evaluate the surface heat fluxes, linearly relating the heat transfers (*interesting each face of the wall*) to the current and previous temperature levels and heat fluxes, and so providing the evaluations of the thermal storage phenomena. This mathematical resolution method, very powerful [63] and solvable without requiring high computational sources, become progressively more unstable when the number of time steps decreases, so that at least 10 – 15 time-steps/hours must be assured. In all our analyses (*Chapters 3, 4 and 5*), at least 30 time-steps/hours were adopted.

As regards some peculiarities of EnergyPlus compared to other building energy simulation codes, one of the E+ best features is the great attention regarding the daylighting evaluations, based on the split-flux interreflection model [71] and on a model of anisotropic sky.

In the chapter 4, more information about the sky model of EnergyPlus will be provided, before the description of the radiation heat transfer resolution, particularly important in the analyses there carried out. In fact, the mentioned chapter investigates the effectiveness of several passive cooling strategies, and some of these are based on the radiative exchanges between the building and the cool sky during the night.

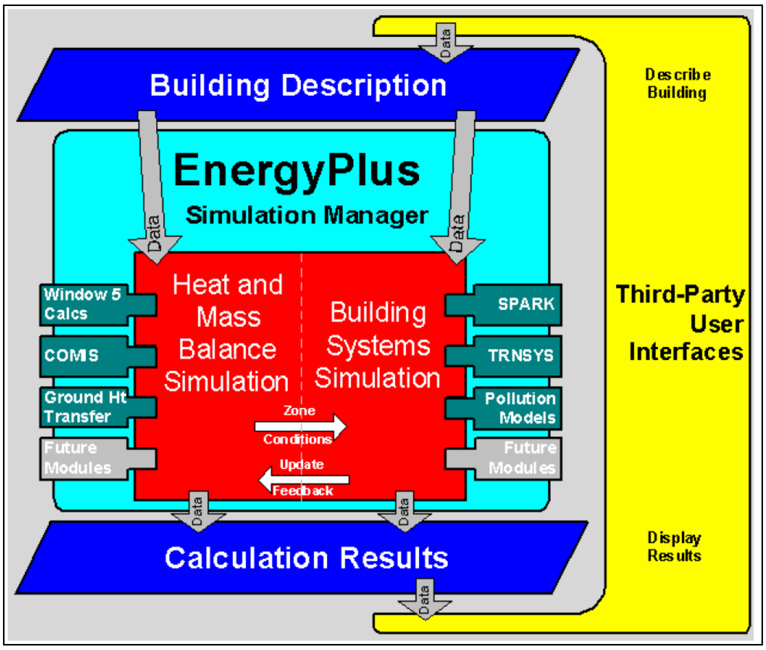



*Figure 2.4.2 – Structure, calculation modules and operative logic of EnergyPlus (source: Crawley et al. [69])*

EnergyPlus detailed the daylight models in order to provide, by means of a specific calculation section (*daylighting module*), the interior natural illuminance, glare phenomena through the windows, artificial lighting integration, possible and best controls, as well as the energy demands (and related thermal gains) due to the necessary artificial lighting integration.

In the recent releases of EnergyPlus (*starting by the version 2.0),* also another daylight module has been provided, and this is based on the radiosity interreflection calculation methods. This new module has been implemented in order to evaluate the daylight also in case of complex windows and transparent surface systems, characterized by transmission multi-directional phenomena.

Furthermore, the last versions include more flexible system modelling, multi-zone airflow systems, three different comfort models (*also based on the new ASHRAE adaptative criteria*). According to Crawley et al., [69] in figure 2.4.2 the overall EnergyPlus structure has been represented.

In the followings, a brief description of the three main sections of this code (*the simulation manager, the heat balance simulation manager and the system simulation manage*r) is reported.

SIMULATION MANAGER. This tool consists in the super-visor section of the numerical code, providing and controlling the interactions among the other simulation tools at the same time step (*hourly or sub-hourly*) and regarding the whole simulation periods. This module manages the solver activities too, providing and managing the input boundary conditions as well as the output data.

HEAT AND MASS BALANCE. This module provides the building thermal zone calculation, assuming that, with reference to each thermal zone, the indoor air can be considered at a uniform temperature level (*i.e. zero-dimensional hypothesis*). Drury B. Crawley, one of the main developers of E+, underlines that "*although this does not reflect physical reality well, the only current alternative is computational fluid dynamics (CFD) — a complex and computationally intensive simulation of fluid (in this case, air) movement*" [72]. In this Thesis (Chapter 5) also this coupling among BEPS and CFD has been carried out, according to the method described in the following of this paragraph.

Another assumption, as regards the heat balance models, consists in the hypothesis that the room surfaces (*i.e. walls, windows, ceilings and floors*) have uniform thermal levels and are interested by the same long and short-wave irradiation and one dimensional heat conduction.

The surface heat balance module simulates the inside and outside surface heat balances, determining continuous interconnections between heat balances and boundary conditions. In the resolution algorithm (*by means of onduction transfer functions or calculation methodologies based on the finite differences*), conduction, convection, radiation, and mass transfer effects are considered; the air mass balance module considers also air mass flows (*ventilation, exhaust and infiltration ai*r). This module, during the calculations, estimates the heat storage and the role of the thermal mass, computing also all direct convective heat gains.

As shown in figure 2.4.2, the heat and mass balance module works implementing various calculation tools, already above cited:

- Comis: multi-zone airflow, infiltration, contaminant and ventilation calculations;
- Window 5: fenestration calculation tools, anisotropic sky module;

- Daylighting module: interior daylight illuminance, window glare and glare control coupled with electric lighting controls;
- Ground Heat Transfer: module for the calculation of the temperature profile under the soil and the evaluation of the ground potential in preheating and pre-cooling; this module has been better described in the Chapter 4.

All these modules make possible, besides an integrated calculation, the evaluation and simulation of several technical solutions. For example, the calculation module *Window 5* provides the handling of several complex transparent systems, such as shadings, blinds, sun controls, movable interior and exterior window shades and electro-chromic glazing, with accurate solver modules for transmission and absorption of the solar/visible radiation, and considering temperature-dependent U-values. Also the sky model is very well built, providing, as described in the Chapter 4, information regarding sun position and cloud covers, including non-isotropic radiance and luminance distribution. This non-uniform radiance distribution permits accurate calculation of diffuse solar radiation interesting each kind of sun-exposed building surfaces.

BUILDING SYSTEM SIMULATION MANAGER. The heat and mass balance module, such as before described, transmits the results of a time-step simulation to the building systems simulation manager; this, then, controls the calculation of HVAC and electrical systems with reference to the same temporary range, updating the zone conditions as regards the microclimatic indoor control (*figure 2.4.3*). The results are again transmitted to the heat and mass balance module, so that the HVAC effects can be computed within the next zone energy balances.

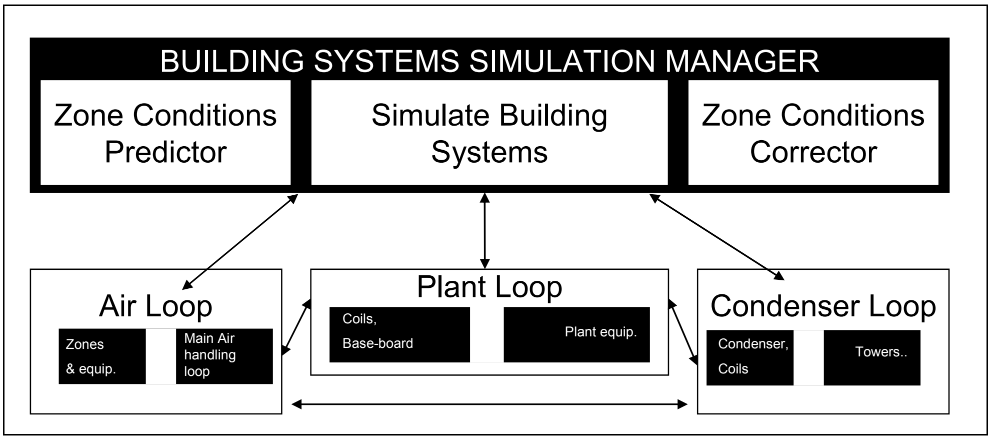



*Figure 2.4.3 – Operation and interrelation of the building systems simulation manager*

This section represents one the best features and peculiarities of E+: it consists into a non-sequential simulation method (*first building loads, then air distribution system, and then central plant*), that instead characterizes all the previous building energy simulation engines (*DOE-2 and BLAST*). On the contrary, EnergyPlus makes possible a full-integrated simulation of loads, systems, and energy active devices.

As regards the HVAC solutions, besides several available typical configurations, the user can manage and develop new kinds, adding or removing specific equipments. About the HVAC calculation, as before cited, two loops are provided: air loop and water loop. The air loop simulates the air transport phenomena, the air-conditioning and the conditioned air supply and return by means of fans, the central heating and cooling, the devices for the heat recovery and outside air economizer. Several zone equipments are provided, such as diffusers, re-heating and re-cooling coils, mixing dampers, VAV box, local units (*fan coils, window air-conditioner, higher temperature radiant/convective units, low temperature radiant panels*). More than one equipment type can be specified for the same zone. As regards the air-loop, the solution method is iterative; in this logic, all the loop components are contemporarily simulated and then the control equations are updated by means of explicit finite differences. This procedure continues until the obtainment of the convergence of the results.

About the waterside, two loops are provided with reference to the HVAC hydronic equipments: a primary loop for supply devices (*boilers, chillers, thermal storage unit and heat pumps)*; a secondary loop for the heat rejection devices, such as condensers and cooling/evaporative towers. The connections among the air loop, the zone equipment and the primary-secondary loops are achieved through a node system, managed by the building system simulation module and explicitly defined in the input file.

Finally, as regards the prospective offered by E+, one of the best characteristics of this engine consists into the possibility of adding new features and modules, with a quite extended flexibility. New model can be added, implementing new physical solvers and inserting these into the cyclic structures, in order to extend the tool routines. About this flexibility, the last versions of the code (*used in the simulations carried out as regards several kinds of buildings and reported in the Chapters 4 and 5*), contains improvements as regards:

- the reliable integrated simultaneous solution algorithms, whit sub-hourly time steps in order to provide energy and mass balances both with reference to the building envelope and to the HVAC;
- simultaneous calculation of radiant and convective effects, for both the interior and exterior surfaces, during each time step;
- transient heat conduction through building elements;
- improved ground heat transfer modelling;
- combined heat and mass transfer model, anisotropic sky model and advanced fenestration calculations;
- daylighting controls including interior illuminance calculations;
- loop based configurable HVAC systems and atmospheric pollution calculations.

Many of these new potentialities have been used for the studies reported in the following chapters.

Presently EnergyPlus results one of the most apt code in order to evaluate building and air-conditioning system performances, both as regards the achievable microclimatic conditions and the energy requests. Of course, all the results are referred to a single node that represents the whole thermal zone (*zero-dimensional approach*). Thus, when an analysis based not on the time but in the "*spatial domain*" is required, the use of CFD instrument remains the only one analysis method for a reliable simulation.

### 2.4.2 THE CFD – COMPUTATIONAL FLUID DYNAMIC ANALYSES

Operating CFD (*Computational Fluid Dynamics*) analyses, it is possible forecasting the performances of mechanical ventilation systems, with the aim to estimate the active equipment effectiveness as regards the distribution of the supply and conditioned air into the indoor environment. The CFD codes offer detailed forecasts regarding the phenomena interesting the conditioned spaces in a fixed temporary moment, concurring to understand the kinetic fields inside the indoor environment, temperature and moisture distributions, as well as the spatial trend of each other parameters that concur in the determination of the microclimate and the thermal-hygrometric comfort.

The obtainment of these results requires significant computational sources, not only as regards the creation of the simulation model, but mainly for the resolution of the complex system of equations; thus, as regards the air-conditioning applications, the use of the CFD is usually limited to the analyses of single rooms, under steady state conditions.

The use of computational fluid-dynamic engines begins in the early '70$^{th}$ years, when the first attention to the air diffusion performances in the air-conditioning has been posed. Recently, new impulses around the improvements of this kind of analyses for air-conditioning problems have been made, in order to render the CFD a reliable calculation tool in order to estimate the aspects related to the thermal-hygrometric comfort [73] and to investigate the IAQ (*i.e. indoor air quality*). CFD analysis can be used for a microscopic examination of the building, resolving the equations of Navier-Stokes in order to obtain information detailed on the kinetic, thermal and hygrometric fields related to the indoor air thermal-dynamic states, as well as the investigation of the airflows and the distribution / concentration of the pollutants into the indoor environment.

Today (*Autumn 2009*), various codes are available, and more and more powerful applications are constantly in phase of development. About this, at least a satisfactory knowledge of the mathematical structure of the code, as well as the knowledge of the modelled indoor environment, are necessary, in order to reduce the errors related to a numerical resolution and for the reduction of the computational costs.

An apt modelling begins with a planning regarding the targets of the study, as well as the available resources and information; when existing buildings are modelled, experimental measures can significantly improve the simulation reliability.

The CFD modelling is particularly useful when known and unknown elements are combined, as, for example, during the simulation of existing and known building behaviours under hypothetic circumstances (*e.g. in order to evaluate the building behaviour in case of fire).* Also in hypothetical buildings (*e.g. during the design phase*), the knowledge acquired through a good CFD investigation can be precious for eventual improvements [74].

Quantitatively, the CFD analysis gives information about the thermal and fluid-dynamic phenomena characterizing an indoor environment; the conceptual model interprets a specific problem through a mathematical model based on conservation principles and relative boundary conditions. The equations that govern the phenomenon remain the same for all the applications of airflows and heat exchange, but the boundary conditions change with reference to the specific situation (*for example, the disposition and the characteristics of the room can be different, as well as the velocity of the supplied air*).

Often the physical phenomenon resolutions are complicated by further occurring heat fluxes (*conduction through the walls, contributions of thermal energy released by inner sources, solar radiation entering through the windows*), phase changes (*air vapour condensation and mechanical water evaporation*), chemical reactions (*combustion*) and mechanical movements (*use of fans, movements of the occupants*).

The CFD resolution consists in a complex solving procedures of sets of partial differential equations, which have to be resolved simultaneously or successively. There are not available analytic solutions. Numerical procedures, aided by computer solver, are the only one way in order to obtain complete solutions for the established equation sets.

A CFD code consists in a numerical procedure for the resolution of the equations that govern the physical phenomena, and this instrument can be usefully used to solve the field of motion of a fluid, the energy exchange in form of thermal energy, as well as the resolution of chemical reactions and thermal stresses. As understandable, the CFD potentialities are very high when applied in order to verify the performance of the building–air-conditioning system, with several advantages, among which:

- reduction of experimental studies and prototyping;
- definition of an only one model on which carrying out several analyses (on varying the design conditions);
- simple visualization of the results.

The prediction of the microclimatic parameter distributions (*the thermal-hygrometric and cinematic ones)* results very useful because it provides the evaluation of effectiveness, as regards the microclimatic control, of the installed air-conditioning system. In particular, this kind of analysis regards the HVAC capability in creating comfort conditions, for the people *(Chapters 3 and 4 of this Thesis*) and, for example, also for the cultural Heritage (*Chapter 5*). In the followings, some words, as regards the mathematical model on which the CFD studies are based, will be spent.

The air-conditioned indoor environments are usually interested by quite turbulent airflows, characterized by causality, diffusivity and energy dissipation. The turbulence is not a property of the fluid (*like, for example, the viscosity and the thermal conductivity*), but it is related to the motion characteristics of the airflows.

The conservation equations for the mass, momentum and energy (*equations of Navier-Stokes*) govern the behaviours of airflows, the convective heat exchanges and the distribution of contaminants. These conservation laws can be express in terms of partial differential equations, non-linear and coupled. With reference to a generic a variable φ, the relative conservation equation can be written (equation 36 [74]):

$$\frac{\partial}{\partial t}(\rho\phi)+\frac{\partial}{\partial x_j}(\rho U_j\phi)=\frac{\partial}{\partial x_j}\left(\Gamma_\phi\frac{\partial\phi}{\partial x_j}\right)+S_\phi \tag{36}$$

where the following terms are present:

- t = time
- ρ = air density;
- φ = transport property (*e.g. air velocity, temperature, contaminant concentration*);

- $x_j$ = distance relative to the j direction;
- $U_j$ = speed component referred to the j direction;
- $\Gamma_\varphi$ = diffusion coefficient;

In case of non-compressible fluids, it is possible to decompose the dependent variables in the sum of a temporal averaged value with a related excursion. Reynolds introduced this kind of procedure and, in this case, it is called approach of Navier-Stokes mediated according to Reynolds [74].

In order to achieve a resolution of the procedure, it is necessary that the values assumed by the variable are known in a first moment, assumed as the initial one. Moreover, on the borders of the calculation domain, the conditions apt to represent the interactions between field of motion and surrounding environment have to be assigned.

The CFD calculation model is based on a numerical procedure that solves the cited equations, by means of a mathematical discretization adopting procedures used in several other engineering fields (*e.g. the structural or aeronautic engineering*), defined the "finite elements"; this discretization process consists in the division of the domain in many elementary control volumes. The necessity to adopt a numerical technique is connected to the impossibility in solving directly the differential equation set characterizing the flow regime within the rooms, so that these are converted in a finite group of algebraic relations, formulated with reference to each point of the calculation grill, such as represented in figure 2.4.4.

In the resolution of the mathematical problem, such as carried out by the CFD simulator, the Boussinesq approximation is used; this ignores the effects induced by the pressure on the air density, being the flow influenced from hydrostatic motion in some zones of the domain. The air is considered as an ideal gas and the buoyancy forces are treated as a generation term. This approach determines a series of simplifications, without modifying the nature of the physical phenomenon, even if it does not result apt in order to solve the created system of equations.

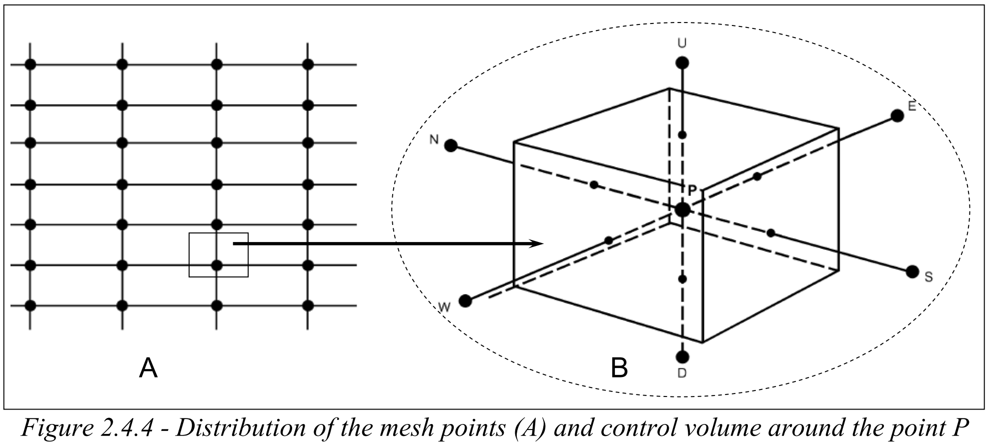


*Figure 2.4.4 - Distribution of the mesh points (A) and control volume around the point P*

One of the more used model, defined in order to solve the turbulence, is the "*two equations k-ε*" standard, that introduces others two equations relative to the turbulent kinetic energy (k) and its dissipation rate (ε). The turbulence model *k-ε* is valid only for turbulent flow when completely developed. About this, usually the airflows inside a room are not everywhere characterized by high Reynolds numbers, because the flows are not completely developed everywhere. Despite this, experimental and numerical comparisons confirm that quite good results are obtainable adopting the k-ε model also in the room areas characterized by lower level of turbulence.

On the other hand, the Launder-Sharma model can calculate the effects of a low turbulence (*near walls and room envelopes*) with low Reynolds numbers [75]. More elaborated models, like the Reynolds stresses, can also be used for the turbulence determination. This last cited model, improving the standard k-ε, includes additional transport equations and makes possible the evaluation of the anisotropic effects of the turbulence. Generally, even if the Reynolds stresses model gives better results than the standard k-ε, these improvements are not always significant, especially as regards the air velocity fluctuations. Instead, with reference to the mean velocities and the temperature profiles, the analyses carried out adopting this model provides better results, when compared when the experimental data, with respect to the model k-ε [74].

THE MESH CONSTRUCTION. The first step in a CFD simulation is the grid definition, because this represents the computational domain. The indoor environment is divided in a great number of small regions called "*cells*", and the equations governing the heat exchange and the flow are solved with reference to these basilar volumes. The whole set of cells is called mesh or grid. More detailed is the mesh construction, better will be the achievable simulation results. Often, as regards the mesh definitions, the following common mistakes occur:

- mesh too much approximate: the simulation results are not accurate;
- mesh too much detailed: expensive computational costs are required, both in terms of calculation time and sources.

Sometimes both these events occur in the same computational domain. In this case, frequently the simulation does not converge. Therefore, costs and reliability of the CFD results are strongly related to the grid quality.

The grids can be structured or not, depending on the connectivity among the contiguous cells. The shape of the cells can be selected among various options, and this determines different peculiarities, each one characterized by vantages and limitations. The most common cell shapes are the classical triangular o quadratic ones, typical for bi-dimensional geometries, and those tetrahedral and hexahedral for three-dimensional geometries. The most important characteristics for a satisfactory mesh are described in the followings.

- high cell density where the temperature and the air velocity gradients can be elevated;
- the expansion ratio between a cell and the contiguous one should be maintained in the range 2 – 5 (*even if, in some critical areas of the computational domain, a lower value could be better*);
- equilateral cells are preferable.

In figure 2.4.5 [74], two examples of structured grids are reported. These meshes can be classified also as orthogonal or not. Orthogonal grids are based on systems of Cartesian orthogonal coordinate system; In this case, a curve profile is approximated by means of a boundary characterized by steps (figure 2.4.5.A). The modelling of inclined or curve surfaces can be carried out adopting the geometrical flexibility of non-orthogonal grids.

During the calculation resolution, the adoption of structured grids simplifies the CFD research of convergence, providing a regular geometry for the matrix of the algebraic equations.

The limit of the structured grids is the impossibility in describing very complex geometries.

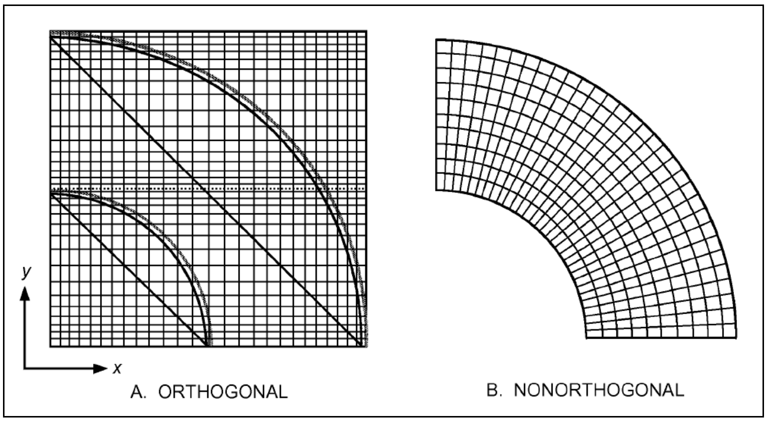



*Figure 2.4.5 – Structured grids orthogonal and not (source: ASHRAE [74])*

On the contrary, unstructured grids are very flexible and can be simply improved in particular regions of the mesh, without doing too complex the remaining part of the computational domain; in this case, various elements characterized by different shapes can be used (*figure 2.4.6*).

In figure 2.4.6-A, a non-structured grid with tetrahedral elements is represented, while in the graph B, a grid with thickened cells near the domain boundaries is realized in order to solve correctly the boundary layers. The quality of the grids can be measured by means of the cell shapes, the size of the single elements correlated to the characteristics of the investigated flow field and analysing the difference characterizing the size of the mesh passing from a domain block to another one.

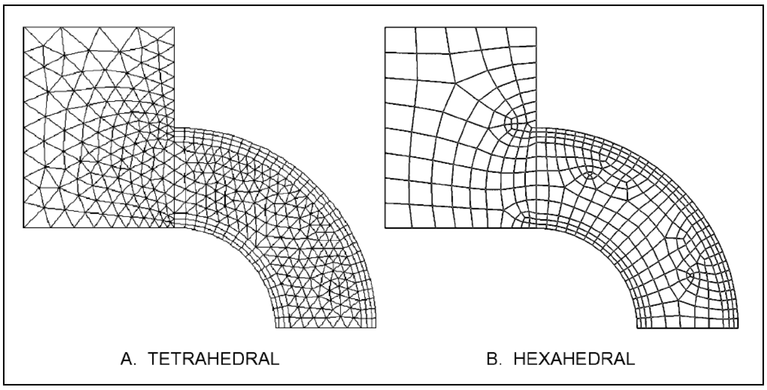



*Figure 2.4.6 - unstructured grid for the simulation of a two-dimensional flux (source: ASHRAE [74])*

The cells should be enough small to solve also the lowest characteristics of the computational domain; for example, when the cell size is too large, curvilinear elements cannot be represented accurately. As already cited, an accurate mesh is required near the domain boundary (*in proximity of the room envelope*), because in these regions high gradient of the investigated variables (temperature, humidity) can be present, and, in this situation, only a good computational grid can reliably solve the calculations.

Often, in the CFD studies applied to air-conditioning problems, a satisfactory solution consists in beginning with a coarse mesh, and then adding cells in the regions more problematic. In this, way, where no perturbation sources are present, the code can save computational sources. The most important verification regards the attention to the independence of the results with respect to the computational grid: *i.e., when the results of two simulations, carried out with different meshes, are comparable without significant differences, then both the grids can be considered satisfactory*.

THE MESH CONSTRUCTION. The assigned boundary conditions (*including the definition of the calculation grid*) are one of the most important aspects related to a CFD study; in fact, a good definition of the starting conditions influences the whole set of results, as well as the reliability of the CFD analysis. A correct definition of the boundary conditions is necessary to solve, properly, the Navier-Stokes equations and the turbulence field; through these, the fluid characteristics (*chemical and physical*) are specified, and these can be constant or variable during the whole simulation period (*i.e. when a transient analysis is carried out*).

The main part of the boundary conditions can be classified as Dirichlet or Neumann ones. An air flux on a free surface requires the definition of specific characteristics, classified as cinematic or dynamic boundary conditions [74]. Typical samples of boundary conditions required in the CFD analyses applied to air-conditioning problems are represented by:

- definition of the devices for the air-diffusion inside the indoor environment;
- room envelope definition and modelling of the surfaces inside the conditioned spaces;
- symmetrical surfaces;
- fixed parameters representing elements of generation or destruction.

In the followings, with reference to each one of the above-cited point, a brief description is reported.

<u>Air-diffusion equipments.</u> The air diffusers require a significant attention, because these, usually, represent the main source of momentum generation, and to this is related the fluid motions responsible of the temperature and moisture distributions, as well as the contaminant concentration. Typical parameters to define the air diffusers are: velocity, pressure and mass flow rate of the supplied air. In order to obtain an accurate simulation, also the turbulence values (*experimentally measured*) can be required.

Adopting the turbulence model k-ε, both the values of the kinetic turbulent energy and its velocity have to be assigned. When the absence of these parameters (empirically evaluated), occur, then physical correlations can be used to determine these.

The accuracy in the definition of the boundary conditions, modelling an air diffuser, is related to its complexity; often, the inclusion of very detailed information causes a complexity that induces no accurate results. Therefore, the use of simplified diffusers is preferable.

Two main methods to model an air diffuser can be identified: <u>momentum method</u> and <u>box methods</u>. The first one assumes that the airflow can be evaluated applying the mathematical formulas of the air jet, using the performance parameters provided by the constructor (*volumetric flow rate, launch, end velocity*) and assuring that the airflow will enter into the room with an adequate value of momentum. This method decouples momentum and mass boundary conditions for the diffuser [74]. Otherwise, the box method doesn't model explicitly the jet behaviour (*near the diffuser*) but, on the contrary, it specifies the conditions on the sides of a rectangular region, adjacent to the diffuser, requiring only the definitions of the velocity profiles (*for example, such reported by the diffuser catalogues*).

Extractions equipments. Exhaust fans, extractors and grilles can be modelled defining the mass flow rate of the extracted air or by means the definition of a constant working pressure; starting by such information, the exiting air velocity is determined. Actually, the evaluated velocity requires correction during the simulation solving, in order to satisfy the principle of the mass conservation during the time and with reference to the analysed domain.

Room envelope definition. Walls and their inside surfaces define the limits of the modelled environment. The velocities are posed equal to zero when fixed walls are considered (*the most frequent case*); otherwise, for a movable wall (*when it can move into a plane*), the fluid in contact with its surface is interested by a carryover, induced by the friction generated between the ambient air and the wall surface [76]. This last one is an example of Dirichlet boundary condition. Both for the laminar and turbulent regimes, the roughness of the surface has to be properly defined, because it influences the kinetic field of the air near the wall surfaces and, therefore, the heat exchange.

Symmetric surfaces. The symmetry boundary conditions must be used carefully. In fact, even if the geometry of the model results symmetric, this doesn't means that the airflow presents symmetric characteristics compared to the same plane. An example of this situation is represented in figure 2.4.7, provided by [74], where the represented duct is symmetric with reference to the plane AA', but the same thing cannot be transferred to the fluid, because the mixing region of the two flows results unstable.

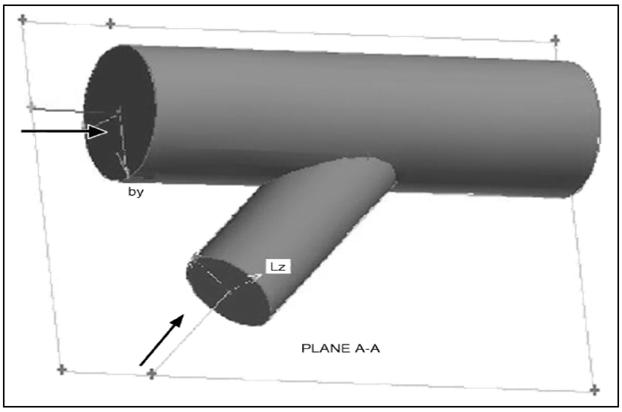



*Figure 2.4.7 – Channel with symmetric geometry respect to the plane AA'*
*(source: ASHRAE [74])*

Sources and Sinks of heat, momentum, mass and contaminants. Typical examples of these boundary conditions are the thermal fluxes induced by the walls and modelled in order to simulate the solar radiation, as well as the thermal flux induced by people, radiators and other sources of contaminants (*the people, the photocopy machines..*) or of momentum (*e.g. installed indoor fans*) [74]. These generation sources can be placed everywhere in the computational domain and the induced effects can vary during the time. The boundary conditions, through which modelling such sources, can be represented through fixed value that describes the source effect. Often, some elements placed within the environment (*furniture, obstacles for the air motions*) can be modelled as generation/destruction sources. It is important to underline that, often, the correct use of the boundary conditions consists in the best physical approximation of the real effect induced by a parameter. Thus, it can be easy understood that the user has to correct evaluate the aptness and the influence of these elements on the CFD simulation results.

SELECTION OF THE TURBULENCE MODEL. As above already cited, in order to solve a flow field, other equations (*closure problem*) must be assigned, besides those governing the specific fluid-dynamic phenomenon. These adding equations concur to define the turbulence model. Several considerations influence the selection of the turbulence model, but, generally, the best method is the one that joins solving simplicity and accuracy, so that the best compromise between computational sources and accuracy of the chosen model must be defined [77]. The following aspects concur to the selection of the most apt turbulence model:

- base hypotheses of the model and relative applicability limits;
- implementation possibility and computational complexity;
- achievable results and relative accuracy, based on the comparison of literature values compared to experimental studies.

In the typical CFD applications, the most common and used turbulence model is the standard two equations k-ε, where k represents the kinetic turbulent energy and ε defines its rate of dissipation. A group of London researchers initially proposed the k-ε; then the model evolved in several forms. The great spread and uses, after around 40 years, determined the knowledge of all the method vantages and defects. The capability of resolution of the flow field is very high, even if this model is not well apt in the wall region, in particular with reference to the viscous-conductive sub-layers. Its application, therefore, is not well apt when complicated flows should be simulated (when, for example, many surfaces and geometries are involved). In figure 2.4.8, it is represented the computational domain, in proximity of the wall, divided in a region characterized by a strong influence of the viscosity and in an other one in which the airflow can be considered as completely developed.

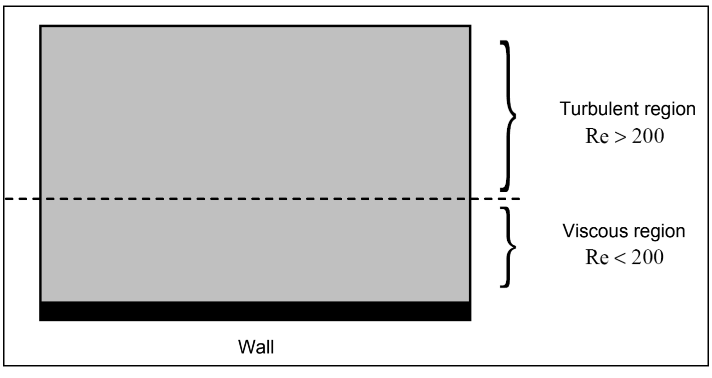



*Figure 2.4.8 – differentiation of the computational domain near the room wall (source: ASHRAE [74])*

In the last 35 years, the model k-ε has had various applications and today it is implemented in all the thermal-fluid-dynamic commercial codes developed to solve fluids in turbulent regimes. There are no doubts that, among the models based on temporal averages, the k-ε represents the better compromise among generality, accuracy of the result, implementation facility and computational stability.

At the present moment, a CFD code joined to a standard turbulence model k-ε, is the most accredited instrument for the numerical simulation of an airflow in a room. The model k-ε, however, turns out to be enough onerous in terms of computational resources and solving time. This event reduces significantly the applicability of such analysis method.

In order to obviate to this problem, other models of turbulence have been proposed during the last years, among which the zero-equation model [78]. This model considers no additional transport equations, making possible the resolution of the turbulent flow field without demanding an excessive calculation source, so that the obtainable calculation time is approximately ten times faster respect to the k-ε use. In fact, by means of the zero-equation model, the turbulent quantities are evaluated through algebraic equations much less complicated than the not linear interactions characterizing the k-ε; According to Chen and Xu [78]: "…*the method assumes turbulent viscosity to be a function of length-scale and local mean velocity…*".

It must be underlined that, in case of significant variability of the problem properties, the zero-equation model is not able to solve, in a correct way, the aspects related the turbulent heat exchange. Despite this, the zero-equation deserves careful attention, because it turns out simple, effective in terms of costs and, if well-calibrated, it gives very satisfactory results.

### 2.4.3 THE COUPLING OF DIFFERENT METHODOLOGIES

Integration between building energy performance simulation (BEPS) analyses and computational fluid-dynamic (CFD) simulations can be carried out in multiple ways, all based on two connection logics: static or dynamic (*both can operate more or less accurately, depending on the adopted integration strategy*) [79].

A stand-alone use of these codes (*i.e. BEPS and CFD*) can gives, in particular applications inherent in the air-conditioning, only partial information, not providing a full description of the problem. On the other hand, coupling the two instruments, the elimination of many hypotheses and imposed arbitrary boundary conditions becomes possible, implementing each simulation with the results supplied from the other and to this complementary.

For example, the connection strategies can be used in order to determine, simply, detailed boundary conditions to well-modelling the CFD studies, in order to supply more numerous indications regarding the conditioned building characteristics and thus making possible the calculation of more detailed and accurate results, as well as reliable forecasts.

The codes for the dynamic energy simulation (BEPS) operate analyses of the whole thermal zone, including the heating, cooling and ventilation systems, spatially averaging the environmental microclimatic conditions. The thermal hygrometric loads, the microclimatic conditions and the energy demands are therefore calculated with sub-hourly steps for a defined period of time, which can be extended from a single day to the whole year. On the other hand, the CFD codes describe the phenomena happening inside the indoor environment in a single moment, determining the knowledge of the events regarding the microclimatic comfort: *e.g. the radiant temperature of the walls, the air thermal level, the relative humidity, the speeds of the air and its quality in each point of the room*. These values of distribution can be used in order to determine the indices of thermal-hygrometric comfort (*predicted mean value PMV or the predicted percentage of dissatisfied PPD, mean age of air and so on…*) [80].

By means of the information deriving from a coupled analysis, energetic (*temporally dynamic but zero-dimensional*) and fluid-dynamic (*temporally static but three-dimensional*), a design of the building, effective as regards the energy requests and comfortable about the indoor conditions, can be planned. In particular, the limits of a simple energy simulation consist in:

- the assumption that the inner air is perfectly mixed (*imposing an improbable perfect uniformity of the environmental conditions*);
- approximate definitions of the thermal-loads, because the convective heat transfer coefficient cannot be accurately calculated (*lacking information regarding the indoor air motion*).

Thus, even if approximate and usually reliable correlations are used, a very accurate evaluation is not possible. This problem is solvable implementing, in the BEPS code, the data resulting by a CFD analysis that, on the other hand, is able to evaluate rightly the rigorous convection coefficient $h_c$.

The achievable advantages, derived by a coupled analysis, not only concur in limiting the approximations of both the studies, but these offer also new possibilities of analysis. For example, studying by means of the CFD code several air-diffusion and extraction solutions, with the aim of the research of the best techniques (*under the indoor comfort point of view*), in a second step, applying to the building a BEPS analysis, also the HVAC configurations that require the lowest energy demand can be chosen.

The two different analyses can be coupled through the convective heat exchange coefficient; substantially, the strategy of connection ES-CFD consists in the interaction between the equations 30, 31 and the equations 36 previously shown. BEPS supplies, as boundary condition for the CFD study, the thermal load that should be balanced, as well as the thermal levels of the surface delimiting the conditioned environment. Moreover, the CFD simulation calculates an accurate value of the internal convective heat transfer coefficient (characterizing the indoor surfaces). In this way, also the boundary conditions of a next energy dynamic simulation can be improved [79], fixing a more reliable value of $h_c$.

A direct coupling strategy consists in the transfer of the air temperature value and related $h_c$ to the BEPS code, implementing the equations 30 and 31 with the convective heat transfer coefficient evaluated by means of the CFD study. Then, following each CFD calculation, the BEPS code upgrades the thermal load calculation, providing to the CFD codes the new surface temperatures. Since the thermal fluxes and the surface temperatures vary in the time, it is necessary to carry out a CFD analysis for each BEPS time-step. Evidently, even if the interaction always converges (*and this is not always true*), the procedures is too much long and complex. The various procedures of integration between the codes will be in the followings briefly described by means of a flow charts. In figure 2.4.9, the operational logic of the codes is represented. This could erroneously induce the idea that the connection consists in this simple exchange of information between the programs, eventually reiterated until the obtainment of the required convergence. Actually, various difficulties are present, among which:

- different "time scale": BEPS is characterized by sub-hourly time-steps, while the CFD studies analyse what happens in a single moment, or few seconds [80];
- discontinuity in the modelling: the indoor conditions, such as analysed by BEPS programs, are averaged with respect to the space, while, on the contrary, a CFD code introduces a large field of variable spatial distribution [80];
- discontinuity of computational time: the times necessary to complete BEPS or CFD calculations are very different, being required a couple of minutes (*usually always less than one hour*) for an energy simulation while a CFD analysis requires, usually, at least 30 hours. At the same way, also the necessary computational sources are much more expensive for a CFD analysis compared to those required for a BEPS simulation [80].

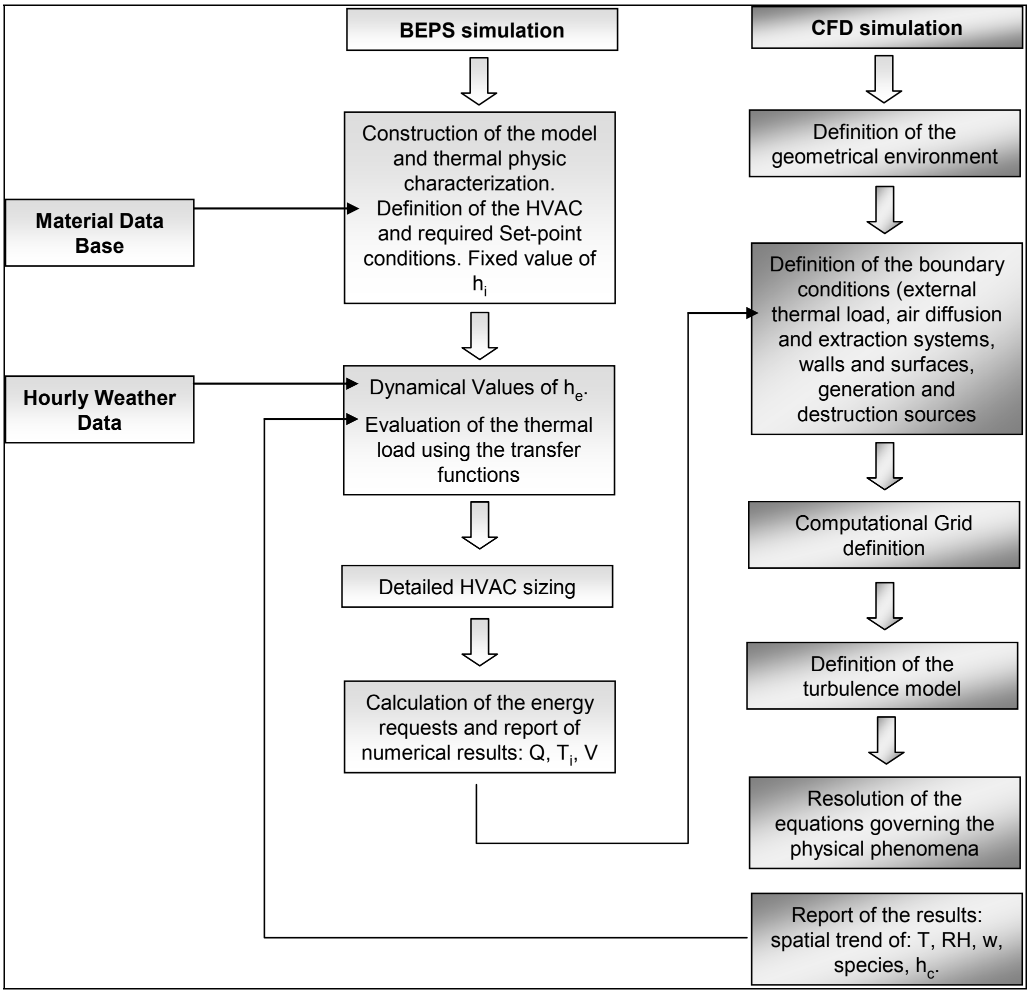



*Figure 2.4.9 – Flow charts of BEPS and CFD codes and coupling logic*

In order to solve these obstacles, special strategies of connection have been recently introduced. As regards the different time scale, the CFD analysis can be carried out only in critical moments of a specified day, such as described in figure 2.4.10. In this way, even if the correction of $h_c$ is not applied to any BEPS time-step, anyway, selecting the crucial instants, a better energy analysis can be obtained. This coupling strategy commonly is called "quasi-dynamic" [79]. Therefore, while the BEPS code evaluates, hourly and considering the whole year, all the thermal phenomena occurring during the day, the CFD simulator analyzes particular moments specified from the user (*figure 2.4.10*), upgrading the boundary conditions of the BEPS simulations as regards $h_c$.

For example, considering the first CFD simulation at 8.00 o'clock, until the following CFD analysis (at the 9.00 o'clock), the BEPS code will use the first fluid-dynamic simulation as regards the convective heat transfer coefficient. Of course, shorter are the CFD time steps, more accurate will be the BEPS results.

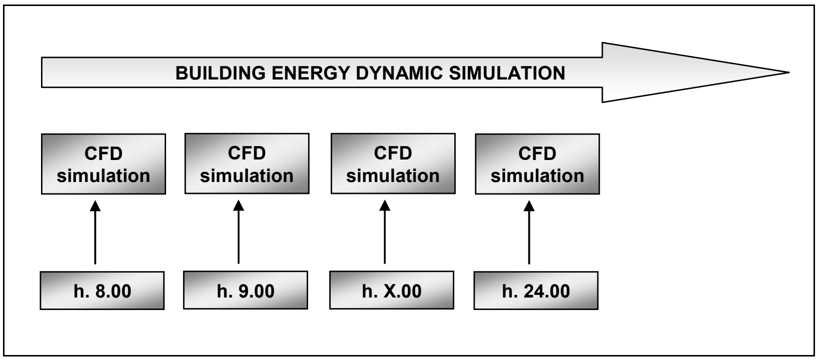



*Figure 2.4.10 – Coupling with respect to the time scale discontinuity*

As regards the modelling discontinuity, the computational domains are very different in the use of the two different codes. Therefore, numerical approximations should be used. Although several algorithms of numerical approximation can have different impacts on the result of the coupling (*depending on the kind of studied problems*), a good definition of the boundary conditions for both the simulations is necessary. For example, a good division of the BEPS domain in well-homogeneous thermal zones is necessary in order to achieve a CFD investigated $h_c$ well representative of the mean value interesting the room surfaces. Actually, this problem has not a rigorous solution, being the BEPS zero-dimensional and the CFD three-dimensional, so that, the averaging of the calculated $h_c$ (*in order to use an only one value*) represents a partially invalidating approximation.

Finally, with reference to the discontinuity of computational times and sources, as already explained, the use of simplify turbulence model, in order to simplify the CFD calculation, is necessary to realize effective strategies of connection.

STATIC AND DYNAMIC STRATEGIES OF CONNECTION: SOME NOTES. The value assumed by the convective heat transfer is important for both the energy simulation analyses and the computational fluid-dynamic ones. On one side, the BEPS code requires well-approximate value of $h_c$ and indoor air temperature T (*which can be calculated through CFD analysis*). On the other hand, the CFD code requires, as assigned condition, the inner surface temperatures estimated through the BEPS study. Therefore, the necessity of the BEPS-CFD coupling is due to an improvement of both their accuracy. In synthesis, it can be said that all it consists in continuous exchange of information regarding $h_c$, that, together with the indoor liminar air temperature, represents the key-factor for the determination of the convection heat transfer.

One of the used methods for the coupling consists in the transfer of the indoor air temperature (near the wall surface) and of the medium convective heat transfer coefficient to the energy simulation code, that, in this way, can estimate accurately the wall temperature. This information is then transmitted to the CFD simulator, that will repeat the calculations and supply new results to the BEPS code. This interactive process will work until a convergence around $h_c$ is achieved.

A dynamic process executes a continuous exchange of information between CFD and BEPS, while a static one provides only few interactions. Actually, no commercial codes do this continuous exchange of information, even if some of them operate, for the same building, both the analyses (*anyway both carried out "separately"*).

In this Thesis, in particular in the Chapter 5, the only one applicable strategy of connection has been tested: Operating with separated codes BEPS and CFD, the some integrations have been realized, by means of a manual transfer of information each other. In this way, a continuous implementation (input/outputs) of both the simulations has been carried out.

A static connection makes possible, according to the technical literature [80, 81], good results when one of the two programs or both are not so sensitive to the exchanged variables, so that, exchanging the information, no large variations result and thus the time steps can be enlarged. An approach of this type can be improved, if the result confirms real benefits, with repeated static passages between the codes (figure 2.4.11).

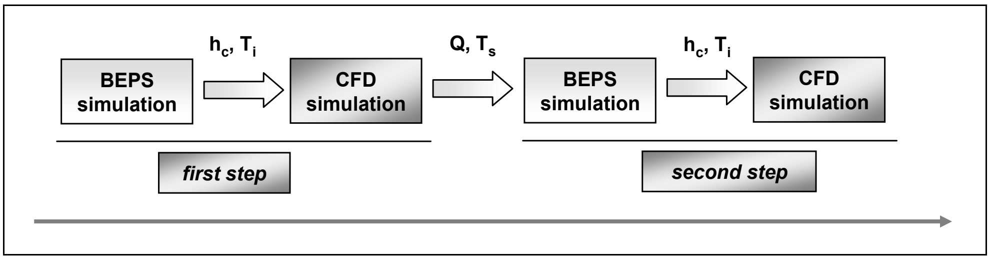



*Figure 2.4.11 – Quasi-dynamic coupling, by means of static interactions [source: 80]*

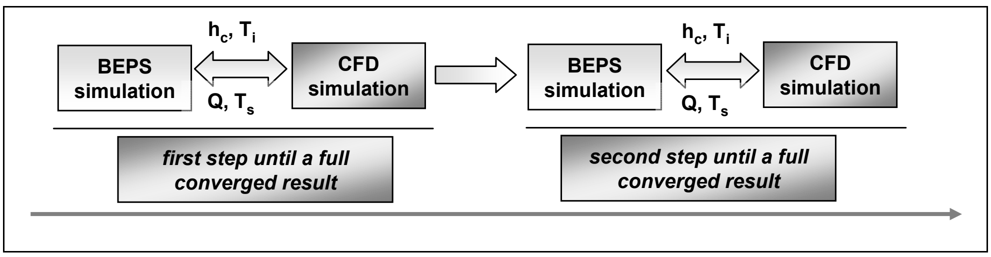



*Figure 2.4.11 – Full dynamic coupling between BEPS and CFD (few time steps possible) [80]*

A dynamic, realizable connection (figure 2.4.12), on the other hand, can be applied only using full-integrated codes that, in the same time, operate and correct BEPS and CFD analyses. For each time step, the iterations continue until a full convergence is achieved. This approach, presently, is only in a first phase of development, characterized by very limited applicability.

Furthermore, several literature sources describe a real usefulness of this method only in the studying of circumscribed and very specific problems, with reference to an only one scene (*e.g. inner comfort or thermal load in a well-specified moment*), with an analysis period not too extended.

Finally, a last method, fit to guarantee an integrated analysis similar to full dynamic one, consists in the estimation of the indoor temperature near the surfaces and of the convective heat transfer coefficient as functions of the thermal loads. In this way, adopting this virtually dynamic approach, only few typological steps are fully dynamically resolved while the other ones adopt pre-calculated values.

Summarizing, each coupling strategy presents advantages and difficulties, related to the accuracy of the achievable results or to the costs in terms of computational sources. As regards each coupling modality, the target is the research of computational convergence and the result stability, with problems related to the numerical and physical differences between the two used engines.

Generally, the characteristics of the building and the scope of the simulation provide advices on the best adoptable connection strategy [79, 80, 81, 82]. For example, a virtually dynamic coupling could be apt for an analysis extended to a whole year, while a dynamic connection turns out more apt in order to estimate thermal comfort and air quality in a well-specified moment.

In order to go in more depth study, all the papers and researches carried out by Z. Zhai and Q. Chen [79, 80, 81, 82] can be consulted.

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# Chapter 3:

# The energy efficiency of Italian dwellings: energy performance evaluation and light cost improvements

## 3.1 REASONS AND PURPOSES OF THE STUDY

The European Directive 2002/91/CE EPBD has been transposed, into the Italian Legislation, starting by the emanation of the Legislative Decrees 192/2005 and 311/2006. As exhaustively described in the 1st chapter, in the following years, further legal measures have been enacted in order to extend and fully transpose the new international trends; about these, the most important ones are the Italian Presidential Decree 59/2009 [1] and the recent National Guidelines for the Energy Certification of Buildings (Italian Ministerial Decree 26 June 2009 [2]). Thus, at the present moment (Autumn 2009), the national legislation regarding the building energy efficiency is almost complete, lacking only not-primary aspects related to the qualification criteria for the energy certifiers of the buildings.

The contents of the above-cited measures have been already presented in the previous chapters. In the following paragraphs, the effectiveness of these measures will be investigated starting by the numerical applications of the new prescriptions and evaluating their effectiveness in terms of limitation of the energy requirements, with reference to both the climatic seasons. Several and different studies will be presented: the target is a critical analysis of some aspects of the new legislations.

Starting from the Law 373/76, the Italian energy legislation does not followed linear evolution, creating overlaps of provisions and cross-references to following decrees too late implemented or never emanated, so that it determined confusions and often absence of well-defined regulations. The effects of the present regulations are in this chapter finally evaluated, proposing a critical reading of the legislative state of art, as regards the technical evaluations of the main new aspects, related to the new prescriptions and calculation methodologies provided in the new emanated technical standards already described.

In the followings, new and numerous elements of innovation will be described and analyzed, evidencing positive effectiveness and also, sometimes, some inconsistencies and uncertainties. These last, newly, could reduce the usefulness of these new and necessary provisions and dispositions, related to the present international and national future of sustainability as regards an efficient energy. Therefore, in the following pages, with reference to the calculation of the energy performance indexes for residential buildings, these methodologies are tested in their critical aspects, with deepening regarding both methods and contents.

All the studies (*some referred to new buildings and other regarding existing residential architectures*) are based on the quantitative results obtained by means of numerical analyses, contemplating both the energy performances of building envelope and the efficiencies of common heating and cooling systems.

The topics related to the international agreements against the climate changes, world atmosphere pollution and global warming became worldwide spread starting from the Kyoto conference (1997) and, still today, are subjects of future conferences (*among which the ONU Copenhagen meeting established for the December 2009*). The $CO_2$ emission reductions represent only one side of the problem. In fact, on the other hand, the cost of energy and the difficulty in the foreign provisions represent other key-points of the question.

About this, as it can be easily seen in table III.1, the Italian situation is quite critical, with a very a high dependence by foreign Nations as regards the energy sources. It determines a loss of the global competiveness due to the higher cost of the energy (*that influences the costs of the Italian industry and manufactures*) and also determines risks related to the often-faltering provisions.

Table III.1: Energy dependence of Italy grouping energy sources and vector [3]

| | 1990 | 1995 | 2000 | 2004 | 2005 |
|---|---|---|---|---|---|
| Solid Fuels | 91.6 | 90.7 | 88.1 | 82.6 | 82.1 |
| Natural Gas | 64.4 | 63.4 | 77.5 | 83.8 | 85.8 |
| Oil | 95.1 | 94.5 | 95.1 | 93.9 | 92.8 |
| Electric Energy Primary | 14.1 | 13.9 | 14.8 | 14.8 | 16.1 |
| Total | 82.8 | 80.9 | 83.8 | 84.3 | 85.1 |
| *The data are expressed in percentage* | | | | | |

In the last years, the frequent diplomatic crises between Russia and Ukraine submit the whole Europe and, first of all, the Italy, to serious risk regarding the provisions of natural gas. The great development and the high request of oil in China, India, Russia and Middle East (*that absorb around 83% of the increase of the demand*) determined a further cause of risk for the European provisions. Furthermore, the perennial political instability in Middle East, the precarious extraction in the delta of the Niger, the Iraqi conflict and the Iranian tensions, as well as the worldwide economical crisis of the last two years, do very unstable the oil prices, so that it vary very strongly during the last period (table III.2).

Table III.2: Unitary cost of the Oil Drum, in U.S. dollars, during the last ten years [4]

| | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
|---|---|---|---|---|---|---|---|---|---|---|
| Cost of the Oil Drum ($) | 32.5 | 26.5 | 26.7 | 30.7 | 38.6 | 52.8 | 62.9 | 71.3 | 150* | 72** |
| * *the data expresses the peak value reached during the 2008 summer* | | | | | | | | | | |
| ** *the data are referred to the oil price during the 1st week of September 2009* | | | | | | | | | | |

The Italian situation is so unstable that, also a sudden and quite banal event as the fall out of a three on the Swiss electrical net determined, on 28th September 2003, a total black-out that deprived of electrical energy the whole Nation for around 15 hours. Presently, the Italy depends for almost the 85% of its overall energy need by foreign nations (*15% the direct importation of electric energy*), so that the lack of autonomy lays on risk the national development.

Without describing each aspect of the present legislation (*already completely defined in the Chapter 1 as regards the main contents, and in the Chapter 2 with reference to the calculation methodologies provided by the new standards UNI TS 11300*), in the followings some aspects of the new mandatory procedures will be described quantitatively. Several studies are proposed, regarding the effectiveness or uselessness of some prescriptions and evaluating some lightweight possible improvements both as regards the legal measures and with reference to the building/active system performances.

The scope of the analyses is the proposition of improvements regarding the most innovative aspects of the present state of art. Only some topics have been investigated, those considered the most significant. The proposed observations, referred to the calculation methodologies of the energy performance indexes and legal values of these, are always supported with quantitative results, obtained by means of numerical analyses (*dynamic energy simulations [5]*) extended to the whole integrated system building/air-conditioning plant.

The innovative aspects of the new procedural measures presently into force, as well as some unsolved nodes, will be investigated, evidencing the criticalities of some prescriptions or calculation methods. About this, a first notation regards the level of complexity, often not harmonic and homogenous, so that the procedures result sometimes extremely complex or, on the other hand, too simplified.

Although the legislative frame is quite complete, the hurdles to overcome are still multiple and, in this study, only some of these could be analyzed, equipping simulations and comments with improvable proposals, studied and suggested in order to simplify or rationalize some key-aspects.

The studies have been carried out by means of numerical energetic analysis, solving the building-active system energy balances with the method of the transfer functions or, whereby necessary, with numerical methods based on the finite difference algorithms.

The used calculation codes have been selected among those more accredited at the international scientific community - e.g. EnergyPlus [5] - or self-developed implementing the procedures of calculation derived from the new sets of international technical standards.

## 3.2 THE BUILDING ENVELOPE: THE EFFECT OF THE TRANSPARENT SURFACE ON THE HEATING ENERGY DEMAND

The Legislative Decree 192/2005 (paragraph 6 of the Annex I) and the Presidential Decree 59/2009 (paragraph 8 of the Article 4) admit, when the global building envelope transparent surface / useful (net) area ratio results < 0.18, a simplified verification procedure instead of the EP index (described in the previous chapters) calculation. The EP index represents the primary energy need of the integrated system building-active energy plant, calculated with reference to the wintertime and referred to a unitary building surface. The simplification provided by the laws consists into the omission of the EP index calculation; in particular, the maximum admitted value would be conventionally considered.

From this approach it can be deduced that the windows, and generally all the transparent surfaces, are considered element of weakness of the building shell, so that, if the proposed limits are respected (as regards low window quantities), the law admits different and much easier evaluation procedures regarding the winter energy performance.

This approach of the Italian Legislator, as regards the role played by the windows, was already clear in the previous law drafts (not definitively enacted) developed to implement the first version of the Decree 192. In fact, in these draft documents, even absolute maximum limits to the transparent surface were hypothetically fixed, establishing the following values to the ratio transparent envelope / opaque envelope:

- maximum 20% with reference to residential new buildings;
- maximum 50% with references to all the other new building typologies.

Fortunately, these prescriptions never have been officially enacted.

Presently, the easier verification, admitted when a ratio lower than 0.18 is achieved, such as established by the transient regime of the Decree 192/2005, has been confirmed in the final and definitive version of the prescriptions, such as reported by the Presidential Decree 59/2009.

With reference to this simplified procedure, the main disputable element consists into the negation of an approach based on the real achievable energy performances. In fact, the reasoning on which this norm is based, is "built" on a quite limitative simplification regarding the thermal performances of the transparent shell, based on the assumption that the glazed elements, compared to the opaque ones, are usually characterized by higher thermal transmittance values, and so are causes of higher winter energy requests. This reasoning is obviously valid when an energy balance is carried out evaluating the "*design conditions*", i.e. when, under a precautionary logic, all the positive contributes for the energy balances are neglected, and, among these, those due to the solar gains through the transparent surfaces. However, as regards the evaluation of the building energy efficiency (and so considering the whole winter period), this criterion (*correctly adopted for the sizing of the air-conditioning system, so that it can be sufficiently powerful also under critical operational conditions*) is wrong.

A correct evaluation of the transparent surface energy performances should consider, in wintertime too, the thermal gains due to the entering solar radiation, such as suggested by the recent international technical standards regarding the evaluation of the net energy demand of the building (aimed to a reliable evaluation of the space heating energy demand).

Of course, the solar gains are not indifferent with respect to the climatic region and, above all, with reference to the exposition of the transparent surfaces.

In the following analysis, the role played by the window as regards the winter energy request of the building has been investigated. By means of dynamic energy simulations, the energy fluxes interesting this part of the building envelope have been calculated. The transparent building envelope has been modelled with characteristics (*as regards the thermal transmittance value "U" and solar transmission factor "g"*) that induce a full respect of the present energy legislation.

The energy simulations have been carried out in 5 Italian climatic zones, (o*mitting, considering its scarce extension, a study concerning the climatic zone A*), adopting the hourly-based IWEC - International Weather Data for Energy Calculation [6] of an Italian city included in each cited climatic area. In particular, the climatic regions and the considered cities are:

- Italian Climatic Zone B → Catania: 833 degrees-day, heating period from 1st December to 31st March;
- Italian Climatic Zone C → Naples: 1034 degrees-day, heating period from 15th November to 31st March;
- Italian Climatic Zone D → Rome: 1415 degrees-day, heating period from 1st November to 15th April;
- Italian Climatic Zone E → Milan: 2404 degrees-day, heating period from 15th October to 15th April;
- Italian Climatic Zone F → Tarvisio: 3959 degrees-day, heating period from 5th October to 22nd April.

With reference to each analysed city, not shaded windows have been modelled; these are characterized by thermal transmittance values respectful of the limits imposed by the present Italian energy legislation (*Legislative Decree 192/2005, Annex C*), such as reported in the table III.3. Then, on varying the exposition of these windows, thermal losses, solar gains and global energy balances have been evaluated.

It is important to underline that, as regards the modelled windows, besides a modelling respectful of appropriate thermal transmittance values, also the lower solar thermal transmittance that characterizes double and triple glazed systems has been taken into account, on the basis of the characteristics of glasses, frames and considering different gasses filling the air-gaps. About this last point, the achieved (*i.e. modelled*) $g_{values}$ are quite similar to those reported by the UNI TS 11300 [7] Italian technical standard (table III.4).

Table III.3: $U_{LIMIT}$ and $U_{MODEL}$

| | $U_{LIMIT\ (2010)}$ | $U_{MODEL}$ |
|---|---|---|
| | W / m$^2$ K | W / m$^2$ K |
| Climatic Zone B | 3.0 | 2.9 |
| Climatic Zone C | 2.6 | 2.6 |
| Climatic Zone D | 2.4 | 2.2 |
| Climatic Zone E | 2.2 | 2.1 |
| Climatic Zone F | 2.0 | 1.9 |

Table III.4: solar transmission factor “g” [7]

| Kind of glass | $g_{gl,n}$ |
|---|---|
| Single Glass | 0,85 |
| Double Glass | 0,75 |
| Double Glass (one low-emissive) | 0,67 |
| Triple Glass | 0,70 |
| Triple Glass (two low-emissive) | 0,50 |
| Double window | 0,75 |

With reference to the analysed localities, included in the climatic regions B, C and D, the obtained results show interesting trends. In fact, as reported in the table III.5, the analyses testify that, during the heating period (*defined in the Presidential Decree 412/93 and considered for the energy simulations*), only as regards the north-exposed windows the thermal losses result higher than the thermal free gains due to the solar radiation.

Table III.5: Energy losses and thermal gains, during the heating period, through a unitary window surface, modeled with characteristics respectful of the present legislation, on varying climatic zone and exposition

| | | | *north window* | *south window* | *west window* | *east window* | *mean value* |
|---|---|---|---|---|---|---|---|
| *Climatic Zone B* | *thermal losses* | *kWh/m$^2$ (heating period)* | 44.7 | 43.6 | 44.2 | 43.1 | 43.9 |
| | *solar gains* | | 31.9 | 120.0 | 58.6 | 57.5 | 67.0 |
| *Climatic Zone C* | *thermal losses* | | 50.9 | 49.7 | 50.4 | 49.7 | 50.2 |
| | *solar gains* | | 34.1 | 169.4 | 69.9 | 74.2 | 86.9 |
| *Climatic Zone D* | *thermal losses* | | 53.4 | 51.4 | 52.4 | 51.8 | 52.2 |
| | *solar gains* | | 35.7 | 202.9 | 89.7 | 87.3 | 103.9 |
| *Climatic Zone E* | *thermal losses* | | 88.6 | 86.0 | 87.8 | 86.6 | 87.2 |
| | *solar gains* | | 28.2 | 179.3 | 66.2 | 65.3 | 84.7 |
| *Climatic Zone F* | *thermal losses* | | 116.4 | 110.3 | 113.5 | 111.9 | 11.0 |
| | *solar gains* | | 26.9 | 131.0 | 56.0 | 54.7 | 67.2 |

*Sic stantibus rebus*, the reason of the allowed simplified method of calculation (*when the “transparent surface” to “useful area” ratio is < 0.18*) results not understandable; in fact, the logic on which this choice is granted is not exact, permitting an evaluation of the energy performance of the building easier, without the $EP_i$ calculation. In this way, the real building energy behaviour is not evaluated.

With reference to the results of figure 3.2.1, the higher *gains to losses* ratio, obtained in the climatic zones C and D, compared to the values achieved for the areas A and B, can be easily understood. In fact, this depends by the longer heating period characterizing the cooler climatic regions (C and D). This longer period for the space heating, such as defined by the Presidential Decree 412 [8], begins earlier and finishes later, so that it causes a relevant growth of the numerator of the *gains/losses* ratio, depending on the computation of the springtime and late-autumnal solar radiation that raises the solar free gains.

As represented in figure 3.2.1 and in table III.5, a further increment of the winter degrees-day (*climatic zones E and F*) begins to be critical for the east- and west-exposed windows, even if, globally, the energy losses are not so higher than the solar gains.

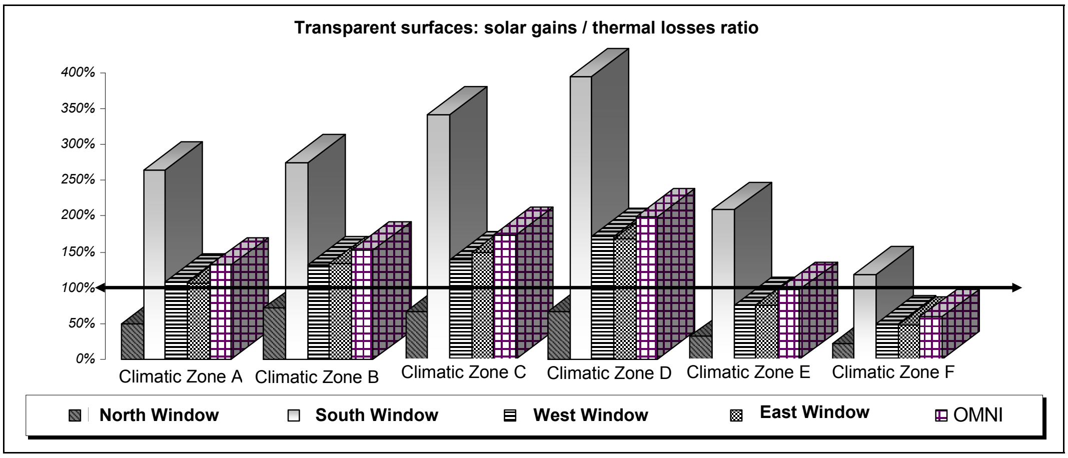


*Figure 3.2.1 – Gains / losses ratio interesting the window, considering a unitary surface and the different exposition.*

Therefore, the presented results show that the criteria adopted by the legislator cannot be considered fair, above all considering that no differentiations have been provided as regards the six Italian climatic regions (*for example, admitting the easier calculation procedures only with reference to the very cold climatic regions*).

*Actually, even if the criterion could have a sense as regards the climatic region F, however a further modification of this legislative measure seems too complicated, so that, the best thing to do is, according to this study, the whole elimination of this simplified alternative procedure.*

After the demonstration that, during the heating season, the transparent building envelope does not mean, automatically, relevant thermal losses and thus cause of energy inefficiency, obviously a correct design of the windows remains a key-point.

Quality, quantity, exposition and shadings of the glazed building envelope play a primary role not only as regards the aspects related to the energy efficiency under the "*heating*" point of view, but also with reference to the right environmental natural and artificial lighting. Furthermore, the transparent envelope plays also a very significant role as regards the summer energy performances of the building, with reference to both the limitation of the active cooling in full-conditioned buildings and the indoor overheating in naturally ventilated architectures.

Therefore, a careful design of the windows represents one of the most important topic of a sustainable building.

## 3.3 THE CALCULATION OF THE BUILDING ENERGY PERFORMANCE IN SUMMERTIME

As already expressed in the Chapter 1, the great diffusion of active cooling systems everywhere around the Europe and above all in the Mediterranean countries, requires urgent regulations regarding minimum energy efficiency requirements, with reference to both the building behaviours and the air-conditioning equipment characteristics. In the Chapter 1, the paragraph 1.4 describes, despite shortly, the evolution of the Italian energy regulations during the last 4 years, even if the first measures regarding the energy efficiency in summertime have been cited (*and never fully defined by the implementing decrees*) already by the Law 10/91.

Actually, real and mandatory prescriptions have been defined, 14 years later for the first time, by the Ministerial Decree 27/07/2005.

As already reported in the previous pages, the European Directive 2002/91/EC contains clear indications as regards the reduction (*or also nullification*) of the building energy requests for cooling. In fact, in the first part of the Directive (point 18), textually it is written: "*Recent years have seen a rise in the number of air-conditioning systems in southern European countries. This creates considerable problems at peak load times, increasing the cost of electricity and disrupting the energy balance in those countries. Priority should be given to strategies which enhance the thermal performance of buildings during the summer period. To this end there should be further development of passive cooling techniques, primarily those that improve indoor climatic conditions and the microclimate around buildings*".

The same document, at the article 2, includes the cooling energy requests and the energy demanded for the ventilation among the energy uses considered for the building energy evaluation and classification. It means that the cooling energy needs will be also reported in the building energy certificate.

As before cited, the Italian Ministerial Decree 27/07/2005 (*the last implementing act of the Law 10*) dedicates the whole article 7 to the "*measures of control of the summer energy consumptions*". The provisions, although completely cancelled only few months later (*because of the emanation of the Decree 192, promulgated during the October 2005*) introduce the question of the building envelope thermal efficiency in summer. In particular, high thermal inertia and the nighttime ventilation are expressly cited as effective solutions in order to "*avoid or reduce, as much as possible, the use of active cooling systems*".

In particular, this legal act imposes that the building designers have to:

- calculate the decrement factor "$f_a$" and the time lag effect "S" of each vertical and horizontal opaque component of the building envelope;
- correctly determine the proportions and the position of the transparent surfaces, with the aim to control the solar radiation during the summer diurnal hours, without penalizing the achievable natural lighting;

- to equip the windows (*except those north-exposed*) with effective shading systems or, alternatively, to provide technical solutions apt to obtain the same performances;
- calculate the summer indoor air temperature, with reference to the most critical thermal zone;
- subordinate the functioning of the air-conditioning system to the verification of actual conditions of thermal discomfort.

The same decree, at the article 4, established that the thermal mass of the building shell was a parameter that has to be used for a $C_d$ coefficient correction. The $C_d$, as reported in the Chapter 1, was introduced by the Law 10/91, and consists into an index expressive of the volumetric thermal loss coefficient of the building envelope in wintertime. According to the Decree 27/07/2005, the $C_d$ index value had to be adjusted, modifying the "*incidence*" of the thermal transmittance of the walls depending on the thermal mass of these.

The emanation of the Legislative Decree 192/2005 cancels completely the cited indications and all the measures above reported, repealing the paragraphs 1 and 2 of Law 10/91 (*and the Ministerial Decree 27/07/2005 was just the implementation of these parts*).

The Legislative Decree 192/2005, being the transposition of the EPBD into the National Legislation, contemplates (at least in the premises) all the energy uses reported by the European Directive, and therefore also the lighting system, the ventilation, the summer air-conditioning and the hot water production, further than, obviously, the winter heating need.

A transient application regime, such as established by the Decree 192 for a first and short period (*actually, longer almost 4 years*) waiting for the final operational measures (among which the National Guidelines for the Building Energy certification), imposed the following prescriptions, reported in the Annex I and referred to both new buildings and significant refurbishments:

a) estimation and documentation of the effectiveness of external window shading systems, in order to reduce the thermal gains deriving from the solar irradiation;
b) mandatory verification, in all the climatic zones (excluding the F one), that the value of the superficial mass of the vertical, horizontal or inclined opaque walls is at least equal to 230 kg/m$^2$. This verification is mandatory in the localities characterized by a mean value of the solar irradiance, on the horizontal plane and in month of maximum solar insulation, higher than 290 W/m$^2$. Alternatively, also new technologies and solution can be adopted, as well as innovative constructive techniques but, in these cases, the same energy performances of high mass buildings have to be shown by means of a detailed technical report;
c) best consideration of the environmental characteristics of the site, as well as the architectonic distribution and rationalization of the indoor zones, in order to favour an adequate natural ventilation which, when not enough or satisfactory, can be integrated by means of mechanical systems.

All the above reported indications are included in the paragraph 9 of the Annex I, while the paragraph 10 introduces the mandatory use of external window shadings for the new buildings and the restoration of existing ones characterized by a useful area higher than 1000 m$^2$.

During the summer 2009, finally the decrees of full implementation of the EPBD have been enacted by the Italian Institutions; in particular, the Presidential Decree 59/2009 [1] and the Ministerial Decree 26/06/2009 [2] (*reporting the National Guidelines for the Building Energy Certification*) came into force, modifying the previous legislative frame. As already briefly described in the paragraph 1.4 of the Chapter 1, a future settlement of the building energy legislation will consider all the energy uses, and thus also the ones related to the artificial lighting and the summer request for cooling. In particular, the global energy balance, as provided by the Italian definitive energy law, is reported in the equation 1.

$$EP_{gl} = EP_{i} + EP_{acs} + EP_{e} + EP_{ill} \tag{1}$$

where the indicators taken into account are:

- $EP_{gl}$ : the sum of the partial indicators;
- $EP_{i}$ : the energy index referred to the space heating in wintertime;
- $EP_{acs}$ : the energy index related to the domestic hot water production;
- $EP_{e,}$: the energy indicator expressing the primary energy need for the summer cooling;
- $EP_{ell,}$: the index related to the energy needs for the artificial lighting.

At the present moment, the evaluation of the energy performance of the building in summertime is mandatory, even if the present $EP_{e,invol}$ indicator doesn't consider the active cooling system inefficiencies, so that this index is referred only to the building envelope performances (*i.e., the $EP_{e,invol}$ indicator expresses the thermal need, not converted in primary energy request*).

With reference to the equation 1, the National Guidelines for the Building Energy Certification [2] consider, in a first phase of application, only the terms $EP_{i}$ and $EP_{acs}$, so that, the $EP_{e,invol}$ , even if mandatory and reported on the certificate, doesn't contribute to the elaboration of the global performance indicator $EP_{gl}$.

As before explained, the $EP_{e,invol}$ is different from the $EP_{e,}$ because it is centred on the envelope thermal performances and doesn't consider the active cooling necessary to keep the indoor environment at a temperature of 26 °C during the summer season; an example of the $EP_{e,invol}$ calculation has been reported in the Chapter 2, at the paragraph 2.3.3. Obviously, also this indicator is expressed in kWh/m$^2$a (*"thermal" and not "primary" energy, as above cited*).

According to the Presidential Decree 59/2009 (*article 4, paragraph 3*), the $EP_{e,invol}$ should be calculated for all the new buildings and the significant re-qualifications of existing ones. As defined and exemplified in the Chapter 2, this indicator can be easy calculated applied the Italian Standard UNI TS 11300-1 [7].

With reference to residential buildings, the same Decree 59/2009 establishes that the $EP_{e,invol}$ has to result lower than:

- 40 kWh/m$^2$a with reference to the climatic zones A and B;
- 30 kWh/m$^2$a with reference to the climatic zones C, D, E and F.

For non-residential buildings, the indicator $EP_{e,invol}$ is expressed in terms of kWh/m$^3$a, so that it represents the energy requirements relative to an unitary cooled volume. In this case, the above expressed limits become, respectively, 14 kWh/m$^3$a (*Zones A and B*) and 10 kWh/m$^3$a (*Zones C, D, E and F*).

Until now, the mandatory prescriptions for new buildings have been reported: as regards the energy certificate of existing architectures, obviously those limits can be also exceeded.

The Guidelines for the energy certification [2] contain also a scheme to evaluate the performance of the building envelope in summertime, based on the evaluated $EP_{e,invol}$, such as represented in table III.6.

Table III.6: Summer performance classification on the basis of $EP_{e,invol}$, time lag effect (S) and decrement factor ($f_a$), according to the Guidelines for the building energy certification [2]

| Performances | Quality of the performances | $EP_{e,invol}$ | Time lag effect | Decrement factor |
|---|---|---|---|---|
| | | kWh / (m$^2$ year) | H | |
| Optimal | I | $EP_{e,invol} \leq 10$ | $S > 12$ | $f_a \leq 0.15$ |
| Good | II | $10 < EP_{e,invol} \leq 20$ | $12 \geq S > 10$ | $0.15 < f_a \leq 0.30$ |
| Sufficient | III | $20 < EP_{e,invol} \leq 30$ | $10 \geq S > 8$ | $0.30 < f_a \leq 0.40$ |
| Poor | IV | $30 < EP_{e,invol} \leq 40$ | $8 \geq S > 6$ | $0.40 < f_a \leq 0.60$ |
| Bad | V | $EP_{e,invol} > 40$ | $6 \geq S$ | $0.60 < f_a$ |

As already described in the Chapter 1, also with reference to the thermal mass of the building envelope, the Presidential Decree 59 introduces some modifications. In fact, the new legal act admits, alternatively, the verification of the wall mass (*the same limit value, such as reported by the Decree 192/2005, of 230 kg/m$^2$ is provided)* or the verification of the time periodic thermal transmittance $Y_{12}$ of the vertical wall.

This dynamic parameter has to result lower than 0.12 W/m$^2$K.

According to the EN 13786 [9], the dynamic thermal transmittance $Y_{12}$ represents the ratio of the complex amplitude of the heat flow rate density through the surface of the component adjacent to zone 1 ($q_1$) to the complex amplitude of the air temperature in zone 2 ($\theta_1$) as expressed in the equation 2.

$$Y_{12} = \frac{\hat{q}_1}{\hat{\theta}_2} \qquad (2)$$

Both definition and calculation of $Y_{12}$ are not so simple (*see the Chapter 2 where, in the paragraph 2.3.3, several examples have been proposed*). Substantially, by means of the dynamic thermal transmittance, it can be evaluated the attitude of an opaque building envelope element in shifting and attenuating the thermal flow crossing it during a fixed time step.

With reference to the window shadings system, the Decree 59 reaffirms the necessity of external systems in all the new buildings, admitting, however, an alternative possibility. In fact, when the designer can show the technical or economic absence of convenience, the window screens can be not used, but, in this case, window glasses characterized by solar transmission factors ($g_{gl,n}$) lower than 0.5 have to be adopted. In table III.4 it can be seen that this limit is really very strict, requiring at least a triple glass or special coatings of the transparent surfaces.

As regards the National Guidelines for the building energy certification [2], the whole paragraph 6 concerns the verification of the summer performances, clarifying that, in a first period, only qualitative aspects have to be evaluated. The document underlines, in fact, that the present state of art, with reference to both technologies apt to reduce the summer cooling requirements and the evaluation of these, is not perfectly developed. For these reasons, only some precautions and easy verifications are imposed.

However, the document underlines the necessary reduction of the cooling energy demand during the warm season, whereby the climatic conditions, the exposure to the solar radiation and building envelopes characterized by the attitude to store the thermal energy can determine particularly critical situations. Therefore, the energy certificate of the building should contain also indications regarding the quality of the building shell as regards the limitation of the building over-heating, based on the scheme reported in table III.6.

With reference to small and medium size single apartments (*smaller than 200 $m^2$*), the summer performance qualification can be omitted. Of course, in this case, conventionally the worst value (*"bad" such as reported in the table III.6*) is attributed.

As reported in table III.6, alternatively to the $EP_{e,invol}$ determination, in some cases the evaluation and verification of other building envelope thermal behaviours can be chosen, in order to classify the building behaviour in summertime, such as clarified by the Ministerial Decree 26/06/2009. In particular, this legal act admits the calculations of qualitative indicators characterizing the building shells in summertime, such as the time lag effect (S) and the attenuation or decrement factor of the summer heat loads ($f_a$). In the Chapter 2, these dynamic thermal parameters are fully described.

Shortly, the time lag (S) is defined as the time shift between the maximum of the thermal flux entering in the indoor ambient and the maximum of the external room temperature, while the decrement factor ($f_a$) defines the ratio of the "module of the dynamic thermal transmittance" to "the thermal transmittance" in steady-state conditions. Both S and $f_a$ are evaluated by means of the standard EN 13786 [9].

When, respecting the legislative limitations, the designer can adopt this second chance for the verifications (*calculation of "S" and "$f_a$" instead of the $EP_{e,invol}$*), the classification method of the achieved performances is based on the last two columns of the table III.6. About this, when time lag effect and decrement factor determine discordant performance quality, for the classification it would prevail the value of the first parameter (*i.e. S*).

Until now, a short lecture of the present prescriptions has been presented; in the followings, a critical analysis of these is provided, with reference to both the vertical walls (*sub-paragraph 3.3.1*) and the horizontal opaque envelope (*sub-paragraph 3.3.2*).

As regards the necessity of improving the building envelope performances in summertime, already several times in this Thesis the good approach adopted by the Italian legislator has been underlined; furthermore, considering the more and more important energy and environmental questions, the last energy dispositions result very appreciable.

On the other hand, according to the following study, it will be shown that not all the new measures are really effective. In fact, as regards the mandatory verifications imposed by the Presidential Decree 59, a weak element of the past legislation is not totally cancelled. In particular, still today, the verification of a performance minimal requirement (*time lag, attenuation factor or periodic thermal transmittance*) can be substituted by the evaluation of a prescriptive parameter, such as the thermal mass (*that, on the contrary, not always correctly foretells the behaviour of the building envelope during the summer*). In fact, even if with reference to the external opaque horizontal surface it necessary the calculation of the $Y_{12}$, as regards the vertical walls is still admitted, alternatively, the determination of the superficial mass.

### 3.3.1 VERTICAL WALLS: TIME LAG, ATTENUATION FACTOR AND DYNAMIC THERMAL TRANSMITTANCE

With calculation software, self-built applying the resolution algorithms provided in the international standard EN 13786, the performances achievable adopting five different opaque vertical walls have been analysed (*figure 3.3.1*).

About these envelope components, the values of the steady-state thermal transmittances are fully respectful of the limits provided by the new legislations (*2010 limits according to the Annex C of the Decree 192*). At the same way, also the values of the thermal mass – or dynamic thermal transmittance – satisfy the present legislation (Presidential Decree 59/2009) except as regards the wall 1. In the table III.7 and figure 3.3.1 the main characteristics, thermal, typological and geometrical of such walls have been reported.

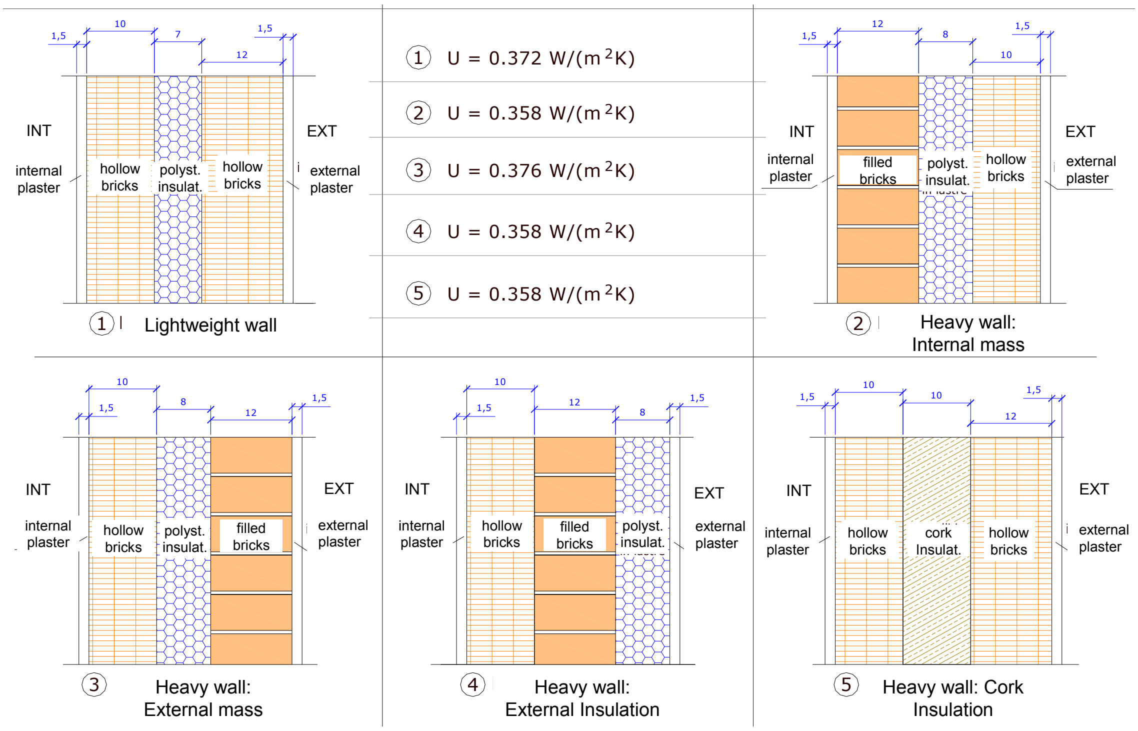


*Figure 3.3.1 – Thermal and geometrical characteristics of the modelled vertical opaque walls*

The performances of vertical walls 1, 2 and 5 have been initially compared. In particular, a lightweight wall (*not regular according to the Decree 59*), a second wall (*regular because it respects the minimum mass value of 230 kg/m²*) and the wall 5 (*regular because it is characterized by a dynamic thermal transmittance lower than the maximum admitted value, i.e.* $Y_{12} = 0.067 < 0.12$ *W/m²K*) are compared as regards the achievable performances.

Table III.7: Thermal parameters, dynamic and stationary, of the modelled walls

| | LIGHTWEIGHT WALL | INTERNAL MASS | EXTERNAL MASS | EXTERNAL INSULATION | CORK INSULATION |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| Thickness (m) | 0.32 | 0.33 | 0.33 | 0.33 | 0.35 |
| Mass (kg/m²) | 178 | 322 | 322 | 322 | 196 |
| U (W/m² K) | 0.372 | 0.358 | 0.358 | 0.358 | 0.375 |
| $f_a$ (decrement) | 0.474 | 0.274 | 0.364 | 0.146 | 0.180 |
| $Y_{12}$ (W/m² K) | 0.176 | 0.098 | 0.130 | 0.052 | 0.067 |
| Time Lag (h) | 8.24 | 9.30 | 9.28 | 9.05 | 14.73 |

In a first study, the superficial indoor and outdoor temperatures have been evaluated, with reference to a summer typical, modelling a building not provided with a cooling system and so leaving the indoor temperature free running. In a second study, the $EP_{e,invol}$ has been instead evaluated, adopting these walls as vertical building envelope components of a simulated house and establishing a fixed indoor temperature equal to 26 °C. All the calculations are referred to the climatic conditions of Naples (*Italian Climatic zone C*) and concern a south-exposed vertical building component. The considered apartment results with a net surface area of 100 m², with a south-west "corner" exposition", situated at an intermediate floor of a residential building, with a surface-to-volume ratio S/V equal to 0.2 m⁻¹.

With reference to the external wall temperatures, no very significant differences have been calculated (figure 3.3.2); in fact, as regards the external layers, the 3 compared vertical components present the same structure, i.e. a traditional plaster and hollow bricks (*see figure 3.3.1*). Instead, as regards the internal surface temperatures, the results are quite different, and, as predictable, attenuated sinusoids can be noted both for the massive wall (number 2) and for the light one characterized by the cork insulation (*high thermal capacity due to the high specific thermal capacity of the wood layer*). This result can be easily explained considering the equation 3:

$$C = c \cdot m \qquad (3)$$

where "C" represents the wall thermal capacity (kJ/K), "c" the specific thermal capacity (kJ/kg * K), "m" the mass of the wall (kg). The numerical values, calculated by means of the application of the EN standard 13786 (table III.7), are quite in accordance to those derived by the dynamic energy simulations (*figures 3.3.2 and 3.3.3*).

In figure 3.3.3, the different effects related to the various time lags (S) are not so clear and it depends by the shortness of the test. On the other hand, it is very evident the variation deriving from the different decrement factors ($f_a$), that can be deduced by the amplitude of the sinusoids. At the same way, it can be clearly seen the correspondence interesting the higher attenuations and the walls characterized by the lower values of dynamic thermal transmittances ($Y_{12}$).

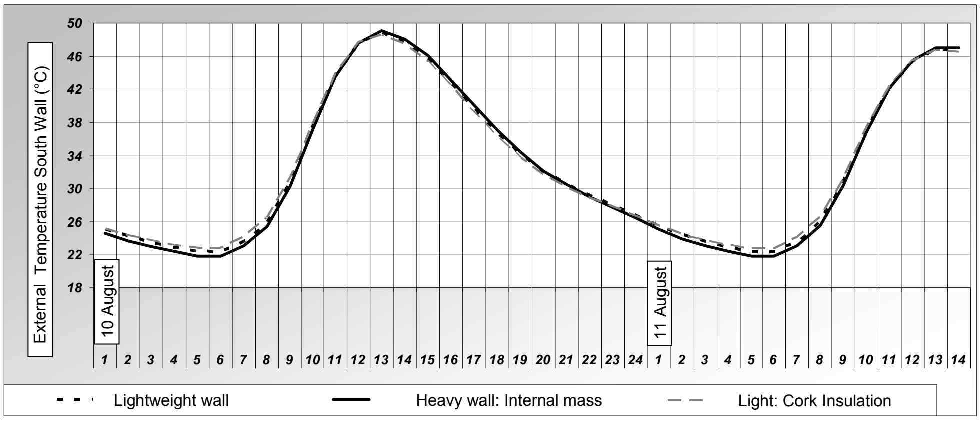


*Figure 3.3.2 – Comparison of different vertical walls: external superficial temperature, south wall, (naturally ventilated building)*

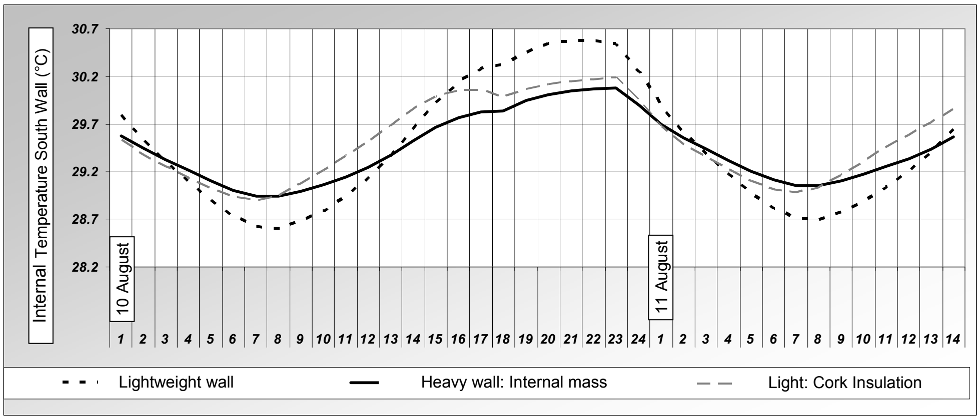


*Figure 3.3.3 – Comparison of different vertical walls: internal superficial temperature, south wall, (naturally ventilated building)*

This event is testified by the temperature cycles (*as regards the thermal level on the inner side of the walls*) very different each other's (figure 3.3.3). In fact, the lightweight wall is characterized by internal temperatures vary variable passing from the diurnal to the nocturnal hours, while, as regards the walls with high thermal capacity, this phenomenon is not so relevant. Thus, during the diurnal hours, the lower temperatures are obtained with the high thermal capacitive walls, while, during the night, the lightweight structure has the lower internal thermal levels. This last event happens because the high capacity walls release, during the nocturnal hours, the thermal energy stored during the day.

In figure 3.3.3, the subtended areas not only make possible the evaluation of thermal comfort conditions achievable inside the indoor spaces, but also are predictive of the cooling energy requests that an air-conditioning system has to balance: for all the cases, it can be noted that the total areas have almost the same extensions.

It means that, considering a continuous use of the building (*residential*) and imposing a constant indoor air temperature at 26 °C (*even if this operational condition is not completely correspondent to the common practice*), no convenience would derive by the adoption of a wall characterized by an elevated thermal capacity. In fact, even if in the simulations carried out in a not-conditioned building, the walls 2 and 5, characterized by a high thermal capacity, determine indoor lower temperatures from the late-morning until the evening, during the night hours these components determine higher indoor thermal levels, compared to the lightweight walls, because these release the heat stored during the day. Contrarily, the lightweight wall, in the night, is interested by a cooling effect very significant (*lowest peak*) and quick (*higher slope of the decreasing function*).

Immediately it can be understood as envelope components fit to store energy, attenuating and shifting the heat release, are particularly apt when adopted in buildings characterized above all by a diurnal use, starting by the late-morning until the first hours of the evening (*commercial buildings and, generally, the whole tertiary sector*). These walls can be used also with reference to the residential dwellings, if coupled to other techniques for the passive cooling of the envelope during the night, such as the activation of the mass (*for example the nighttime ventilation [10]*). Finally, the higher benefit achievable adopting massive walls consists into the containment of the thermal level cycles during the night and day variations.

In the following study, with the same methodologies of the previous one, the performances achievable using 4 different walls (*regular according the Presidential Decree 59*) are compared. In particular, the walls 2 and 5 (*figure 3.3.1*) already studied, and the structures 3 and 4 (*figure 3.3.1 and table III.7*) are investigated; the last two walls have the same layers of the structure 2, being changed only the order of location within the component.

Comparing the results, achieved by means the dynamic energy analyses (*figures 3.3.4 and 3.3.5*) and calculating the dynamic thermal parameters (table III.7), it can be noted that:

- the higher time lag effect is obtained with the use of the cork-insulated wall (wall 5), being this insulating material characterized by a high specific thermal capacity; the achieved time-delay is around 14 hours (*optimal performance according to the Italian National Guidelines, as shown in table III.6*);
- the variation of the layer order, and so analyzing the behaviours of the walls 2, 3 and 4, doesn't cause relevant variation of the time lag (*delays around 9 hours*), with a performance only "*sufficient*" according to the Italian law (table III.6);
- as regards the dynamic thermal transmittance $Y_{12}$ and the attenuation factor $f_a$, the order of the disposition of the layers is a strongly incident element (table III.7);
- the higher peaks, as regards the internal surface temperature, are measured on the wall with external insulation; this event is due to the position of the thermal insulating material. In fact, this obstacles the heat transmission toward the inner side of the wall, so that the solar radiant energy on the external surface, absorbed by the plaster, rises the temperature of the superficial layer being not transferred toward the internal wall layers;
- the lower peaks of external surface temperature, instead, interest the wall with the thermal mass located on the external side;
- the higher excursions of the external superficial temperatures characterize, at the same way, the wall with external mass, with minimum values globally lower compared to the other walls (*in the first day of the time*) and maximum values higher than the other

(*in the late-evening*). This result can be also anticipated seeing the values reported in table III.7, where the decrement factor of the wall 3 (*wall with external mass*) is higher than the same parameter of the other structures ($f_a = 0.364$).

- the wall with high mass on the internal side (wall 2) results the best one as regards the environmental thermal comfort (figure 3.3.3). This because in the hours characterized by the higher crowding (*afternoon-evening, between 13.00 and 24.00*), when high endogenous loads occur (people, artificial lighting), this wall contains the thermal level of the indoor air and of its inner layers. This because the high thermal capacity of the room-exposed side (due to the high mass presence) provides a great storage capability of the radiant indoor energy [11], while, when this thermal capacity results lower (*wall with external mass*), the radiant temperature of the internal wall surfaces grows quickly. The most penalizing results would be obtained insulating the wall from the inner side.

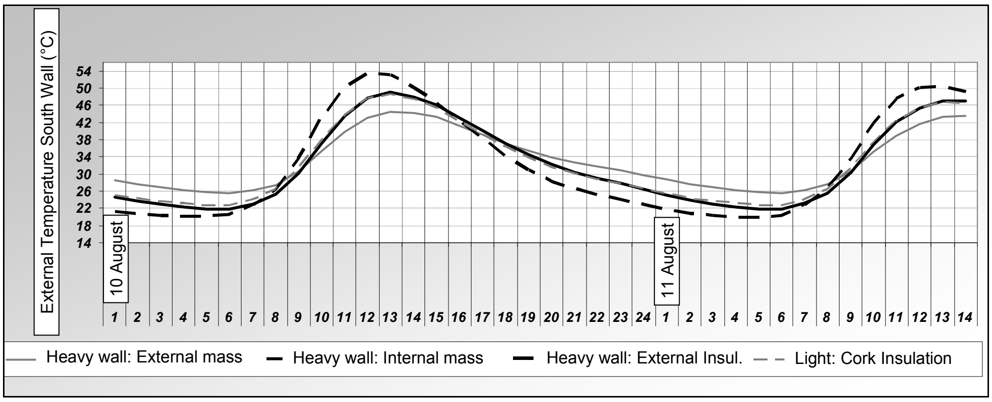


*Figure 3.3.4 – Comparison of different vertical walls: external superficial temperature, south wall, (naturally ventilated building)*

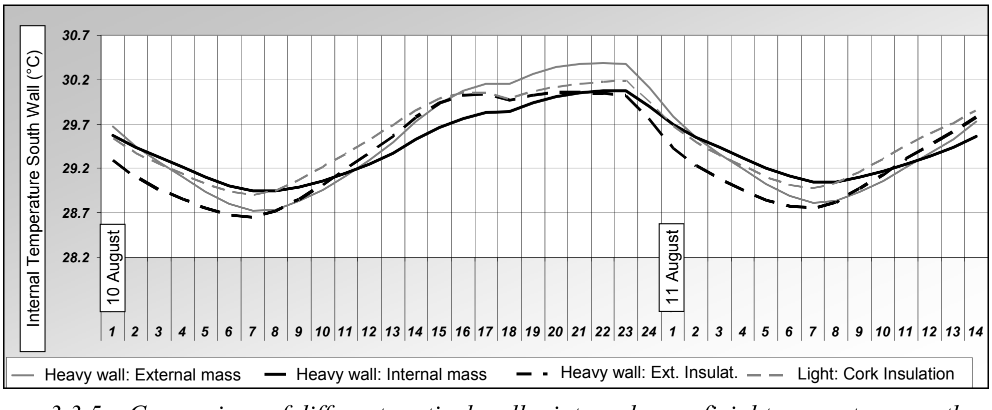


*Figure 3.3.5 – Comparison of different vertical walls: internal superficial temperature, south wall, (naturally ventilated building)*

Despite the above reported differences, it is important to underline that, globally, the achieved results do not testify performances very different. Decrement factor and time lag effects vary the temperature peaks and the moment when these occur, but, in terms of global cooling energy need in summertime, the variations among the different solutions (*characterized by the same $U_{value}$*) are not so relevant. Obviously, this happens if the indoor air temperature is maintained at a constant value (*in this case, the typical summery thermal comfort conditions achieved with an air temperature equal to 26 °C*).

In fact, a high thermal capacity determines attenuation and delay of the thermal flux during the diurnal hours (*when solar radiation and high external air temperatures cause great thermal gains*). However, at the same way, the thermal inertia attenuates and shifts the heat dissipation during the night (*when the temperature differences between internal and external environment would determine a natural building free cooling*).

Definitively, the same conclusions, already before inferred, are confirmed, and thus the strict connection existing among the energy performances and the kind of use of both the building and the active cooling systems.

The analyses on the indoor temperatures (*figure 3.3.3 and 3.3.5*), even if have been carried out considering a building without summer thermal control (*no active cooling system*), infer also useful information about possible energy savings in full air-conditioned buildings. In fact, the temperatures characterizing the inner side of the walls are proportional to the total cooling loads that the air-conditioning system has to balance.

Reading the curves diagrammed in figure 3.3.5, it can be noted that:

- walls with thermal mass situated on the internal side guarantee better comfort conditions and lower energy costs for the space cooling when the building is typically used during the central hours of the day, starting by the late-morning until the evening. In the followings, it will shows that, together with the nighttime ventilation, this strategy will offer very useful performances, inducing a natural free cooling in temperate climates [12], when the nocturnal ventilation causes the thermal mass discharge;
- external thermal insulation and walls with thermal mass located on the external side are useful if the building use is mainly nocturnal. This because a higher thermal storage interests the external sides of the walls, so that, during the night, the energy dissipation is more effective, being these layers exposed to the external air (*nocturnal convective cooling*) and to the cool sky (*nocturnal radiative cooling*).

Despite all these notations, as it will be show also in the following pages and in the chapter 5, the present Italian legislation and, in particular, the Presidential Decree 59/2009, don't give the right importance to the strategy for the mass activation. This is a strong limit, above all considering the significant cooling potential obtainable through an appropriate use of the nighttime ventilation. In fact, the effectiveness of this kind of passive cooling solutions (*quite simple to realize*), as regards the reduction in the cooling energy demands, is testified in several numerical [13] and experimental [14] studies and investigated by important research centres. On the contrary, the Presidential Decree 59/2009 introduces minimal performance values regarding the building envelope components (*dynamic thermal transmittance, thermal mass…*) without attention to the night ventilation as strategy to contain the indoor overheating or apt for a cost-effective reduction of the active cooling use in conditioned building.

Therefore, in these studies, the absence, inside the present energy rules, of a satisfactory attention to these aspects is underlined, while several prescriptions regard limits and parameters that, alone, not always can be effective.

Finally, some words about the influence of the spectral characteristics of the external and sun-exposed surfaces. Until now, all the analysed walls have been modelled, as regards the radiative characteristics of the external coatings, by solar absorption / reflection values and infrared reflection / emissivity, quite typical for the materials commonly used for building, such as external plasters characterized by ochre colour or clear gray concrete.

Increasing the reflection coefficient from 0.3 (≈ *fire-bricks, clinker external coatings, medium gradations of the gray and the blue*) to 0.9 (≈ *clear gypsum plasters, white lime paintings*) and leaving unchanged the thermal emissivity (*typically high for the building materials*), new energy simulations have been then carried out, evaluating the thermal requests in order to keep at 26 °C a conditioned building.

The energy analyses, also in this case derived by means dynamic energy simulators, evaluate the energy performances of the building, calculating the $EP_{e,invol}$ and so the cooling needs of the above-described apartment, considering the whole summer period. The results, shown in figure 3.3.6, testify that:

- on varying the building envelope components and keeping the same rate of diurnal and nocturnal ventilations, no significant differences in the summer cooling energy needs are achieved, if the wall $U_{VALUES}$ are the same and the external sun-exposed surfaces have similar spectral characteristics. About this, similar results have been evaluated also in [15].
- significant savings, as regards the building cooling needs, are achieved adopting both the lightweight and heavy reflective walls, with seasonal savings around 7%;

Therefore, it becomes quite clear that the increase of the solar reflectance of the external coating is more useful than the increase of the mass.

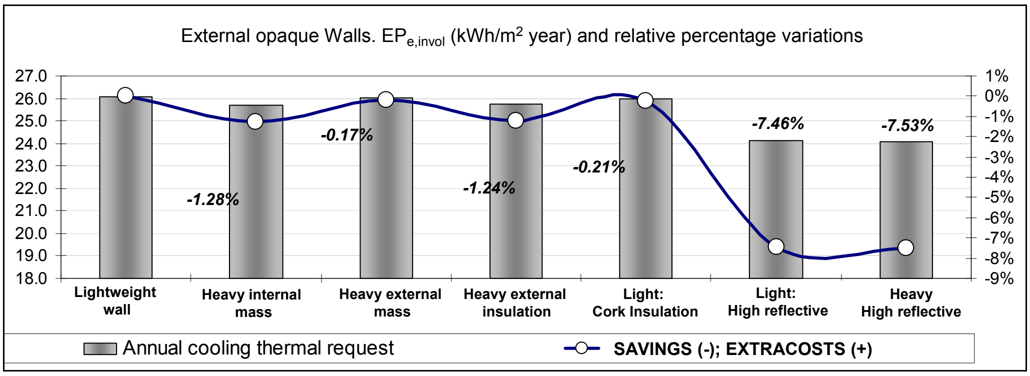


*Figure 3.3.6 - summer energy requests on varying the external coatings of the exposed vertical walls.*

Figures 3.3.7 and 3.3.8 report the results calculated for the same walls before investigated, but raising (*i.e. improving*), in this case, the solar reflectance of the external sun-exposed surfaces.

During the central hours of the day, the high reflective walls are characterized, on the outer side, by thermal levels lower than those correspondent to the high solar absorptive walls: the temperature difference is around 15 °C. This, naturally, has effects on the entering thermal energy flow, so that (*figure the 3.3.8*) the temperatures of the inner sides are meanly lower of about 0.7 °C if the spectral characteristics of the wall have been improved.

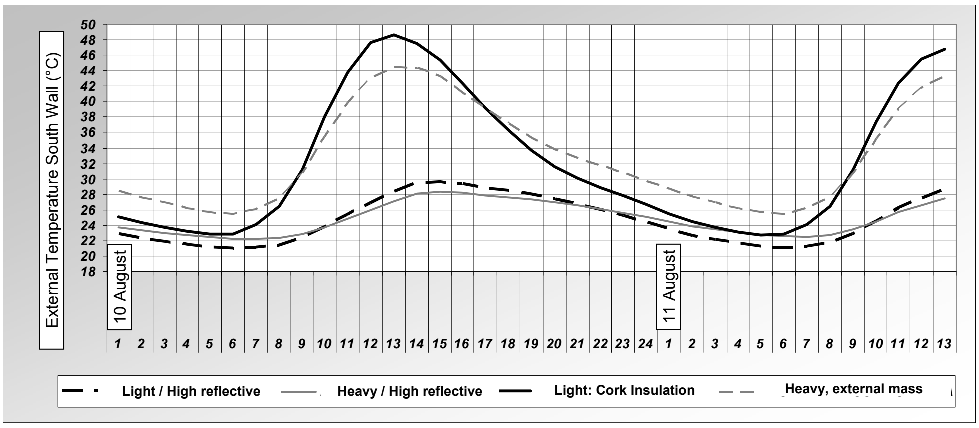


*Figure 3.3.7 – Comparison among vertical walls with different external coatings; external temperatures values (naturally ventilated building)*

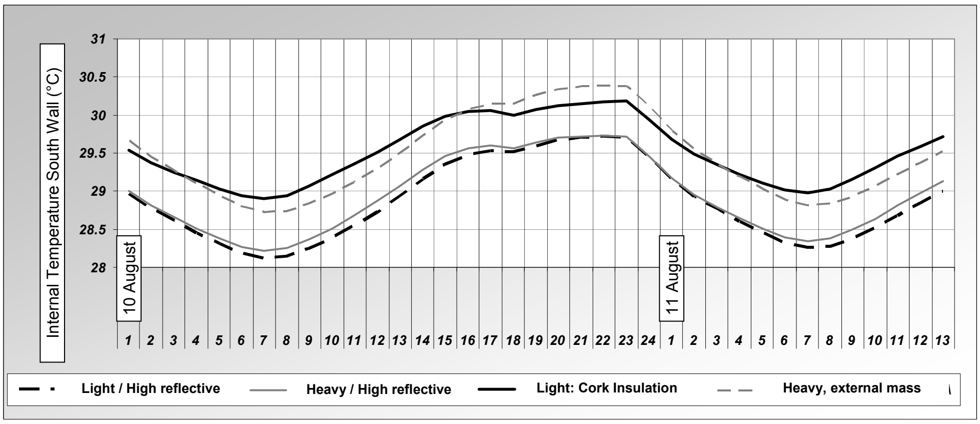


*Figure 3.3.8 – Comparison among vertical walls with different external coatings; internal temperatures values (naturally ventilated building)*

The obtained results are strongly related, quantitatively, to the defined operational boundary conditions, such as defined in this study. Therefore, changing climatic locality, static and dynamic ventilation rates, thermal parameters of the building envelope opaque components, entity and quality of the exposed surfaces, these results would be characterized by different values, also much more evident [16].

Also in the paper [17], it is evidenced that, acting on the external coating of the opaque building components, both the summer cooling loads and the winter need of thermal energy are influenced. Therefore, the external surfaces (*reflective or characterized by high solar absorptance)* of the sun-exposed walls and roofs should be designed accurately considering the specific boundary conditions, the weather related parameters, the kind of building use, the thermal comfort requirements, and carrying out energy evaluation extended to the whole year.

The poor attention that the Italian Legislator gave to these aspects has been here underlined. Therefore, besides the enacted prescriptions, also other measures should be issued in order to effectively reduce the high energy requests of the Italian stock for the summer air-conditioning. In particular, thermal mass discharge/activation and attention to the external coating of the building components can be, in the climate zones strongly radiated, cheap techniques in order to reduce the space cooling need. This will be better shown in the followings, extending the analyses to the roof behaviours.

### 3.3.2 ROOFS: TIME LAG, ATTENUATION FACTOR AND DYNAMIC THERMAL TRANSMITTANCE

In the previous pages and in the Chapter 1 of this Thesis, it has been reported that, as imposed by the Presidential Decree 59/2009, with reference to the building roofs the only admitted mandatory verification imposes a maximal dynamic thermal transmittance $Y_{12}$ lower than 0.20 W/m$^2$K.

Surely, it is appreciable the substitution of an only prescriptive parameter (mass) with one related to the real performances ($Y_{12}$). Despite this, it is not understandable why, in spite the roofs have a view factor with the sky double than the vertical walls (*…and so are much more irradiated*), with reference to the horizontal building components the admitted dynamic thermal transmittance is higher compared to the vertical walls (0.20 >> 0.12 W/m$^2$K). This is quite incomprehensible, above all considering that, also as regards the structure composition, a roof is usually much more massive (*and so much more thermal capacitive*) of a wall, being constituted at least by two concrete layers (one structural and one for the right slope) and by another one realized in a mixed concrete-brick composition (figure 3.3.9).

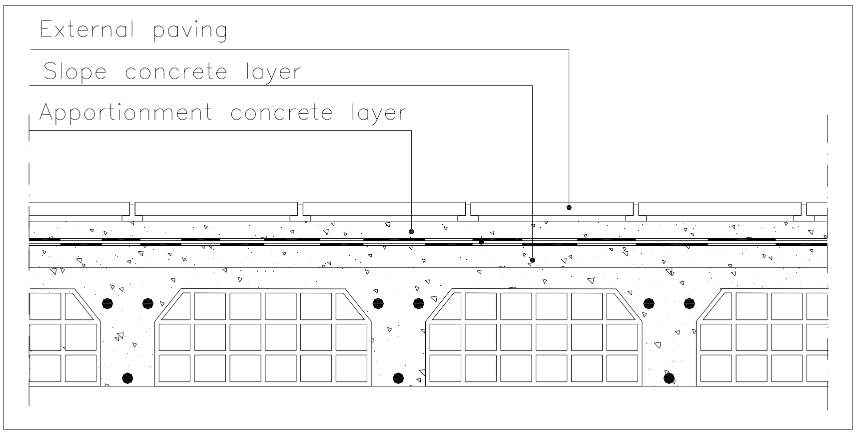


*Figure 3.3.9 – European building technology: a typical roof structures*

Therefore, considering that a roof has more mass than a vertical wall and insulating layers almost equal (*similar values, according to the Legislative Decree 192 for the admitted U*) and also taking into account the more critical operational conditions as regards the solar radiation, it is quite strange that, as regards the $Y_{12}$, the law admits higher values.

At the same way already shown for the vertical walls, in the followings the superficial thermal levels, both internal and external, as well as the cooling requests in summertime, are evaluated, considering different roof solutions (table III.8). In particular, two different roofing structures are compared, both equipped with an external insulating layer.

The solution 1 provides, upon the inner plasterboard, a structural corrugated metallic sheet with an upper reinforced concrete stratum (*figure 3.3.10 a*); the second solution, instead, is constituted by a traditional mixed layer with alternation of brick and concrete cross beams (*figure 3.3.9 and figure 3.3.10 b*). Over the above reported structural systems, the other layers are the same for both the two solutions, and, in particular, these consist in the waterproofing membrane, wrapping layers, thermal insulation, levelling stratum and external paving.

Table III.8: Thermal parameters, dynamic and stationary, of the modelled Roofs

| | LIGHTWEIGHT ROOF | HIGH MASS ROOF |
|---|---|---|
| | 1 | 2 |
| Thickness (m) | 0.25 | 0.43 |
| Mass (kg/m$^2$) | 187 | 353 |
| U (W/m$^2$ K) | 0.38 | 0.35 |
| $f_{a.}$ (decrement) | 0.56 | 0.18 |
| $Y_{12}$ (W/m$^2$ K) | 0.21 | 0.064 |
| Time Lag (h) | 5.8 | 10.2 |

Deliberately, the first solution has been designed for not satisfying the limits imposed by the new legislation about the about the $Y_{12}$. The same solutions, in a first time characterized by an external paving with solar reflection equal to 0.15 and thermal emissivity of 0.9, in a second case have been cool-painted, so that the first one coefficient (solar reflectance) has been changed in 0.65. This value has been selected adopting typical external roof surfaces such as reported by the American Rooftile Coatings.

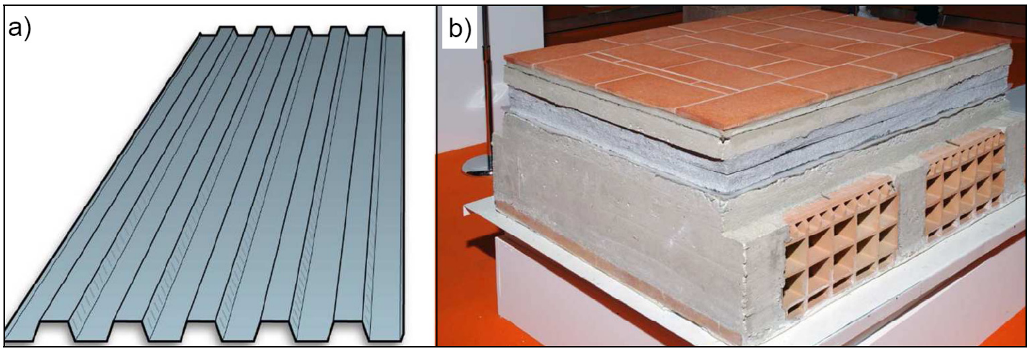


*Figure 3.3.10 – The light (a) and heavy (b) structural layers of the simulated roofs*

The results calculated for Naples (*same boundary conditions before considered, with a different S/V, now imposed equal to 0.3 and dispersing surface entirely considered as the roof one*) are reported in the figures 3.3.11, 3.3.12 and 3.2.13, respectively with reference to the surface temperatures (*external and internal*) and to the cooling energy requests.

In figure 3.3.11 it can be seen that, in the central hours of the day, during the summer, also temperatures higher than 70 °C are reached; instead, when the external surface – sun exposed – is clear and high reflective, the value of the external surface thermal level is meanly lower than 32 °C, with maximum values never higher than 45 °C.

In the same figure 3.3.11 it can be noted that, as regards the external roof temperatures, no differences derive from the two adopted different (*as regard the structural layers*) roofs, respectively characterized by a lightweight and heavy compositions. Definitively, in both the cases, the influence of the solar reflectance and of the infrared emissivity is much higher than the incidence of the thermal capacity (*here expressed by means of different structural masses*).

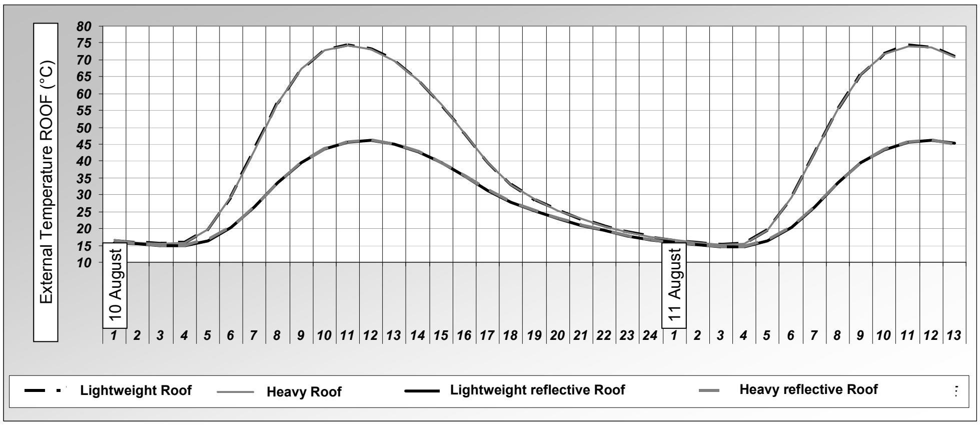


*Figure 3.3.11 – Comparison among various roof structures and different external coatings; external temperatures values (naturally ventilated building)*

Of course, this has effects on the amount of thermal energy transmitted into the building. In figure 3.3.12, with reference to the same structures, the temperatures calculated on the internal side of the roofs are represented and, obviously, the thermal loads inside the building are strongly related to these.

As regards the massive (heavy) roof, regular according to the Presidential Decree 59/2009, the low dynamic thermal transmittance ($Y_{12}$) and the low decrement factor ($f_a$) contribute in containing the excursions of the thermal level, attenuating the diurnal-nocturnal differences. Despite this, meanly the internal surface of the roof is characterized by a temperature around 2 °C (*maximum value equal to 32.4 °C*) higher than the thermal levels achieved by the lightweight and reflective roof (*maximum value equal to 30.6 °C*). Paradoxically, this second structure is not regular according to the present Italian legislation (Decree 59/2009)!

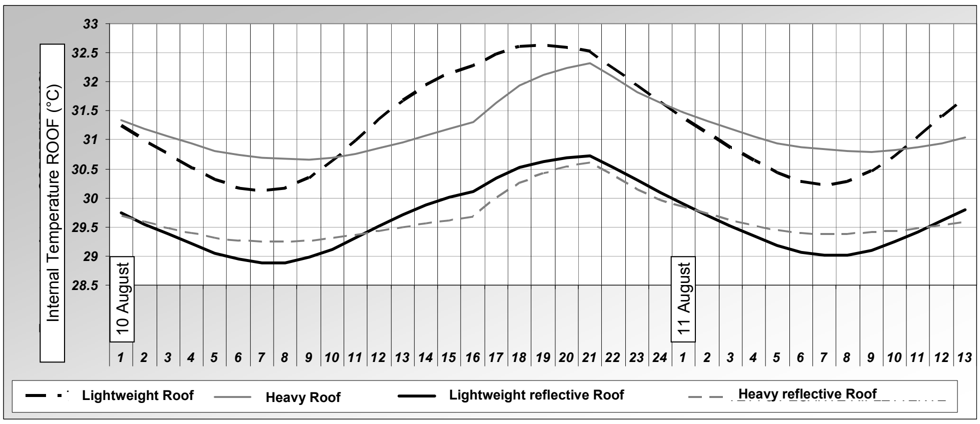


*Figure 3.3.12 – Comparison among various roof structures and different external coatings; internal temperatures values (naturally ventilated building)*

Even if, quantitatively, the results are strongly connected to the specific defined boundary conditions, however these show relevant behaviors.

The same results are achieved changing the considered energy parameter. In fact, also evaluating the $EP_{e,invol}$ index instead of the indoor summer temperature of the building envelope components, and so evaluating the global seasonal energy demanded for the space cooling, the Italian prescriptions seem not so effective.

In this study, as typical in Italy and according to the most relevant national and international standards, an indoor air temperature of 26 °C has been considered in summertime inside an air-conditioned building.

As shown in figure 3.3.13, surely a roof characterized by a low dynamic thermal transmittance ($Y_{12}$) guarantees better performances than those deriving by the use of a lightweight structure, with lower values, as regards the summer energy request, meanly around the 2.6%.

However, it is not this the main "road" that has to be undertake; in fact, also in this case, acting on the radiative characteristics of the roof external coating a non-regular roof can obtain performances much better than a regular roof with poor solar refection characteristics. In the first case (the cool-painted structures), in fact, the $EP_{e,invol}$ is equal to around 20 kWh/m$^2$a, while the heavy and not-reflective roof determines performance of 26 kWh/m$^2$a, and so higher of about the 27%.

Substantially, according to the Presidential Decree 59, the high reflective roof is not regular, while the heavy high absorptive one satisfies all the prescriptions, despite the first one induces energy performances, in summertime, really much better. Therefore, it emerges clearly that the approach is wrong. This is quite clear also classifying the performances according to table III.6 (*National Guidelines, i.e. Ministerial Decree 26/06/2009*), where the reflective roof determines an almost "good" performance, while the heavy one determines an only "sufficient" energy quality.

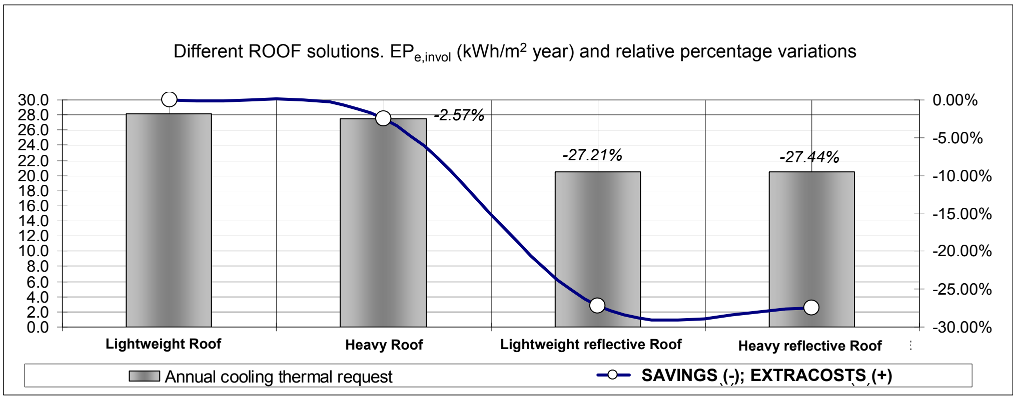


*Figure 3.3.13 - summer energy requests on varying the roof structure and the external coating*

The aspects related to the spectral characteristics of external coatings of the building envelope have been surely underestimated by the Italian Legislator.

The impression is that the formulation of the technical standards and laws has been concentrated on solutions "to distort" the summer thermal wave, attenuating and time-shifting its transmission into the building, without the necessary attention to solutions apt for the reduction of the "pushing force". Thus, about this, the Legislator approach was the same of the one adopted as regards the nighttime ventilation (*not named in the recent energy laws and only* *shortly cited in one of the technical norms which these are related, i.e. the UNI TS 11300 Part 1*). In fact, also about the thermal-physics properties of the opaque envelope and its behavior in summer, the Italian laws preferred to insist on important aspects (*dynamic thermal transmittance, time lag and decrement factor*) globally less influent than other characteristics (*e.g. the effect determined by the quality of the external coatings*).

Probably, with reference to the nocturnal ventilation, it is too complex to "impose" mandatory prescriptions. Despite this, it would be opportune at least to provide more exhaustive indications and suggestions; this because the night ventilation is a strategy that guarantees, operatively, a higher effectiveness of the same solutions established by law. In fact, the imposed time lag of heat transmission, alone, is not a decisive action, while, if it is coupled with a free nocturnal cooling of the structures, can become very useful.

On the other hand, as regards the spectral parameters of the building external coating, the absent Legislator attention results quite strange. In the United States, several research centres, both public and private (*among which: the Lawrence Berkeley National Laboratories, the Environmental Energy Technologies Division, Cool Roof Rating Council, The ENERGY STAR® program, California Energy Commission, Florida Solar Energy Center, U.S. Environmental Protection Agency*) investigate solutions in order to contain the building envelope surface temperatures. In particular, the variation of radiative parameters (*solar absorption/reflection and thermal emissivity*) is considered as the most effective and low-cost passive cooling strategy.

Besides the cited research centers, these aspects interest also the trade sector that is strongly engaged in the research of solutions fit to increase, also on non-clear surfaces, the solar reflectance index. In particular, during the last few years, a tight collaboration among industry and study-centers determined the development of "non-white cool roofs": these consist in colors and pigmentations for roof coatings that induce, also guaranteeing multiple colorations and various materials, an average increase of the solar reflection coefficient around 0.20 – 0.30, compared to the same external color, traditionally painted.

The certifications "ENERGY STAR" (*Energy Star Roofing Program of EPA - American Environmental Protection Agency),* the studies of the Cool Roofs Rating Council (CRRC), the indications contained in the "bible" of the energy efficiency in summer regime (*the California Energy Commission Title 24*) and the construction of the SRI (*the ASTM Solar Reflectance Index*) underline the importance of the radiative characteristics. All these studies and proposed indexes "certify" the importance of the aspects related to the control of the summer thermal gains due, in moderate and warm climates, above all to the high solar irradiation.

Only a relevant investigation is here reported: the Berkley National Lab Institute esteems that, applying white and reflective roofs to commercial and residential buildings, a potential saving, as regards the summer active cooling costs, around 750 million dollars/year could be obtained.

Once again, if in climatic conditions quite similar to those characterizing many Italian regions, important and technologically advanced countries study and research in this direction, it means that, also in the Mediterranean context, the same techniques and solutions (*as previously shown*) can be effective. Thus, it is quite evident that the new Italian legislation, not incorporating these trends, risks to neglect an effective strategy to contain and reduce the urban heat islands, the peaks of the summer electric energy request, the elevated energy demands due to the air-conditioner extensive use [18].

According to the EPBD introduction about the necessity of solutions thought to enhance the summer energy performances of the building in the Mediterranean area, the above presented studies testify that as regards cool paints, night ventilation and other kinds of passive cooling, the Italian legislation results not fully effective.

## 3.4 THE SURFACE TO VOLUME RATIO (S/V): INVESTIGATION OF THE INFLUENCE IN SUMMERTIME

As already cited in the previous paragraph, the Presidential Decree 59/2009 establishes a mandatory verification of the building quality in summertime, by means of the calculation of the $EP_{e,invol}$, representing the thermal (cooling) need necessary to keep the indoor spaces at an indoor temperature of 26 °C. The $EP_{e,invol}$ is calculated like the ratio of the global cooling need to the net surface area (*or volume*), so that it is measured in thermal kWh/m$^2$a (*or kWh/m$^3$a*). This prescription is mandatory for the new buildings and for the significant refurbishments of existing ones. With reference to the residential buildings, the $EP_{e,invol}$ must results, as already cited, lower than 40 kWh/m$^2$ year and 30 kWh/m$^2$ year, respectively for the climatic zones A-B and C-D-E-F.

Of course, it is important, necessary and right the imposition of a limit to the use of the active cooling in summertime, and, about this, the verification of the thermal behaviour of the building represents the correct way to guarantee satisfactory performances, both as regards the indoor comfort conditions and the energy consumptions. Despite this, the criterion adopted by the Legislator is quite approximate and unjust.

The Presidential Decree 59 refers to the technical standard UNI TS 11300-1 [7] as regards the calculation methodologies of the $EP_{e,invol}$; about this, for a complete description of the procedure, the Chapter 2 of this Thesis can be consulted. Without analysing the algorithms for the evaluation of the calculation period (*already analysed in the paragraph 2.3.3*), in this section some not-coherent aspects contained in the Decree 59 will be explained.

The logic through which the limit values are identified, as regards the maximum admitted cooling energy need, represents an element of real weakness; the only one assumed differentiation regards the climatic zone, and also about this concept a first and relevant approximation can be identified. In fact, the Italian division in climatic homogenous areas is built identifying ranges derived by the values of the winter degrees-day. It means that, automatically, the Italian law considers more critical the summer conditions of the areas characterized by a wintertime less cold, defining a strongly wrong syllogism: 1776 winter degrees-day >> 899 winter degrees-day → the winter is colder in Matera than in Crotone → in summer Crotone is hotter than Matera. *This is absolutely false*.

Surely, the winter climatic zone can be predictive of the duration of the cooling period, and therefore predictive of the entity of the energy demand in summer; but these effects are not enough clear and universal to provide a summer climate differentiation based only on the winter conditions. Not only the adopted criterion is quite ineffective, but also the absolute values (*40 kWh/m²a for the climatic zones A and B, 30 kWh/m²a for the climatic zones C, D, E and F*) are not correct, being no gradualism and considering a too high differentiation step (*i.e. 10 kWh/m²a*).

As shown table III.9, that proposes some weather data reported by the Italian technical standard UNI 10349 [19], it is not understandable why Crotone admits higher values for the $EP_{e,invol}$ that Matera, when, as visible in the table, both the external temperatures and the solar radiation are higher for the second cited city. Moreover, the UNI 10349 (*elaborated around 15 years ago*) doesn't consider properly the urban heat islands, that today make more critical the summer conditions in the big Italian cities.

Table III.9: Parameters influencing the cooling need in summer and $EP_{e,invol}$ limit values

| | | Crotone | Napoli | Matera | Caserta | Messina | Cosenza |
|---|---|---|---|---|---|---|---|
| Winter degrees-day | | 899 | 1034 | 1776 | 1013 | 707 | 1317 |
| Climatic Zone | | B | C | D | C | B | C |
| $EP_{e,invol}$ (limit value) | (kWh/m$^2$) | 40 | 30 | 30 | 30 | 40 | 30 |
| Ambient mean Temperature (June – July – August) | (°C) | 25.03 | 25.67 | 25.50 | 25.27 | 25.30 | 24.97 |
| Mean daily global solar radiation (average value 06-07-08) | (MJ/m$^2$) | 24.27 | 25.80 | 24.93 | 26.37 | 26.37 | 27.27 |

Every year, the worst conditions, about the peaks of summer temperatures, are verified in cities usually located in the Italian peninsula hinterland, characterized by a continental weather and not interested by the beneficial effects due to the summer Mediterranean breeze. The Italian Civil Protection Agency, on 23 July 2008, established the warming level III (*i.e. conditions over the alert threshold*) for Bolzano, Brescia, Verona, Milan, Turin, Florence, Perugia, Rieti, Civitavecchia, Rome and Latina: <u>it is clear that no one of the cited cities is located in climatic zone A or B</u>.

At the same way, also during the summer 2009, the highest temperatures have been registered in analogues cities (*40 °C in Milan on August, 25 2009*). This only to underline that there is only a partial correspondence between summer warmness and winter climatic zones.

Despite this, the present Legislation is characterized by other approximations as regards the limit imposed for the summer cooling need request. The highest mistake is represented by the indifference of the cooling need limits with respect to the building typical surface-to-volume ratio. In fact, the two identified limits for the $EP_{e,invol}$ do not operate differentiations as regards "quantity" and "quality" of the building envelope external surface.

Starting by the law 373/76 (*and the implementation Ministerial Decree 30/07/1986*), the limit values for the winter heating performance indexes (*Cd, FEN,* $EP_i$) have been always calculated with respect to the winter degrees-day and also evaluating the entity of the dispersing (external exposed) envelope surface, by means of a double interpolation. Therefore, the knowledge of the effect of S/V factor on the thermal energy demand is 30 years old, and it astonishes that, in summery regime (*when such aspects are perhaps also more influent*) the S/V has been totally neglected.

The reason of this negligence is probably imputable to the lack of consolidated criteria in order to establish the variability of the cooling requirements with respect to the kind of envelope surface, because, in summertime, different effects are achieved depending on the kind of dispersing surface exposure. In fact, in wintertime, the heat losses are mainly due to the temperature difference between the indoor and outdoor environment and between the indoor thermal level and the ground one, and these $\Delta T$ are generally interested by the same order of magnitude. This because the thermal gains due to the sun radiation are limited, so that only moderate differences, as regards the winter overall energy balances, interest the different sun-exposed surfaces (*the external surface temperatures, influencing the thermal exchanges, are quite similar, independently by the surface exposure: north, south, west, east, roof or basement*).

In summertime, this is not true.

The amount of dispersing surface, with respect to the indoor building volume, is a parameter that, alone, does not supply any useful information. It is easy to understand that, even if an apartment placed at the ground floor and one, in the same building, located at the attic, have the same surface-to-volume ratio, this doesn't means equal cooling need. In fact, as regards the amount of the cooling requests, the first house is helped (in the reduction) by the contact with the fresh soil, while the second one is penalized by the high diurnal solar radiation picking on the roof (*with some benefits, during the night, due to the radiant cooling with the sky*).

The effects of the amount of exposed surface, regarding the winter thermal dispersions and summery thermal (solar) gains, have been largely investigated in the international technical literature, also as regards the aspects related to the cooling potential of the natural ventilation. Also about this last point, in fact, the shape of the building is strongly incident [20].

According to the above reported consideration, it can be understood the distance between the limits proposed by the Italian legislators and those that, on the other hand, can represent the right limitation in order to contain the summer energy need.

The following analysis has been carried out in order to verify, numerically, just the incidence that the surface-to-volume ratio S/V, differentiated with respect to "quantity" (*i.e. surface area*) and "quality" (*i.e. exposure*) of the envelope dispersing surface, has on the building cooling demand. Also in this case, the adopted building energy simulator is EnergyPlus [5].

The simulations have been carried out modeling various buildings, on varying of the geometrical and exposure characteristics, everyone respectful of the present Italian energy legislation both as regards the building envelope stationary thermal transmittance U (*Annex C of the Legislative Decree 192/2005*) and periodic thermal transmittance $Y_{12}$ (*Presidential Decree 59*). The simulated buildings are placed in geographic contexts and climatic locations chosen in order to represent the entire national territory, from Turin to Palermo.

In the building modeling, the amount of dispersing surface varies, as well as its exposure; furthermore, when an apartment has been located at the ground floor ("*ground"* in figure 3.4.1), then, in the next simulations, the same flat has been placed also at the last floor of the building (*"sky"* in figure 3.4.1).

In figure 3.4.1, the results of the simulations are represented; as regards the grey curve, representative of the limits established in the Presidential Decree 59 with reference to the admissible values for the $EP_{e,invol}$, the absence of any relationship with the real performances of the building can be noted. In other words, the same apartment can result respectful or not of the Italian laws, according to parameters (*quality and amount of the dispersing surface*) that are not considered in the present regulations and thus not contemplated in the calculation of the admitted limits.

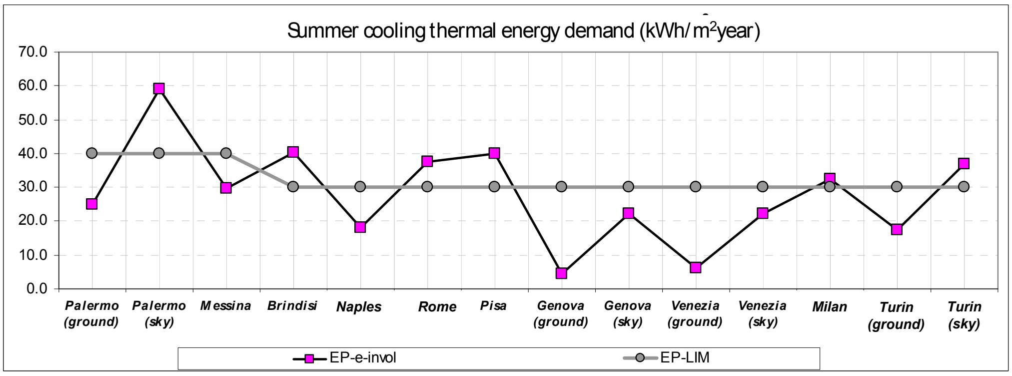


*Figure 3.4.1 – Calculated summer energy requests and limit values according to the Decree 59*

The paradox is that, with reference to the same building and in the same conditions as regards the thermal-physical properties of the building envelope, an apartment could result respectful of the law while another one would be not regular.

From this point of view, the case of Palermo is emblematic, where the 2 flats forming a detached house (*an apartment at the ground floor, the second one placed at the second and last floor*) have, although very different achievable energy performances indexes (*as regards the summer cooling demand*) the same legal limit value.

The analyses carried out in the other cities show that, even if meanly in the central-north Italian regions normally a lower summer energy demand is evaluated (*and this depends by the shorter cooling season*), $EP_{e,invol}$ higher in Turin compared to Messina can be also verified. This happens when the building envelope dispersing surface (*always modeled respecting the Italian prescriptions*) of the flat located in Turin has an exposure much penalizing as regards the summer solar irradiation.

The cases that present higher cooling requests are the strongly "irradiated" buildings located in the south- (*Palermo, Brindisi*) or central- (*Rome, Pisa*) Italian regions. In this last two case (central-Italy), the criticality derives by the lower admitted limit values for the $EP_{e,invol}$ index (*climatic zone C, D, E, F* → $EP_{e,invol}$ *limit = 30* $kWh/m^2a$), so that also the apartments located at the building intermediate floors (*i.e. low S/V*) require energy for cooling higher than the admitted value.

In order to identify, fixing the parameter "climatic context", a correlation between the nature of the building and the summer energy performance, multiple simulations have been carried out considering different buildings placed in Naples. Starting by reduced S/V factors, then the building envelope dispersing surface has been progressively incremented.

Cumulative analyses, increasing progressively the surface-to-volume ratio of the apartment, have been carried out in order to quantify the "weight" of the exposure of each building envelope element, both as regards the winter and summer energy demands,

*In order to evaluate the incidence of the "quality" of the added thermal dispersing surface, three different progressions have been considered, varying both the starting configuration and the order for the addition of the dispersing surface.*

In table III.10 the structure of the 3 progressions is explained, while in table III.11 the main results have been summarized.

Table III.10: Definition of the 3 considered progressions for a progressive increase of the building envelope dispersing surface.

| *PROGRESSION 1* | *S/V* | *PROGRESSION 2* | *S/V* |
|---|---|---|---|
| *1. NORTH* | *0.1* | *1. GROUND* | *0.29* |
| *2. NORTH + EAST* | *0.2* | *2. GROUND + NORTH* | *0.39* |
| *3. NOTH + EAST + WEST* | *0.3* | *3. GROUND + NORTH + SKY* | *0.67* |
| *4. NOTH + EAST + WEST + SOUTH* | *0.4* | *4. GR. + NORTH + SKY + EAST* | *0.77* |
| *5. NOTH + EAST + WEST + SOUTH + GR.* | *0.7* | *5. GR. + NORTH + SKY + EAST + WEST* | *0.87* |
| *6. NOTH + EAST + WEST + SOUTH + GR.+ SKY* | *1.0* | *6. GR.. + NORTH + SKY + EAST + WEST + SOUTH* | *1.00* |
| *PROGRESSION 3* | | | |
| *1. SOUTH* | *0.1* | *4. SOUTH + EST + WEST + NORTH* | *0.4* |
| *2. SOUTH + EAST* | *0.2* | *5. SOUTH + EST + WEST + NORTH + SKY* | *0.7* |
| *3. SOUTH + EAST + WEST* | *0.3* | *6. SOUTH + EST + WEST + NORTH + SKY + GR.* | *1.0* |

PROGRESSION 1

Starting by a low surface-to-volume ratio, determined by a low building envelope dispersing surface (and completely north-exposed), and increasing the quantity of the external exposed area, a linear growth of the winter heating energy requests can be noted, with a function characterized by a slope lower than the limit value line (*figure 3.4.2 A*).

This result confirms the literature data, showing a well approach of the Italian law, i.e. the substantial independence, in wintertime, of the dispersing surface "quality" (exposure) on the building heating need. *Finally, the only incident factor, as regards the heating request, is the amount of the S/V ratio*.

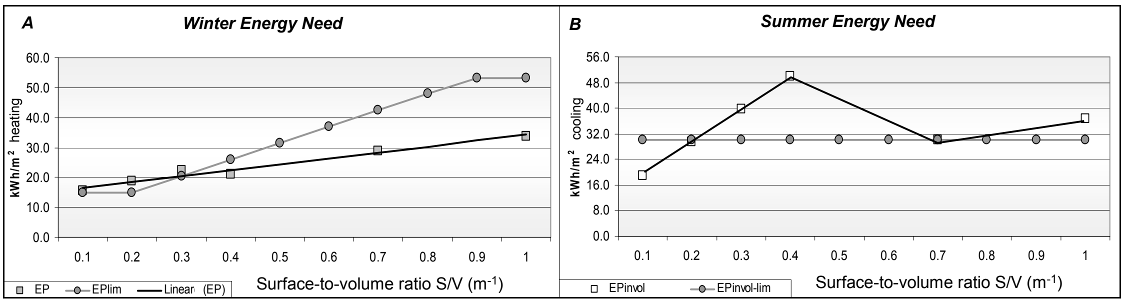


*Figure 3.4.2 – Progression 1: primary energy for the winter heating and summer cooling needs on varying the surface-to-volume ratio S/V*

It is important to note that, at least according to these boundary conditions, the winter limits imposed by the Italian legislator are more penalizing for the dwellings characterized by low values of the S/V factor. Another consideration regards the south-exposed dispersing surfaces, which even in wintertime do not cause an increment of the heating energy need.

In summertime, an opposite trend can be seen compared to the above reported notations referred to the winter season (*figure 3.4.2 A*). In fact, starting by the only one north-exposed surface and then increasing the thermal dispersing building envelope (*i.e. removing the adiabaticity of the east-, west- and south-exposed vertical walls*), a constant and significant growth of the cooling need can be noted. Then, making thermal dispersing also the ground basement, an important decrease of the cooling need happens, despite the high increment of the S/V factor; obviously, this depends by the free cooling effect determined by the transmission heat losses from the indoor environment (T = 26 °C) toward the cool soil (T ≈ 14 °C).

Increasing the building envelope external exposed surface with further 100 $m^2$ (*and so considering also the dispersing surface of the roof structure*), the cooling energy demand rises. This growth is not characterized by a very high slope, because of the substantial nocturnal radiation that contributes, in these climatic conditions, to the radiant energy dissipation and cooling interesting the high thermal mass of the roof structure (figure 3.4.2 B). The nocturnal radiative cooling will be well-described in the Chapter 4 of this Thesis.

PROGRESSION 2

This second analysis begins with the simulation of a flat characterized by thermal dispersions only through the basement; the dispersing surface has been then incremented, progressively, considering the north-exposed wall, the roof, the east vertical wall, the west wall and, at last, the south one.

Also in this case, again, in wintertime the heating energy demand grows linearly increasing the external exposed surface (fig. 3.4.3 A), and this result confirms the trend already shown in the description of the progression 1. It is very interesting to note that a same slope interests the black lines of figures 3.4.2 A and 3.4.3 A; this notation confirms the substantial independence of the S/V "*quality*" on the heating energy demand, while its "*quantity*" is the real influent parameter.

Also in this case, it can be noted that the south-exposed wall is not thermal penalizing in wintertime, inducing, despite an increment of the S/V, a light decrement of the heating request.

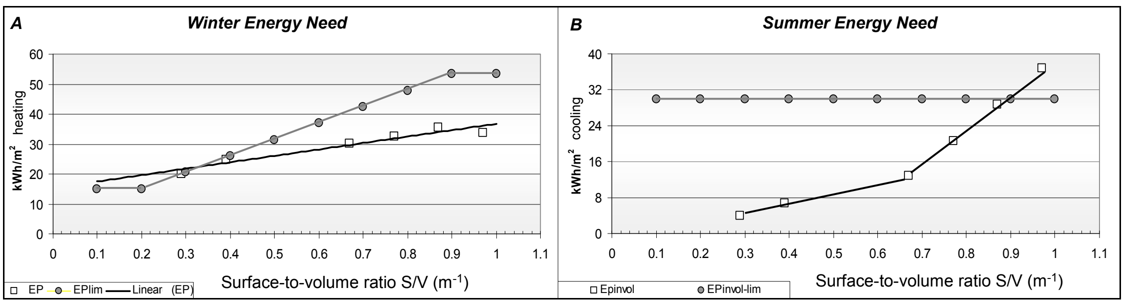


*Figure 3.4.3 – Progression 2: primary energy for the winter heating and summer cooling needs on varying the surface-to-volume ratio S/V*

This results is related also to the free heat gains due to the solar radiation entering through the transparent south-exposed surfaces. Globally, once again the winter linearity, as regards the increase of the energy demand together with the surface-to-volume ratio, is confirmed.

In summer, the result deriving from the analysis is diametrically opposite; in figure 3.4.3 B it can be noted that a flat interested by thermal transmissions only through the basement, practically, doesn't need any indoor active cooling, being the cooling effect due to the contact with the cool soil enough in order to balance the endogenous gains. Increasing the dispersing surface, removing the adiabacity of the north wall, and then of the east, west and south ones, instead, a progressive growth of the cooling demand is verified, with an increase characterized by a not linear trend. In particular, a higher slope characterizes the growth of the cooling demand when the east, west and south walls are exposed to the external environment. This event depends not only by thermal heat transfer phenomena due to the different temperatures between the indoor and the outdoor environment, but is mainly due to the high solar radiation on these building components.

PROGRESSION 3

In this third combination of progressive increment of the surface-to-volume ratio S/V, starting by the only south wall as interested by outdoor-indoor heat transfer, then, progressively, the east, west and north walls have been added as dispersing surfaces; finally, also the roof structure and the basement on the ground have been considered.

As already understandable just analysing the previously obtained results, also in this case (figure 3.4.4 A) the winter studies testify the quite light dependence of the dispersing surface quality on the heating demand, while the very influent parameter consists in the S/V ratio numerical value (*i.e. S/V quantity*). Thus, the growth of the heating demand is anyway linear, independently by the added dispersing surfaces (*that are different as regards the amount of picking solar radiation*). This result, as regards the progression 3, is even more evident, being the south wall located as base case and thus the light thermal gain, caused by this building component, does not compromise the linear increase of the heating demand. Once again, the slope of the black trend line is the same of those previously shown (*figure 3.4.2 A and figure 3.4.3 A*).

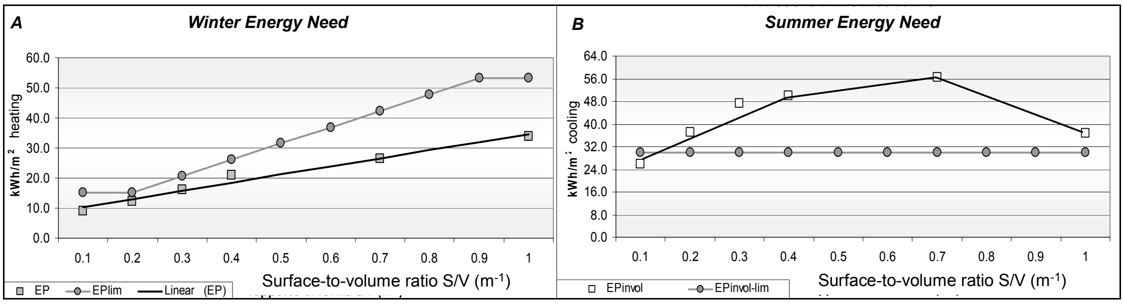


*Figure 3.4.4 – Progression 3: primary energy for the winter heating and summer cooling needs on varying the surface-to-volume ratio S/V*

In summertime (*figure 3.4.4 B*), already in the case 1 (i.e. thermal solar gains only through the south wall), the entity of the cooling energy demand is significant (26 $kWh/m^2 year$)

and it progressively increases removing the adiabaticity of the east wall and then also of the west one.

In Naples, the moderate nocturnal summer conditions make also significant the increase of the cooling energy demand due to the heat exchange through the roof structure, even if this happens above all because of the relevant amount of the added radiated surface (100 $m^2$). On the other hand, even if the roof is interested, during the day, by a significant thermal gain due to the solar radiation, during the night a radiative free cooling, between the charges thermal mass and the cool sky, is verified, balancing, at least partially, the diurnal thermal gains.

As regards the last point represented in figure 3.4.4 B, it can be noted that, also in this case, the thermal exchange between the indoor space and the ground, through the building basement, induces significant reduction of the indoor environment cooling request, even if the S/V ratio is growth.

*All the results of the described progressions and analyses are summarized and reported in table III.11.*

Table III.11: Progressive variation of the S/V factor: results of the energy dynamic calculation

| *PROGRESSION 1* | $EP_i$ | $EP_{e\text{-}invol}$ | *S/V* | *PROGRESSION 2* | $EP_i$ | $EP_{e\text{-}invol}$ | *S/V* |
|---|---|---|---|---|---|---|---|
| *1. N* | *15.7* | *19.1* | *0.1* | *1. GR* | *20* | *3.9* | *0.29* |
| *2. N + E* | *18.9* | *29.6* | *0.2* | *2. GR + N* | *24.9* | *6.8* | *0.39* |
| *3. N + E + W* | *22.3* | *39.9* | *0.3* | *3. GR + N + SKY* | *30.1* | *12.8* | *0.67* |
| *4. N + E + W + S* | *21.0* | *50.0* | *0.4* | *4 GR + N + SKY + E* | *32.6* | *20.6* | *0.77* |
| *5. N + E + W + S + GR* | *29.0* | *30.2* | *0.7* | *5. GR + N + SKY + E + W* | *35.5* | *28.8* | *0.87* |
| *6. N + E+ W + S + GR + SKY* | *33.9* | *36.8* | *1.0* | *6. GR + N + SKY + E + W + S* | *33.9* | *36.8* | *1.00* |
| *PROGRESSION 3* | | | | | | | |
| | $EP_i$ | $EP_{e\text{-}invol}$ | *S/V* | | $EP_i$ | $EP_{e\text{-}invol}$ | *S/V* |
| *1. S* | *8.9* | *25.9* | *0.1* | *4. S + E + W + N* | *21.0* | *50.8* | *0.4* |
| *2. S + E* | *12.4* | *37.0* | *0.2* | *5. S + E + W + N + SKY* | *26.4* | *56.6* | *0.7* |
| *3. S + E+ W* | *16.0* | *47.4* | *0.3* | *6. S + E + W + N + SKY + GR* | *33.9* | *36.8* | *1.0* |

As shown in the table III.11, the inadequacy of the criteria chosen to select the $EP_{e,invol}$ limits, such as provided by the Presidential Decree 59/2009, it is quite evident. The error consists not only into the proposed values (*30 – 40 kWh/m²a*), meanly acceptable, but in the adopted approximate approach, only based on the winter climatic zones.

Therefore, a new method to select more reliable limit values for the summer cooling need of building has been researched, with the aim to build a criterion that considers both the quantity of dispersing surface (*calculated with respect to the cooled building volume*) but also the "quality" of the building envelope, in particular with reference to its exposure.

In fact, as shown in the studies of the 3 progressions, these two factors (*quantity and quality of the S/V ratio*) have a great influence on the summer cooling need. The method proposed in the followings is not exhaustive but, even if it requires further investigations, anyway represents a rational and bright starting point for future developments.

The method is based on a large regression analysis (*so that it can be considered as statistically significant*) starting by the reasoning derived from the previous studies and considering the same building before investigated.

In particular, many other different simulations have been carried out, varying amount and characteristics of the envelope surface, using the flat before studied as base module combined with many others in different configurations. In this way, several buildings characterized by different dimensions and shapes have been modelled.

Starting by the results of the previous study, the polynomial function 4 as been hypothesized:

$$EP_{e,invol} = a_0 + w_1 \frac{S_N}{V} + w_2 \frac{S_W}{V} + w_3 \frac{S_E}{V} + w_4 \frac{S_S}{V} + g_5 \frac{S_{GR}}{V} + s_6 \frac{S_{SKY}}{V} \quad (4)$$

where "S" is the area of the dispersing building envelope surface, "V" the net cooled volume, the subscripts "N", "W", "E" and "S" identify the exposure with respect to the cardinal points and, finally, "GR" (i.e. ground) and "SKY" signify, respectively, the location at the ground and at the last building floor.

The coefficients "a", "w", "g" and "s" represent the values that identify the "weight" of any exposure-differentiated S/V.

With reference to approximately 35 simulations, anyone carried out varying the building dispersing surface and the cooled volume, by means of the OLS - Ordinary Least Squares - method, the coefficients of the polynomial function 4 have been determined, evaluating the standard error with reference to each one; the evaluated values of the coefficient are reported in table III.12.

Table III.12: Coefficient of the polynomial function

| $a_0$ (KNOWN TERM) | $w_1$ (NORTH) | $w_2$ (WEST) | $w_3$ (EAST) | $w_4$ (SOUTH) | $g_1$ (GROUND) | $s_1$ (SKY) |
|---|---|---|---|---|---|---|
| *kWh/m²* | *kWh/m* | *kWh/m* | *kWh/m* | *kWh/m* | *kWh/m* | *kWh/m* |
| *+ 18.3* | *+ 27* | *+ 96* | *+ 92* | *+ 91* | *- 59* | *+ 24* |

Different names have been assigned to the coefficients of the polynomial 4: *w → walls, g → ground, s → sky*; the different names would underline that these numbers express deeply different phenomena and dynamics, so that they are not immediately comparable. In particular, the coefficients referred to the vertical walls are numerically amplified from the presence of reasonable amounts of glazed surfaces, and these, in summertime, obviously determine the highest energetic flows for unit area, due to entering solar radiation; this doesn't happen with reference to the roof structure.

Moreover, the direct comparison is not possible, because of the different amounts of dispersing surface, as well as because of the different view factors with the sky, that, during the day-night cycles, determine significant solar radiation or a cooling effect related to the night radiative phenomena. Also the different operational conditions and the simultaneity of the other energy gains (*infiltrations, ventilations, endogenous loads*) do a direct comparison quite complicated.

Other studies, here not reported in order to avoid a too long descriptions, testify that, imposing the same boundary conditions (*thermal-physical properties of the building components, no glazed surfaces*) the coefficient $s_1$ would result higher than all the other ones.

Operating a statistical analysis as regards the whole simulation set, the highest calculated maximum deviation between the summer energy need, estimated by means of dynamic analysis, and the value determined using the polynomial 4 is equal to 2.5 kWh/m$^2$a, and the average error does not exceed the value of 1.1 kWh/m$^2$a. The determination coefficient, variable between 0 and 1 and predictive of the coefficient reliability in determining a value of the function closed to the known data, results very satisfactory, being equal to 0.991.

Also the standard errors, considering each coefficient and the known term, show optimal correspondence.

Thus, a method, empiricist but quite reliable, has been determined in order to estimate, approximately, the $EP_{e,invol}$ index, as regards a building realized according to the prescription of the Italian law, with reference to the thermal-physical properties of the envelope components. Then the known term of the polynomial function 4, and so the value of "$a_0$", has been opportunely raised, assigning it the numerical value of the mean temperature evaluated considering the typical months of the cooling season (*May → October*); for example, 23.3 °C with reference to the typical climate of Naples. Then, imposing the value of "$a_0$" equal to 23.3 kWh/m$^2$, the polynomial 4 application provides the results reported in figure 3.4.5.

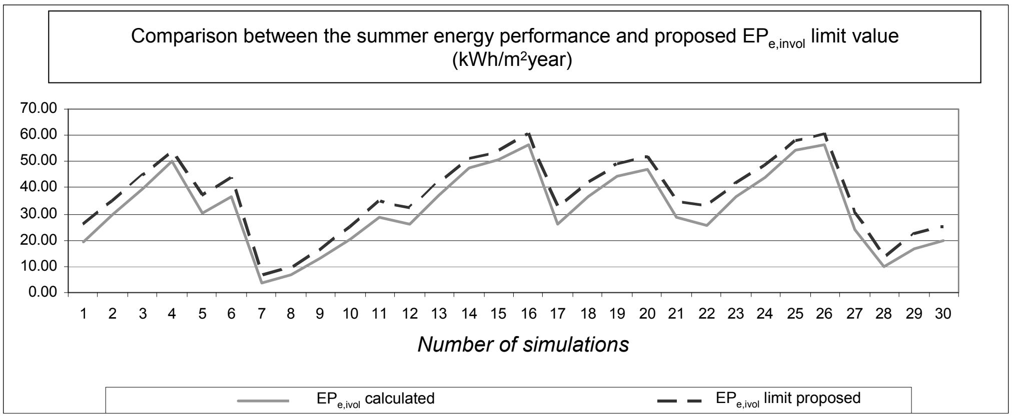


*Figure 3.4.5 – Climatic condition of Naples: energy need for the space cooling and proposed limit value*

With reference to figure 3.4.5, here the results achieved simulating around 30 different buildings and verifying the proposed criterion validity have been reported. Of course, each simulation considers a building well-designed, considering high mass and favourable S and fa factors, so that it has to satisfy the Italian prescriptions related to the summer energy performances.

In particular, in figure 3.4.5, an optimal correspondence between the $EP_{e,invol}$ calculated by means of the dynamic energy analyses (*grey lines in figure 3.4.5*) and values derived applying the proposed criterion for the limit values determination (*black hatched lines*) is evident, even if the method should be tested by means of a larger set of studies and simulations.

Anyway, it has been considered important to emphasize that, even waiting for future deepening, the choice of the variables, used to build the polynomial function 4, gives back very satisfactory results in order to identify a new, and more reasonable, method to establish a limit value for the summer cooling demand. Other studies are however necessary for different climatic context.

*For example, a reasonable improvement of the present legal method enacted to identify the maximum $EP_{e,invol}$, could vary the coefficient of the polynomial 4 depending on 5 ÷ 10 summer context.*

### 3.5 Renewable energies: integration of different sources in buildings

The present Italian energy laws (the definitive EPBD transposition, i.e. the Presidential Decree 59/2009) impose, for all the building typologies, the mandatory adoption of renewable energy sources, both with reference to the production of the domestic warm water and as regards the electric energy.

This prescription, valid for both the public and private buildings, is referred to new architectures and substantial refurbishments of exiting ones, and also it results mandatory when the technological systems are interested by renovations. In particular, the 50% of the thermal energy necessary for the domestic hot water production has to be converted by solar plants (*20% for the buildings located in the city historical centres*). About it, the article 4, paragraph 23, of the Decree 59 sends back to future implementing decrees the applicative modalities to make effectively applicable the previously cited prescription. The same article and paragraph of the Decree 59 make mandatory, for new constructions and significant renovations, the use of photovoltaic systems for the electric generation production, without defining minimal percentages of integration.

On the other hand, the financial Law 2007 (Law 27 Decembers 2006 n. 296) introduced, with the paragraph 350, a modification to the Presidential Decree 380/2001 (*Unified Body of Building Laws*). This modification introduces, at the article 4, the paragraph $1_{bis}$ reporting the following prescriptions: "*In order to obtain the release of the permission for building, it is mandatory the installation of photovoltaic systems in all new buildings, sized to guarantee at least 0.2 kW with reference to each building unit*". Moreover, the financial Law 2008 (Law 24 Decembers 2007 n. 244) introduces further modifications to the Decree 380/2001, establishing that, starting by January 2009, it must be provided an installation of renewable energy plants in order to guarantee at least an electric power of 1.0 kW/apartment, compatibly with the technical feasibility of the intervention. Thus, the minimal integration passes from 0.2 kW to 1.0 kW, and the renewable energy source becomes not necessarily the solar photovoltaic one. However, in the following study the attention is centred on this kind of systems, being, anyway, the commonest renewable solution as regards the renewable conversion of electric energy in buildings.

In addition, the important incentives provided by the Italian law in the last years (*Ministerial Decree 19.02.2007*) determined, about the photovoltaic spread, a great diffusion of installed plants. For these reasons, the photovoltaic represents surely the renewable source characterized by the highest applicative interest.

According to the legislative dispositions above recalled, today both the obligations about the installation of solar thermal systems (*50% of the domestic hot water need*) and photovoltaic plants for the conversion of electric energy (*1 kW/apartment*) coexist.

In this paragraph, the topic of adoption and conjugation of these prescriptions with the free available space that the building envelope offers will be investigated. At the same time, also the prescription (*solar or photovoltaic systems*) that seems more relevant and mandatory has been critically discussed, in order to select a "priority order".

According to opportunity criteria, as regards the choice of one between thermal or the electrical conversion by renewable sources, it seems reasonable to give priority to the thermal plants, considering that approximately 85% of the demanded building final energy has this "nature" (*i.e. 70% heating, 10% domestic hot water, 5% kitchen*). Thus, only the remaining 15% is necessary to satisfy the electrical uses (*data: Italian Minister for the Productive Activities, such as elaborated by ENEA [3]*).

In a typical flat for 4 persons (*around 100 $m^2$ according to the crowding indices of the UNI 10339 [21]*), the above reported percentages mean, meanly, the request of around 4000 $kWh_{ELECTRIC}$ and 2500 $kWh_{THERMAL}$ for the only production of the domestic hot water. With reference to the thermal uses, only the need for the hot water production is here considered, being the only one energy use cited by the Italian law as regards the thermal integration by renewable sources.

Analyzing the above described typical apartment, and estimating the effectiveness of the solution adopted as regards the reduction of the polluting emissions, in the following study it is supposed that the domestic hot water is obtained using a natural gas (methane) boiler. Moreover, usual coefficients as regards the greenhouse emissions (i.e. 0.47[2] kg $CO_{2eq}/kWh_{ELETTRIC}$ e 0.20 kg $CO_{2eq}/kWh_{THERMAL}$) have been taken into account. Simple calculations testify that:

- a correct design, with reference to the climatic conditions of Naples, of a photovoltaic system characterized by a peak power equal to 1 kWp (*7.1 $m^2$ of solar panels, south-oriented and inclined with a 30° angle with respect to the horizontal plane, with a gross cluttered roof surface around 16.5 $m^2$*) determines a net energy production of 1485 $kWh_{ELECTRIC}$. This induces a greenhouse gas emission saving around 698 kg $CO_{2eq}$/flat;
- the production of 1250 $kWh_{THERMAL}$, in order to guarantee the 50% of domestic hot water demand, instead, concurs to avoid the emission of 250 kg $CO_{2eq}$/flat.

Therefore, with reference to a typological apartment very diffused in the Italian residential context, respecting the present legal dispositions (*Presidential Decree 59/2009*) as regards the domestic hot water production, a reduction (referred to the greenhouse gas emissions) around the 36% compared to the saving achievable adopting the measure referred to the mandatory installation of photovoltaic system can be obtained. Thus, the Presidential Decree

*[2] As regards the choice of the emission coefficients (ENEA data), the whole stock of Italian national electric system has been considered, including the renewable source plants. The calculated emissions, evaluating only the traditional thermal-electric conversion plants, would be estimated equal to 0.575 kg/kWh.*

380/2001, such as modified by the financial law 2008, and regarding the mandatory use of photovoltaic, is more effective as regards the pollution emissions.

This result is achieved considering a correct design of both (*solar and photovoltaic*) the systems.

Therefore, only analyzing the effects induced by the Legislator prescriptions as regards the fight against the global warming, it results much more effective the legal measure referred to the installation of photovoltaic systems.

On the contrary, a different result would derive from an analysis of energy convenience more deeply carried out, and based also on plant costs, efficiency, possibility of complex system design (contemplating also the energy uses for the space heating and cooling). In particular, other studies testify that the thermal solar renewable technology offers energy saving potential much higher, as well as a higher environmental protection, than those obtainable by means of the photovoltaic technology [22].

Currently, the two cited legislative acts contemplate the question according to different approach. The Presidential Decree 59/2009 establishes the minimal value of the solar produced thermal energy in terms of an integration percentage with respect to the total demand, while, on the other hand, the financial Law 2008 imposes a size of the photovoltaic plant, establishing a criterion that doesn't guarantee a well-defined electric production. In particular, the Law 24 December 2007 n. 244 modifies the Unified Body of Building Laws imposing an integration of the electrical energy request by means of a photovoltaic system sized at least equal to 1 kW/apartment. In this way, the dimensions of the flats are not computed, so that the same size of the plant (*i.e. 1 kWp*) is required for poor dwellings (for example 50 m$^2$) and luxury villas (e.g. 400 m$^2$). Furthermore, the identified limit is quite out of a rational criterion too. The power (size) of a photovoltaic system, in fact, is calculated considering standard design boundary conditions, being referred, in particular, to a radiation equal to 1000 W/m$^2$ and a temperature of the solar modules of 25 °C. Of course, the Italian law is referred to this operational conditions, and it doesn't guarantee anything about the real achievable energy conversion.

In other words, as it has briefly reported in table III.13, it is possible that different photovoltaic systems, characterized by the same size, determine very different energy conversion performances, due to different locations, exposures, inclinations, efficiency of the panels.

Table III.13: Photovoltaic systems: variability of electric energy conversion, considering the same size of the plant (climatic data: UNI 10349)

| *Size of the photovoltaic system* | *Azimuth angle* | *Tilt angle* | *Net conversion* | *$CO_{2eq}$ avoided* |
|---|---|---|---|---|
| kWp | ° | ° | kWh/year | Kg |
| 1.0 | 0 (South) | 30 (optimized) | 1485 | 698 |
| 1.0 | 0 | 0 (horizontal) | 1329 | 625 |
| 1.0 | 0 (South) | 90 (vertical) | 965 | 454 |
| 1.0 | ± 90 (East/West) | 90 (vertical) | 913 | 429 |

Therefore, it becomes clear that, not only the real conditions as regards the solar radiation (also considering the geographic context and eventual shadows) are neglected, but also important design choices are not taken into account. Surely, it would been more useful the imposition of a minimum integration percentage, calculated with respect to the overall electric demand (*at the same way adopted for the solar thermal systems as regards the domestic hot water production*), e.g. considering the crowding density and the flat useful surface.

For example, considering an annual mean request of electric energy around 750 $kWh_E$/person, a reasonable integration percentage, achievable adopting a photovoltaic system, is around the 36% of the overall electric need. This means that, recurring to the crowding index reported by the UNI standard 10339 (*for residential application → 0.04 persons/m²*), then, imposing the established integration percentage (36%), an apartment of 100 $m^2$ should be equipped with a photovoltaic system with an annual energy conversion of 1050 kWh. This electric production by renewable could be assured by the different solutions proposed in table III.14.

In the table III.13, it merges clearly the mismatch between the data imposed by the law and the real electric conversion capability of a photovoltaic system. *It would be favourable that a corrective legislative provision removes this mistake, in particular establishing new prescriptions in which the concept of "power" is replaced by the one of convertible electric "energy".*

Table III.14: Differences (technology, exposure, location) of photovoltaic systems considering the same energy conversion quantity*

| | *Required energy* | *Position* | *Azimuth angle* | *Tilt angle* | *Plant size* | *Technology* | *Photovoltaic areas* | *Gross Surface* |
|---|---|---|---|---|---|---|---|---|
| | kWh/year | | ° | ° | kWp | | $m^2$ | $m^2$ |
| 1 | 1050 | Flat roof | 0 (South) | 30 | 0.70 | polycrist. | 6.4** | 14.7** |
| 2 | 1050 | Flat roof | 0 (South) | 30 | 0.70 | monocrist. | 5.0** | 11.5** |
| 3 | 1050 | Flat roof | 0 | 0 | 0.80 | polycrist. | 7.2 | 7.2 |
| 4 | 1050 | Flat roof | 0 | 0 | 0.80 | monocrist. | 5.7 | 5.7 |
| 5 | 1050 | Vertical wall | ± 90 (East/West) | 90 | 1.15 | polycrist. | 10.5 | 10.5 |
| 7 | 1050 | Vertical wall | 0 (South) | 90 | 1.10 | polycrist. | 10.0 | 10.0 |
| 8 | 1050 | Vertical wall | ± 90 (East/West) | 90 | 1.15 | monocrist. | 8.3 | 8.3 |
| 10 | 1050 | Vertical wall | 0 (South) | 90 | 1.10 | monocrist. | 7.9 | 7.9 |

** simulations carried out considering the Naples climate ** projection on the horizontal plane*

*Figure 3.5.1 – Public housing programs (Law 167/'62): dwellings of Ponticelli (Naples)*

Besides the cited aspects, related to the coherence of the new prescriptions established by the Italian legislator, a clear question about the compatibility, in the same building, of both solar thermal and photovoltaic plants exists. In fact, with reference to common buildings, the free external surface area, sun-exposed, is limited. For technological reasons, a solar collector panel can be difficultly located on a vertical wall, while this inclination, even if not preferable, anyway can be used for a photovoltaic module.

Therefore, it is clear that, on the roofs of the buildings (flat or inclined) the location of solar thermal modules will be necessary, with the correct quantity calculated in order to satisfy the prescriptions as regards the 50% of integration by renewable solar sources. Thus, it can be immediately understood that, with reference to the high intensive housing, not enough space could be available. In fact, for a tower building (*characterized also by 12 - 15 floors*), the only satisfaction of the thermal solar prescriptions is quite critical.

In the following example, a sanitary warm water requirement around 40 litres/day person has been evaluated. The roof of the building represented in figure 3.5.2 (*typical of the Italian building tradition during the last 40 years*) cannot guarantee more than 65 $m^2$ of net solar surface.

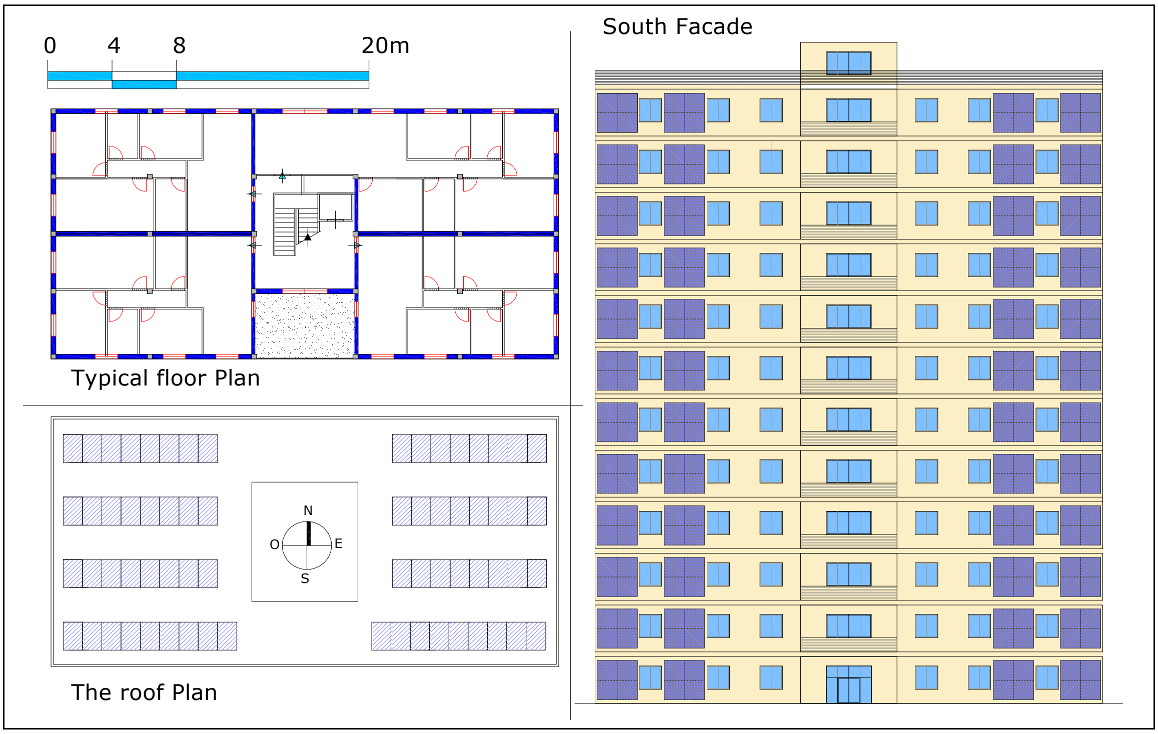


*Figure 3.5.2 – Coexistence criticalities of different renewable sources as regards the intensive housing*

The 65 $m^2$ have been calculated as net area, and so respecting the right distances among the modules, in order to limit the mutual shadows. Imaging the adoption of selective glazed solar modules with an inclination of 30°, and south-oriented, in this way a 46% of the hot water need of 228 persons in Milan can be guaranteed. Considering the building of figure 3.5.2 (*4 apartments/floor, i.e. 18 - 20 persons/floor*) the roof will be just enough to guarantee the 50% integration if the building would have until 12 floors. The real problem regards the installation of the photovoltaic system. In fact, as regards the building roof, no more space is available, so that necessarily the vertical walls have to be used. According to the recent legal acts (financial Law 2008), at least 48 kWp of photovoltaic have to be designed (*1 kWp, 48 apartments*). It means the use of 300 $m^2$ of the south-exposed vertical walls occupied by PV panels, as well as other 70 $m^2$ both on the west and east oriented vertical surfaces. These are the results of the calculations considering the adoption of mono-crystalline modules. It can be understood that the situation is very critical and will become, in the future, very common with reference to the suburb growth (usually interested by low free space so that, in the last year, the housing have been strongly built in the "vertical" direction). About this, a further critical aspect will be represented by the shadows due to the buildings placed around (figure 3.5.1).

With reference to the not urban urbanization, the problem will be much less critical, being here available more space for different housing typologies (sticks, line, block), in an environmental context not so congested as regards the building density. Furthermore, in this case, also the more free surroundings will determine lower shadings and thus higher radiation on the building solar and photovoltaic modules.

Definitively, the question is still unsolved. Until now, the impact of the new prescriptions related to the mandatory use of renewable sources has been underestimated. In the future, analogously to the present city growths in other nations (Japan, Israel and Germany, above all), also the Italian cities will necessarily grow designing buildings with an intensive use of solar systems, so that the aspect of the towns will change greatly.

The future challenge is, therefore, a full architectonic integration of the renewable energy source within the architectures, not only in a simplified join of building components and solar panels, but according to a deeper meaning. The building shell will become, at the same time, also an energy component, so that envelope structures and technical services would be an only one architectural element, characterized by several functions.

## 3.6 THE ENERGY PERFORMANCE OF EXISTING BUILDINGS

### 3.6.1 INTRODUCTION: RESIDENTIAL BUILDING STOCK AND BUILDING ENVELOPE BEHAVIOUR

Until now, this chapter has investigated some critical aspects regarding the Italian new energy laws referred to the building energy efficiency, both with reference to the legal and procedural aspects. Inside a large and quite innovative international and national context, considering the European directives and the Italian measures, the international CEN standards and the national technical documents, the Italian legislator worked hardly during the last years.

Obviously, the continuous evolution interesting the building energy question in the last years determined great difficulties as regards the harmonization and transpositions of several trends, prescriptions and procedural methodologies, so that not the whole work is, at the present moment, perfectly running. Thus, the job, significant and meritorious, carried out, in Italy, by the several institutions, technicians and all the involved people, requires further investigations and tests, being natural some mismatches and overlapping.

The proposed analyses, until now carried out and referred above all to the new buildings, concerned some of the most important and new topics developed by the present legislative and procedural context. In particular, the role played by the glazed surface in wintertime, the building shell behaviour during the summer, the prescriptions related to the summer performances of a building and, finally, the compatibility of renewable sources have been analysed.

The achieved results, sometimes well-correspondent to the knowledge of the specific technical literature, sometimes quite significant as regards the underlining of some deficiencies and defects of the Italian context, have been reported in order to stimulate new investigations and reflections in the national technical community.

In this section, a new great topic related to the Italian dwelling energy efficiency will be discussed, in particular focusing the attention to the energy performances and to possible light energy improvements of the existing building stock.

As already reported in the Chapter 1, in the European Union (*the world region characterized by the highest housing density*) the energy requirement for heating, cooling, lighting and the other technological functions connected to the use of the building represents about the 40% of the global energy use.

The European Union EPBD Directive 2002/91/CE (Energy Performance of Building Directive) and the related standards and national laws demand close attention to energy efficiency in buildings. In particular, recently, energy saving prescriptions were introduced also for the existing building re-qualifications. In this paragraph, the energy efficiency of the system building-thermal plants has been evaluated, with reference to the existing architectures, considering also the summertime performances, because of the warm period is very important in the Mediterranean area.

From this point of view, the Italian rules result quite approximate (*as shown in the previous paragraphs*), so that the analysis of winter performances (adapt in the central-northern Europe) is still now the main energy prescription. Presently, except some general indications, effective strategies about the summer cooling energy requirements are absent, while air-conditioning systems are now very frequent in each building, public or private, with the correlated growth of peak demand for electric energy in summertime [23].

Out of the Europe, in particular in Florida and California, studies of passive solutions on the building envelope are carried out by various and authoritative research centres, above all with reference to roof components, that, contrarily to vertical walls, are interested by solar irradiation all day long. As above reported, in the United States, in addition to many local organizations, nationwide societies operate in this sector, such as the Energy Star Roofing Program of the Environmental Protection Agency (EPA) and the Cool Roofs Rating Council (CRRC). These research centres carry out studies, energy diagnoses and certifications of building envelope components, as regards the energy performances in terms of the structure aptitude to absorb and transfer inside the solar radiation or to reject it. In particular, the CRRC certifications define performance levels of a building component evaluating its solar (whole spectrum) reflectance and far-infrared emissivity.

The American Society for Testing and Materials (ASTM) introduced, referring to roofs and almost horizontal building surfaces, the SRI - Solar Reflectance Index – that combines solar reflectance and far-infrared emissivity. This coefficient is conventionally fixed equal to 100 for a standard white surface and equal to 0 for a standard black surface; it is calculated through analytical correlations based on measured values of solar reflectance and far-infrared emissivity. Coatings characterized by high SRI values result useful to reduce the peak demand for electric energy in summertime in temperate climatic zones, as well as to reduce the energy requirements for summer cooling in hot climates, with savings ranging from 10% to 60% [24].

In multilayer walls (widespread solution in the constructive European tradition), reducing temperature excursions becomes functional also to extend the life time of building structures, that are exposed to minor thermal shock during the day-night cycles.

Already starting from the second half of the '60s, many experiments were carried out in Israel on small buildings characterized by identical composition of the building envelopes, which differed only in the external surface treatments [25]. The studies, carried out in non-ventilated buildings, showed that during the summer the grey buildings internal average temperature was around 3 °C higher than that measured in the same building white painted. In the 90's, in India [26] experimental analyses showed that a white building, without air-conditioning system, in summertime maintained internal average temperatures of 4 ÷ 8 °C lower than the same building with dark external coating.

All studies conducted in the early 90's, through experiments and numerical simulations, have shown that acting on spectral characteristics of the outer envelope surfaces is the most effective action, both in terms of costs and achievable benefits for thermal comfort inside not air-conditioned buildings and in order to reduce energy demands in conditioned spaces [27, 28, 29, 30].

The Florida Solar Energy Center has investigated on the performance achievable using 37 different surface finishes [31], evidencing that, also compared to new technologies and solutions, clear colours of external surfaces induce the best performances; this happens because, even if some coatings result more reflective (some metal surfaces), it is necessary the evaluation of the infrared emissivity too. Extending the reasoning to a larger scale, numerical analyses [32] showed that clear, reflective and high-emissive external surfaces help to reduce heat islands of urban contexts too, and, therefore, these are useful also in reducing the peak demand of the electric energy for the summer air-conditioning [33].

In addition to the action on spectral characteristics of the external coatings in order to reduce the peak cooling loads and the energy requests of the building air-conditioning during the summer period, it is necessary to investigate, at the same time, the influence and the performance induced by different levels of thermal inertia and capacity of the envelope structures.

The influence of high thermal mass of the building envelope structures have been studied largely in the last years. About this topic, only some scientific papers will be cited, extracting the most significant results with respect to the aim of the study reported in the Thesis.

Balaras showed, in an extended review [34], the role of thermal mass in reducing the peak cooling load and its capacity in containing the temperature swings during the diurnal-nocturnal cycles; this author underlines the role of thermal mass mitigation on the indoor temperature, so that a higher indoor comfort is provided. This author notes that an elevated thermal inertia becomes very important not only in summertime but, above all, during the intermediate seasons, when the large variations of external climatic condition during the 24 hours could be mitigated inside the indoor spaces. The same author underlines the important role of nighttime ventilation, when the summer outdoor air temperatures, usually lower than the internal ones, discharge the heated mass of the envelope, so that the building results again ready to store energy during the following day.

Kolokotroni [35], in an experimental study carried out through field measurements in refurbished UK offices, shows the effectiveness of summer nocturnal ventilation, evidencing that when the spaces are ventilated during the night time, in the following days the indoor temperature results lower, above all in the first hours of the working time.

Similar studies have been conducted also by Givoni [36] that, evaluating the results obtained monitoring the indoor conditions inside several buildings with different mass levels in South California, on varying the night–time ventilation amount, evidenced that only in heavy structures the role of night free cooling becomes significant. The results obtained coupling thermal mass and nighttime ventilation are very significant, determining attenuated thermal level during the day and the discharge of energy during the night hours. The Givoni's studies show that the diurnal indoor temperatures in massive building depend on the building envelope storing capacity, as well as on the effectiveness of the nocturnal ventilation in cooling the structure. The same author, 16 years before [37] extended to the whole building the thermal time constant of each envelope component, introducing the TTTCB (*Total Thermal Time Constant of Building*).

During the 1997 warmest period (January – March), Ogoli [38] monitored the indoor conditions of 4 environmental test chambers characterized by various thermal mass levels in Kenya; air changes are constant and equal to 0.5 $h^{-1}$. The microclimatic measurements showed that the high mass is useful to reduce the peaks, so that the thermal level swings result limited. Of course, even if the indoor diurnal temperatures of massive building are lower than the temperatures of light building, in the nighttime an opposite situation occurs, so that the light weight chamber (timber walls) has indoor temperatures significantly lower compared to the heavy (stone walls) test-cell. Opaque building components able to store energy (*shifting and attenuating the energy transmission to the indoor environment*) become therefore useful to reduce the temperature fluctuations within the indoor spaces, and it means lower thermal level during the external thermal peak load but also higher temperatures during the night. According to Henze [39] the attenuation of the indoor temperature swings, using high thermal inertia building envelope, could be a strategy of energy savings, only if adaptive thermal comfort criteria are adopted for the HVAC control. On the contrary, in the last section of this paragraph (*sub-paragraph 3.6.3*) it is shown that, when a fix set-point temperature is necessary and maintained, thermal mass without nocturnal cooling doesn't induce any useful energy saving.

Finally, as already cited in the paragraph 3.3 of this chapter, massive envelope are well fit when the use of the building is above all in the central period of the day (second half of morning and afternoon). Instead, as regards massive residential constructions, the nocturnal free cooling and other techniques of mass activation become necessary to limit the thermal discomfort or/and reduce the night cooling loads, being these higher in heavy buildings compared to lightweight envelopes.

The role played by the building coatings and by the envelope mass are here investigated, proposing new considerations, in particular with reference to the Italian and European context, also proposing new methodologies apt to improve the existing building performances depending on these parameters.

In Italy, the cited Law 167/1962 instituted the formation of urban planning zone, for the construction of social housing residential settlements, quite always realizing dormitory districts representing the national image of social and urban blight of large areas of Italian cities.

The following study is conducted through the instruments of dynamic energy simulation [5], applied to a building case-study, modelled with constructive and typological characteristics of many dwellings built in Italy during the last fifty years.

After a brief introductory analysis about the different energy needs on varying the exposure, choosing the south-west apartment as sample reference for simulations, some studies have been carried out, initially with reference to the climatic conditions of Naples (Italy), analyzing the effect of surface finishes on the thermal energy requests of the building. In particular, on varying absorptance/reflectance factors and far-infrared emissivity, the external coatings become elements that strongly affect the level of energy requirements, also maintaining the same building heat transfer overall coefficient (overall $U_{value}$).

Moreover, still with reference to existing constructions, criteria to choose the most adapt surface coatings are identified, depending on the weather conditions, introducing a general method of choice based on summer solar radiation related to the coldness and duration of the heating season. Finally, the effects of ventilation on the energy requirements for the summer cooling are evaluated, on varying the thermal inertia of the structures.

### 3.6.2 ANALYSES OF A CASE-STUDY: INFLUENCE OF THE BUILDING EXPOSURE, EXTERNAL COATINGS AND ENVELOPE MASS ON THE HEATING/COOLING ENERGY REQUESTS

The case-study is based on a reference building (figure 3.6.1), built in reinforced concrete, with vertical multilayer claddings in double layer of hollow bricks with air gap and horizontal structures in mixed brick / concrete materials. The plan dimensions are 30 m • 16 m; any floor presents 4 apartments, each one placed in a corner of the building so that it is characterized by a double exposure. The other main characteristics of the building are reported in table III.15

Table III.15: Case-study: building description and boundary condition definition

| | | | |
|---|---|---|---|
| DIMENSIONS OF EACH APARTMENT | | | |
| Length (N-S direction) | 8.0 m | Width (E-W direction) | 12.5 m |
| Height | 3.5 m | Plant area and Volume | 100 $m^2$ - 350 $m^3$ |
| BOUNDARY DESIGN CONDITIONS | | | |
| Climatic file and data | File IWEC and TMY2 | Occupancy (design)* | 5 persons per apartment |
| Metabolic Index | 1.5 met per person | Natural ventilation | 1 Vol / h |
| Artificial lighting (design)* | 15 W / $m^2$ | Other installed electric equipments* | 5 W / $m^2$ |
| $T_{SUMMER-SET-POINT}$ (24 h - 7 days) 26 °C | | $T_{WINTER-SET-POINT}$ (24 h - 7 days) 20 °C | |
| $U_{WINDOW}$ | 3.0 W / $m^2$ K | $U_{VERTICAL-STRUCTURES}$ | 0.84 W / $m^2$ K |
| Thermal Mass | 156 kg / $m^2$ | Electric energy cost | 0.18 € / kWh[1] |
| HEATING: System global efficiency : | 0.57 | Natural Gas cost | 0.65 € / $Nm^3$ |
| COOLING: Seasonal Energy Efficiency Ratio: 2.9, i.e. 10 BTU / Wh | | Thermal to electrical conversion efficiency | 0.36 |
| $CO_{2-eq}$ emissions: 0.20 $kg/kWh_{THERMAL}$ | | $CO_{2-eq}$ specific emissions: 0.60 $kg/kWh_{ELECTRIC}$ | |
| ** A hourly scheduling with reference to occupancy, artificial lighting and other installed electric equipments is fixed* | | | |

The indoor design temperatures correspond to Italian standards, 20 °C for winter from D.P.R. 412/93 (*President of the Italian Republic [8])* and 26 °C for summer. With reference to the energy re-qualification of urban residential buildings, simple radiators for heating and split systems for cooling have been considered. The heating system global efficiency is fixed at 0.57, considering a typical hot water boiler, centralized control system, un-insulated distribution with pipes within external walls and radiators.

About summer cooling, split system SEER (*i.e. Seasonal Energy Efficiency Ratio*) of 2.9 has been considered (in the United States, since January 2006 the new residential air-conditioners must have a minimum SEER of 3.8, i.e. 13 BTU/Wh, but a medium value for a typical split system previously installed is around 2.8 – 3.0).

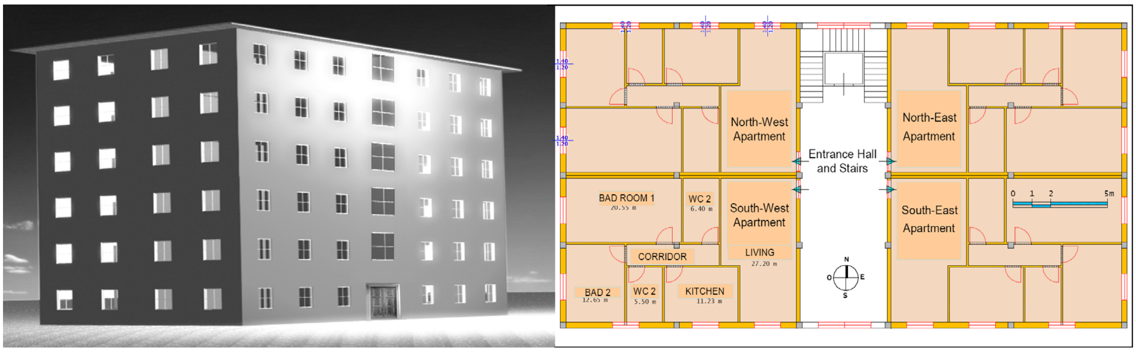


*Figure 3.6.1 – Case-study building model and typological floor*

The calculations have been executed using coefficients provided by the most authoritative Italian Organizations (Italian Regulatory Authority for Electricity and Gas, Italian Federation for Rational use of Energy). In particular, the emissions have been obtained evaluating the natural gas and electricity annual needs and multiplying them, respectively, for the $CO_{2\text{-eq}}$ specific emission coefficients.

When not differently specified, the following analyses are referred to Naples (South Italy) and to apartments situated at intermediate floors.

a) EFFECTS OF VARIOUS EXPOSURES ON ENERGY REQUESTS FOR WINTER HEATING AND SUMMER COOLING

The energy simulations produced very similar results for the two couples of apartments south-west/south-east and north-west/north-east. With reference to the only energy needs of building envelope (*i.e. without considering the heating/cooling system efficiency ratios*), the best performances are obtained, in wintertime, by the south-oriented apartments, inducing these energy savings of 10 % as regards the heating demand compared to north-oriented flats. In summer, the north-exposure guarantees, of course, a lower thermal load, with seasonal savings around the 16 % with reference to the cooling need.

Of course, the same trends, calculated with reference to new buildings and reported in the paragraph 3.4, are confirmed, even if the absolute values are obviously different in the study here reported, referred to the existing popular districts.

In order to pass from the building envelope energy needs (QE) to primary energy requests (EP) and to environmental impact (table III.16), the heating efficiency, the cooling SEER and the specific $CO_{2\text{-eq}}$ emission coefficients have been considered, such as reported in the table III.15.

As clear in table III.16, the various exposures do not cause significant *annual* differences in the energy requirements of the apartments, while the opposite result occurs considering singularly the heating and cooling seasons.

Table III.16: Yearly specific primary energy and $CO_{2eq}$ emissions on varying the apartment orientation

| | $EP_{HEATING}$ | $EP_{COOLING}$ | $EP_{TOTAL}$ | $CO_{2eq\text{-}HEATING}$ | $CO_{2eq\text{-}COOLING}$ | $CO_{2eq\text{-}TOTAL}$ |
|---|---|---|---|---|---|---|
| | (kWh / m$^2$) | (kWh / m$^2$) | (kWh / m$^2$) | TONS/apartment | TONS/apartment | TONS/apartment |
| south-west | 43.2 | 18.3 | 61.5 | 0.86 | 0.40 | 1.26 |
| south-east | 43.2 | 18.4 | 61.5 | 0.86 | 0.40 | 1.26 |
| north-east | 47.9 | 15.4 | 63.3 | 0.96 | 0.33 | 1.29 |
| north-west | 48.0 | 15.4 | 63.4 | 0.96 | 0.33 | 1.29 |

It can be noted that, considering a very favourable surface to volume ratio S/V (*external surface/heated gross volume*) equal to 0.2 m$^{-1}$ (*a value quite common for apartments in blocks*), the limits of the $EP_{HEATING}$ fixed by Italian Legislative Decree 192/2005 for Naples are yearly about 13-14 kWh/m$^2$.

Thus, $EP_{HEATING}$ values around 45 kWh/m$^2$ (table III.16) are not at all satisfactory and testify very poor energy performances obtained by this large worldwide building typology.

b) VARIATION OF ENERGY REQUESTS AS A FUNCTION OF REFLECTANCE AND FAR-INFRARED EMISSIVITY OF BUILDING ENVELOPE EXTERNAL SURFACES

In summertime, the heat transfer overall coefficient (thermal transmittance) and the thermal capacity are not exhaustive indicators of the building envelope thermal behaviour. In fact, the heat transfers are not only determined by the energy flows induced by temperature differences, but the thermal exchanges are also strongly affected by the solar radiation on opaque and transparent surfaces. The solar radiation incident on a surface is partially transmitted (transparent components), partially absorbed and partially reflected by the structure, that transfers the stored energy, softening and delaying the thermal wave.

The radiant solar energy (*5 % ultraviolet, 43 % visible, 52 % near-infrared*) on an opaque surface is partially reflected and partially absorbed by the structure, depending on absorptance ($\alpha$) and reflectance ($\rho$) factors, related to the type and colour of external finishing. In addition, the infrared emissivity ($\varepsilon_{FAR\text{-}INFRARED}$) of the external envelope coating is important, because it affects the attitude of the surface as regards delivering radiant energy.

In warm climates, where the summer cooling needs prevail over the demand for winter heating, much better performances are obtained using a surface finishing with high far-infrared emissivity (a considerable part of energy is thus re-radiated to the sky in the high wavelength field), and high external solar reflectance.

White plaster and clear (cool) paints can reflect up to 95 % of solar radiation, emitting a great deal (infrared emissivity up to 90 %) in form of thermal radiation (high wavelengths). Thus, the amount of heat transmission towards the indoor environment is inversely proportional to solar reflection and infrared emissivity.

The equation 5 [40] defines the sol-air temperature introduced for the calculation of the summer cooling load (UNI, 1995): the solar absorptance factor (α) of surfaces has been taken into account, while the infrared emissivity (ε) has not been considered, which means operating under safety criteria.

The equation 5 can be replaced by equation 6, according to a more complex model proposed by ASHRAE [2005]:

$$T_{\text{SOL-AIR}} = T_{\text{EXTERNAL}} + \left(\alpha_{\text{SOLAR}} \cdot I / h_{\text{EXTERNAL}}\right) \qquad (5)$$

$$T_{\text{SOL-AIR}} = T_{\text{EXTERNAL}} + \left(\alpha_{\text{SOLAR}} \cdot I / h_{\text{EXTERNAL}}\right) - \left(\varepsilon_{\text{FAR-INFRARED}} \cdot \Delta R / h_{\text{EXTERNAL}}\right) \qquad (6)$$

where ΔR represents the difference between radiation emitted by blackbody at outdoor air temperature and long-wave radiation transferred on the envelope surface from sky and surroundings. In both the equations, $h_{\text{EXTERNAL}}$ represents the heat transfer coefficient for radiation (long wave) and convection.

From equation 6, it can be inferred that in summer a medium-high reflective surface (such as metals) offers poor performances if it has a low infrared emissivity, because not enough energy is radiated back, determining an increase in surface temperature. It occurs although this surface presents better characteristics compared to a low-reflective surface, as regards the amount of reflected solar energy.

The difficulty in determining ΔR often leads to neglect the last term of equation 6: this approach, as regards the vertical surfaces, is admitted [41] only to calculate the $T_{\text{SOL-AIR}}$ for the peak thermal load evaluation (necessary for sizing the air-conditioning system).

Otherwise, about the evaluation of building energy efficiency, in many geographic regions a high $\varepsilon_{\text{FAR-INFRARED}}$ determines relevant energy savings for the summer cooling, as shown in the followings. For example, the surface coating in metal panels has a bad behaviour about the far-infrared emission, even if it presents high solar reflectance.

Therefore, the choice of surface coatings highly affects the building envelope performances and the active energy amount, by means of the use of an air-conditioner, required to maintain indoor comfort conditions in both the climatic seasons.

After the theoretical considerations above reported, the envelope energy needs of the south-west apartment are analyzed below, on varying the characteristics of the envelope external coatings with fixed values of thermal transmittance and capacity.

The surface coating in light concrete for the vertical walls has been used as comparison reference. In figure 3.6.2, elaborated simplifying a Florida Solar Energy Center study, illustrates the radiative characteristics of different surface coatings. In particular, the white circles show the coatings used in the following simulations.

In table III.17 and in figure 3.6.3, the apartment thermal energy requests in winter and summer, for unitary surface, are reported as a function of external coatings. In winter (table III.17 and figure 3.6.3a), aluminum panels induce consistent heat gains and thus an energy demand reduction of about 16 % compared to the reference case. External coatings in red brick and white plaster, in winter, cause a higher energy request, respectively of about 4 % and 16 %.

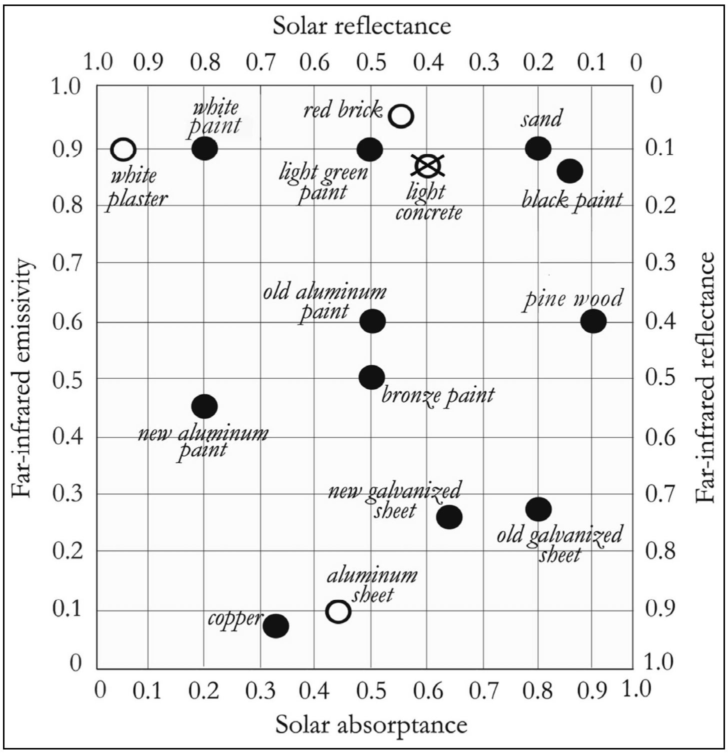


*Figure 3.6.2 – Radiative characteristics of various building materials*

Table III.17: Building yearly specific energy requests (QE) and percentage variations as a function of the external coating

| | White Plaster | Red Brick | Light Concrete | Aluminum Panels |
|---|---|---|---|---|
| $QE_{HEATING}$ (kWh / m$^2$) | 28.62 | 25.90 | 24.71 | 20.80 |
| HEATING INCREASE/DECREASE | + 15.8% | + 4.0% | ------- | - 15.8% |
| $QE_{COOLING}$ (kWh / m$^2$) | 14.02 | 18.60 | 19.25 | 23.90 |
| COOLING INCREASE/DECREASE | - 27.1% | - 3.5% | ------- | + 24.1% |

As regards the summer cooling (table III.17 and figure 3.6.3b), the results confirm those reported in the technical literature, and already known in many historical Mediterranean buildings. The white plaster provides summer energy savings higher than 27 % compared to the concrete; aluminum panels determine a summer indoor overheating, implying an increase of energy requests for cooling, about +24 % compared to the reference case. This is because, considering the equation (4), aluminum emits less than concrete, even if it reflects more (figure 3.6.2).

A slightly better result compared to concrete is obtained by using strips of red brick.

Moreover, figure 3.6.3a shows winter energy requirement trends varying external finishes to be quite similar for each month and with monthly differences quite constant. Figure 3.6.3b shows that in the warmest months, July and August, these differences become greater as white plaster and aluminum panels increase their tendency to induce, respectively, the best and the worst performances.

Referring again to table III.17, the aluminum coating causes a specific yearly cooling requirement of 23.9 kWh/m$^2$, while the white plaster requires 14.0 kWh/m$^2$ (-70 %).

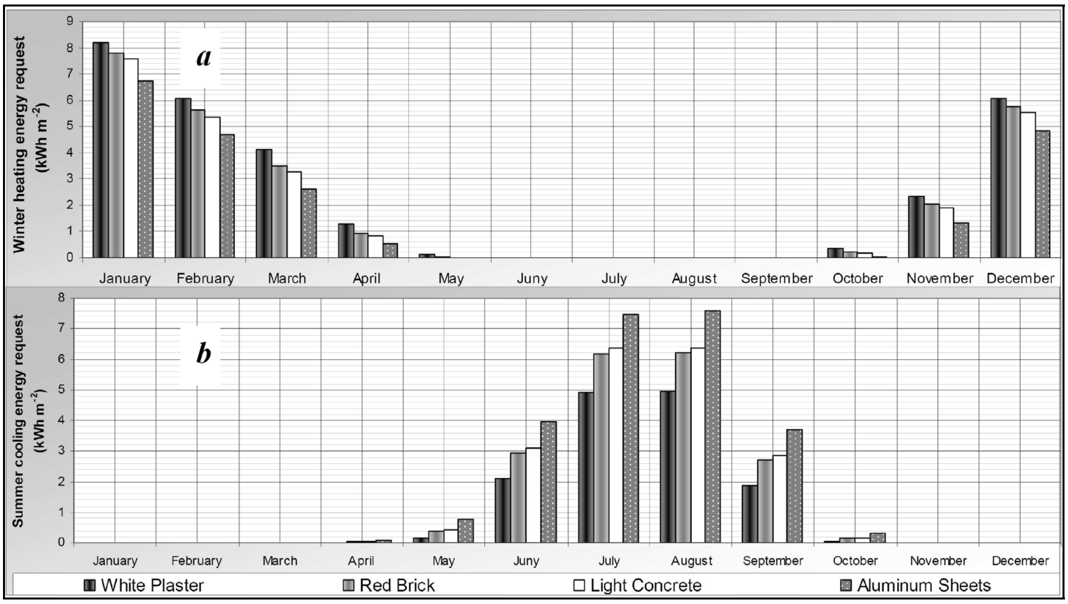


*Figure 3.6.3 – Building specific monthly energy request for winter heating (a) and for summer cooling (b)*

Note that only the apartment with aluminum panel has energy requirements for summer cooling which are greater compared to winter heating requirements (*23.9 kWh/m$^2$ vs. 20.8 kWh/m$^2$*). Of course, the results obtained are closely linked to the imposed boundary conditions e.g. the ratio between external exposed surface and gross conditioned volume (S/V), the Mediterranean climatic conditions of Naples, the thermal-physical characteristics and the exposition of the dwellings.

In any case, regardless of the specific boundary conditions, the abovementioned radiative characteristics, scarcely considered by rules and laws, can profoundly affect building energy performances. For example, a simple and inexpensive painting of the facades can change the class of the energy certificate (see European 2002/91/CE EPBD).

In figures 3.6.4 and 3.6.5 the external and internal surface temperatures of the south wall are reported, considering some significant days of the year and hourly time steps, for both the winter (figure 3.6.4) and the summer (figure 3.6.5) seasons.

In winter, the highest peaks and the most relevant thermal cycles, with reference to the outdoor surface temperature, are inducted by the aluminum sheets, which in January can reach almost 35 °C in the middle of the day (figure 3.6.4a).

As expected, the lowest outdoor and indoor superficial temperatures are caused by the external surface in white plaster (figures 3.6.4a and 3.6.4b), that causes also the lightest night/day thermal cycles. Moreover, figure 3.6.4b shows that the external coating in aluminum causes also the maximum winter indoor surface temperature, with T even higher than 21 °C, and minimum value of 18.7 °C.

Again, the performances achieved using red bricks and light concrete result quite similar and intermediate (as inferable from Figure 3.6.2), while the lowest temperatures (18 °C ÷ 20.5 °C) refer to white plaster.

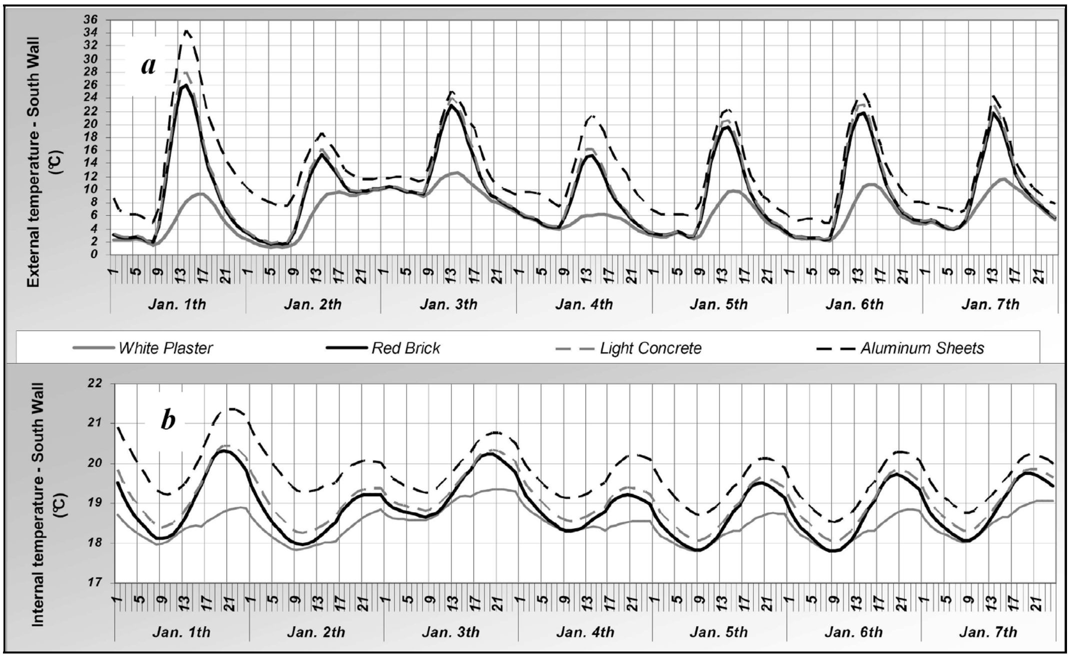


*Figure 3.6.4 – External (a) and internal (b) surface temperatures of the south wall as a function of the considered external coatings, for some winter days*

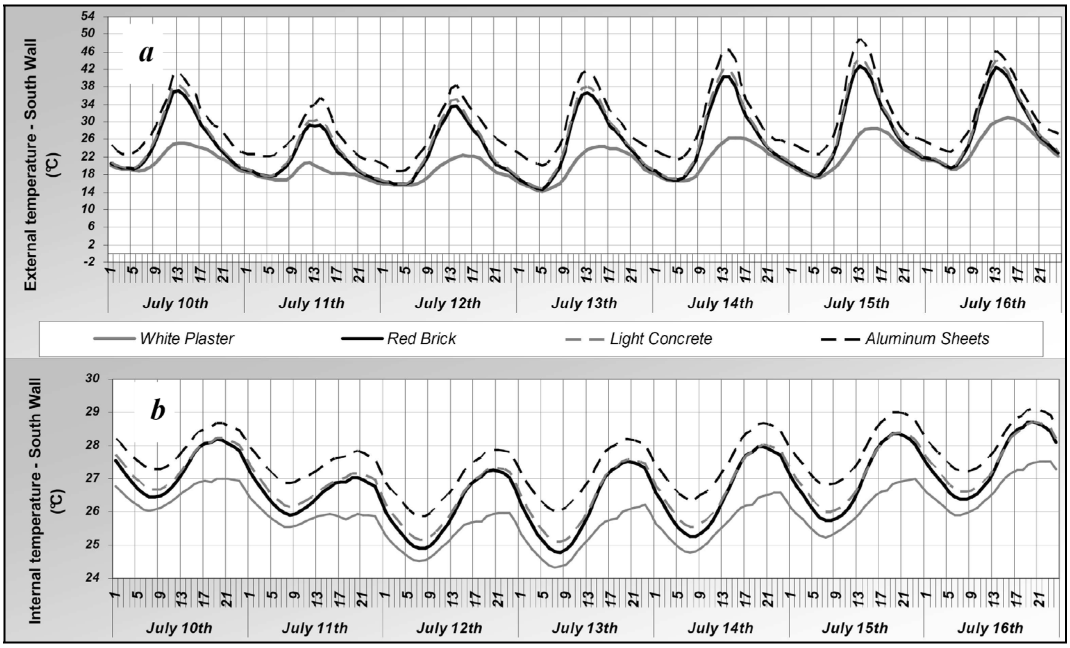


*Figure 3.6.5 – External (a) and internal (b) surface temperatures of the south wall as a function of the considered external coatings, for some summer days*

In summer (figure 3.6.5), the external coatings also affect the indoor comfort conditions as well as the demand for cooling energy. Thermal comfort depends on the operative temperature that can be defined as the average of the mean radiant and indoor air temperatures weighted by heat transfer coefficients ($T_{OPERATIVE}$ influences the winter comfort too, but in the examined case it is closely approximated to indoor air temperature).

In figure 3.6.5a, with reference to the external surface temperature of a south-facing wall, very large temperature cycles result using aluminum panels with T variable between 19 °C and 48 °C. On the contrary, the temperature excursion of the white surface is contained with minimum and maximum values of about 14 °C and 31 °C, respectively. Intermediate values have been obtained for red brick and light concrete coatings.

As stated above, for an indoor air temperature set point fixed at 26 °C in summer, thermal comfort depends on the $T_{OPERATIVE}$, which should be between 24 °C and 26 °C. Considering the external white plaster, the internal surface temperature (Figure 3.6.5b) results between 24.5 °C and 27 °C and is thus quite close to the indoor design conditions and so discomfort is avoided. The results for concrete and red brick are again very similar to each other with internal surface temperatures in the range 24 °C - 28.5 °C. Moreover, figure 3.6.5b shows that aluminum panels, besides higher energy consumption (table III.17), are characterized also by the worst indoor conditions, due to the high temperatures of the wall internal surface (even over 29 °C); this will inevitably raise $T_{OPERATIVE}$ above 26 °C, if the air temperature is fixed at 26 °C, and so could cause discomfort.

- The same analysis of figure 3.6.5b has been carried out considering a not cooled apartment in summer (figure 3.6.6): on varying the external coatings, the wall internal surface temperature vary strongly. In particular, cool paints guarantee indoor surface temperature always lower than 30 °C, while values of almost 33 °C are reached using aluminum; this result corresponds well to some experimental investigations [25, 26].

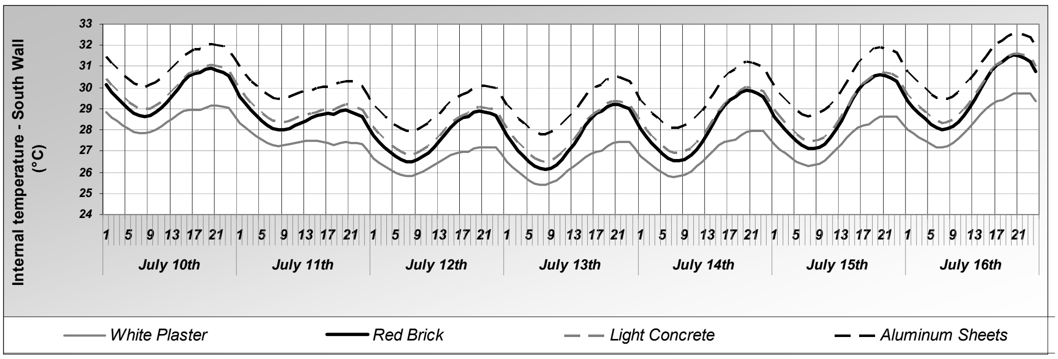


*Figure 3.6.6 – Internal surface temperatures of the south wall as a function of the considered external coatings, for some summer days, in absence of air-conditioning*

Table III.18 reports the primary energy requests for heating and cooling (the system efficiency values have been used as well as the electric to primary conversion factors).

Thus, while in table III.17 winter and summer requests result not so different, in table III.18 the heating energy requests become higher. Moreover, table III.18 shows that globally the annual differences are not very relevant in the Naples climate, due to the opposite seasonal results. A different result is obtained considering separately the climatic seasons: in summer, the cooling primary energy demand for aluminum coating is much higher (more than 70 %) compared to white plaster.

The opposite occurs in winter when a saving of about 27 % in energy demands is permitted by using aluminum instead of white plaster because of the raising of the free heat gain. Considering the whole year, if the most important target is the reduction of the energy used, aluminum sheets are more convenient than cool paints (*59.1 - 63.4 = -4.3 kWh/m², i.e. -7%)* in the Naples climate.

On the contrary, cool paints become preferable in order to reduce the summer cooling peak load (figure 3.6.7). Intermediate values have been obtained for red brick and light concrete coatings (table III.18), e.g. yearly primary energy savings of around 2 kWh/m² have been obtained using light concrete instead of white plaster.

Table III.18: Yearly specific primary energy and $CO_{2eq}$ emissions on varying the external coating

| | $EP_{HEATING}$ | $EP_{COOLING}$ | $EP_{TOTAL}$ | $CO_{2eq\text{-}HEATING}$ | $CO_{2eq\text{-}COOLING}$ | $CO_{2eq\text{-}TOTAL}$ |
|---|---|---|---|---|---|---|
| | (kWh / m²) | (kWh / m²) | (kWh / m²) | TONS/apartment | TONS/apartment | TONS/apartment |
| White Plaster | 50.1 | 13.3 | 63.4 | 1.00 | 0.29 | 1.29 |
| Red Brick | 45.3 | 17.7 | 63.0 | 0.91 | 0.38 | 1.29 |
| Light Concrete | 43.2 | 18.3 | 61.5 | 0.86 | 0.40 | 1.26 |
| Aluminum Sheets | 36.4 | 22.7 | 59.1 | 0.73 | 0.49 | 1.22 |

On the contrary, cool paints become preferable in order to reduce the summer cooling peak load (figure 3.6.7). Intermediate values have been obtained for red brick and light concrete coatings (table III.18), e.g. yearly primary energy savings of around 2 kWh/m² have been obtained using light concrete instead of white plaster.

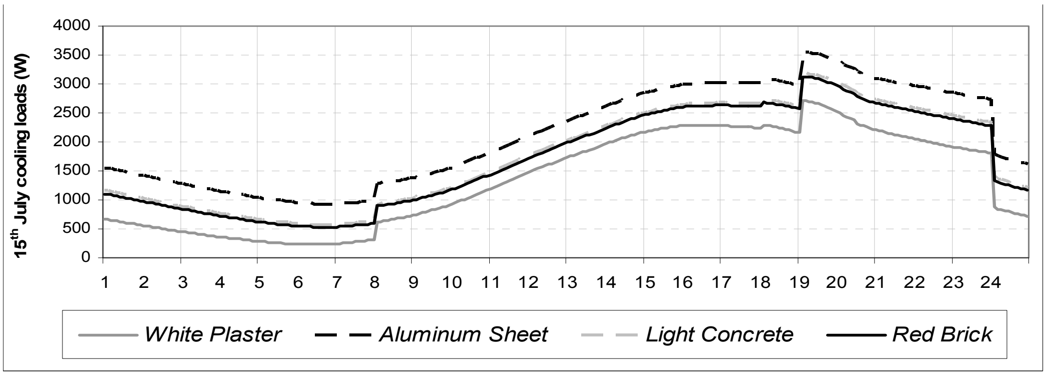


*Figure 3.6.7 – Variation of the cooling load of the apartment during the summer design day*

The following are some examples: considering 100 m² apartments and referring only to the 85′000 dwellings built between 1962 and 1982 in some Neapolitan suburbs (Naples: 975′000 inhabitants calculated with 2006 population census, 3′100′000 inhabitants according to OECD - Organization for Economic Co-operation and Development – with reference to the whole metropolitan area).

- Considering the yearly primary energy demands, the use of aluminum sheets instead of cool paints, with reference to the Neapolitan suburbs considered (85′000 houses), could induce a yearly saving of 36′550 MWh (3140 TOE) and 7500 tons of $CO_{2\text{-eq}}$ avoided.
- The summer cooling peak load (afternoon of 15th July for Naples) is around 2700 W for an apartment with white plaster and 3600 W in the case of aluminum sheets. It means a difference of 0.9 $kW_{THERMAL}$ (-25%), about 0.30 $kW_{ELECTRIC}$, and so, with reference to the abovementioned popular suburbs, a difference of 25 $MW_{ELECTRIC}$.

Therefore, even if the single value might not seem so relevant, the extension to the whole suburban area becomes significant.

These values, of course, are strictly connected to the specific boundary conditions fixed and so are useful only as examples. The above reported yearly primary energy savings have been calculated considering a population of around 300′000 inhabitants (only the popular buildings); taking into account the entire urban population, these results could be a considerable underestimate.

It should be noted that the use of aluminum panels for Naples is only worthwhile if the focus is the annual primary energy saving of dwellings which are fully air-conditioned.

On the contrary, cool paints are preferable in these climates if the main needs are the summer reduction of:

- urban peaks of electricity;
- urban heat islands;
- discomfort in non air-conditioned houses;
- cooling system size.

c) CRITERIA FOR A CORRECT CHOICE OF EXTERNAL COATINGS DURING THE ENERGY RE-QUALIFICATION OF DWELLINGS

This analysis has been carried out for different climatic regions with reference to duration and intensity of the heating season and intensity of summer solar radiation. The purpose, still referring to energy refurbishment actions on existing buildings, is the identification of criteria for choosing the optimal external surface treatments in order to minimize the annual thermal energy demand. The same building as in the previous study has been considered.

In Table III.19, the main climatic data of the cities under consideration and the main results of simulations are reported. The values which represent the best solution as regards energy required, energy costs and emissions are underlined; the various solutions are still compared to the light concrete external coating.

Starting from Cairo, it is quite evident that in the Mediterranean climates the clear external treatments are more suitable. In fact, these coatings determine annually primary energy savings of up to 18 $kWh/m^2$ (-24%) compared to aluminum panels, with a consequent decrease of $CO_{2eq}$ emissions (-25%). Of course, this trend can be generalized, while the specific value depends on the climatic features.

Table III.19: Climatic characteristics and results of the simulations for different climatic locations

| | CAIRO | LOS ANGELES | SEVILLA | ATHENS | JERUSALEM | ROME | NAPLES | NEW YORK | BERLIN | LONDON |
|---|---|---|---|---|---|---|---|---|---|---|
| *Monthly average maximum daily solar radiation (Wh $m^{-2}$)* | 7614 | 7003 | 7518 | 7529 | 8069 | 6805 | 6797 | 6301 | 5109 | 5020 |
| *Winter degrees-day (base: 18°C)* | 390 | 720 | 916 | 1112 | 1364 | 1444 | 1364 | 2743 | 3156 | 2866 |

| | Red Brick | | | | White Plaster | | | | Aluminum Sheet | | | | Light Concrete | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $\Delta EP_{HEAT.}$ | $\Delta EP_{COOL}$ | $EP_{TOT}$ kWh $m^{-2}$ | $CO_{2\text{-}eq}$ TONS | $\Delta EP_{HEAT.}$ | $\Delta EP_{COOL}$ | $EP_{TOT}$ kWh $m^{-2}$ | $CO_{2\text{-}eq}$ TONS | $\Delta EP_{HEAT.}$ | $\Delta EP_{COOL}$ | $EP_{TOT}$ kWh $m^{-2}$ | $CO_{2\text{-}eq}$ TONS | $EP_{TOT}$ kWh $m^{-2}$ | $CO_{2\text{-}eq}$ TONS |
| CAIRO | 25.6% | -1.9% | 66.0 | 1.4 | 116.4% | -17.6% | 56.7 | 1.2 | -61.5% | 12.6% | 74.6 | 1.6 | 67.0 | 1.4 |
| LOS ANGELES | 16.4% | -8.8% | 9.2 | 0.2 | 92.4% | -56.3% | 6.5 | 0.1 | -32.8% | 39.2% | 12.3 | 0.3 | 9.6 | 0.2 |
| SEVILLA | 10.3% | -2.2% | 55.7 | 1.2 | 51.5% | -20.4% | 52.5 | 1.1 | -33.8% | 14.9% | 57.8 | 1.2 | 55.3 | 1.2 |
| ATHENS | -6.8% | 2.4% | 64.0 | 1.3 | 19.6% | -18.3% | 62.0 | 1.3 | -25.3% | 17.2% | 65.6 | 1.4 | 64.7 | 1.4 |
| JERUSALEM | 7.1% | -4.1% | 50.9 | 1.1 | 28.6% | -30.5% | 49.9 | 1.0 | -16.7% | 21.8% | 51.1 | 1.1 | 50.0 | 1.0 |
| ROME | 5.7% | -3.3% | 61.7 | 1.3 | 21.4% | -25.2% | 62.5 | 1.3 | -14.4% | 17.0% | 58.9 | 1.2 | 60.3 | 1.2 |
| NAPLES | 4.5% | -3.1% | 63.0 | 1.3 | 15.8% | -27.1% | 63.4 | 1.3 | -15.8% | 24.5% | 59.1 | 1.2 | 61.5 | 1.3 |
| NEW YORK | 2.9% | -2.8% | 145.2 | 2.9 | 9.3% | -23.8% | 148.8 | 3.0 | -5.0% | 12.6% | 138.7 | 2.8 | 142.3 | 2.9 |
| BERLIN | -2.4% | 4.3% | 167.4 | 3.4 | 2.4% | -31.8% | 173.3 | 3.5 | -6.5% | 27.4% | 161.7 | 3.2 | 171.1 | 3.4 |
| LONDON | 3.1% | -12.5% | 127.8 | 2.6 | 8.3% | -56.3% | 133.4 | 2.7 | -6.6% | 43.8% | 116.7 | 2.3 | 124.1 | 2.5 |

Similar results, even if less evident, are also obtained for Los Angeles, Sevilla and Athens, i.e. where elevated summer radiations (maximum monthly average daily solar radiation > 7000 Wh/$m^2$) or mild winter conditions do convenient the cool paint adoption. For Jerusalem, the 4 coatings present quite similar results; considering the high solar radiation (*Jerusalem >> Los Angeles*), in summertime the cool paints provide a reduction of summer cooling load, but also an increase of the thermal energy due to the cold winter (*winter in Jerusalem is cooler than in Los Angeles*).

Of course, if the building is naturally ventilated (*i.e. no cooling system in summertime*), the higher energy demands for winter heating related to cool paints could be justified by the need to contain the summer indoor overheating in order to reduce thermal discomfort.

Note that similar values of solar radiation (*Los Angeles, Rome, Naples*) do not mean similar results about energy and emissions: in fact, annually, the only entity of solar radiation is not enough in order to well choose the best external surface coating.

For all the climatic regions, it is possible to define the Surface Factor (SF, dimensionless) as reported by the equation 7:

$$SF = \frac{\text{Monthly average daily solar radiation on the horizontal plane}}{10000} \cdot \frac{1000}{\text{Winter degrees-day}} \tag{7}$$

SF is obtained dividing the monthly average daily solar radiation on the horizontal plane (*with reference to the month characterized by the highest sunstroke*) by a fixed reference value of 10000 Wh/m$^2$, and repeating the same operation with winter degrees-day and a reference value of 1000 °Cd.

As shown in table III.20, the SF ratio guarantees the choice of the best solution for the external coatings. In figure 3.6.8, the “areas of convenience” of the various superficial coatings are shown.

Table III.20: Criteria for the correct choice of external coatings within energy retrofit actions, as a function of the Surface Factor SF

| | |
|---|---|
| SF ≤ 0.40 | → *ADOPTION OF SOLAR PICKING UP COATINGS, LOW-REFLECTIVE AND/OR LOW-EMISSIVE* |
| 0.40 < SF < 0.65 | → *LIGHT DEPENDENCE BETWEEN ENERGY EFFICIENCY AND SPECTRAL CHARACTERISTICS OF COATINGS* |
| SF ≥ 0.65 | → *ADOPTION OF COOL PAINT EXTERNAL COATINGS, HIGH-REFLECTIVE AND/OR HIGH-EMISSIVE* |

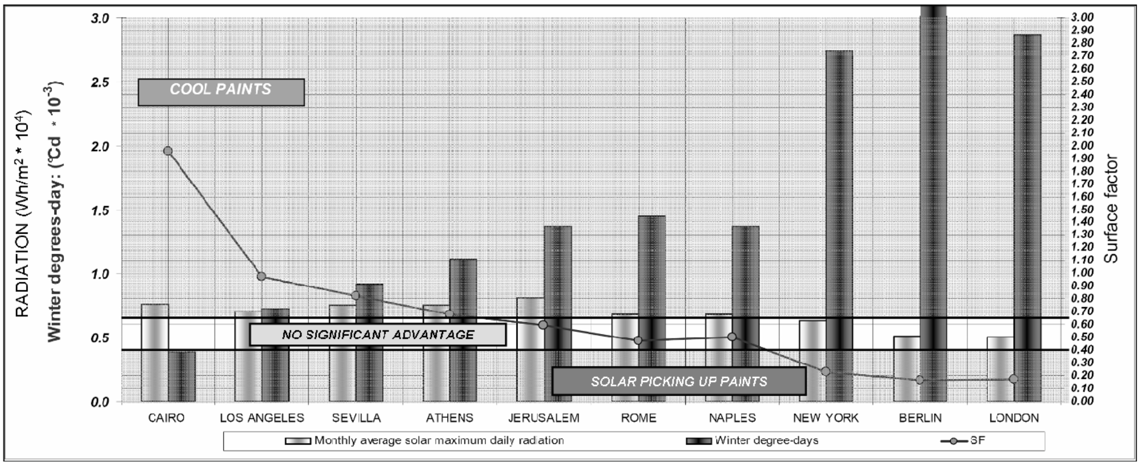


*Figure 3.6.8 – Areas of convenience of different coating solutions, as a function of Surface Factor (depending on solar radiation and winter degrees-day)*

For each city, SF value determines its location in one of the 3 identified areas; each area represents the suitability of an external surface coating. 3 macro-areas have, therefore, been identified: solar picking up (*low-reflective and/or low-emissive*) coatings, cool paints, no significant advantage.

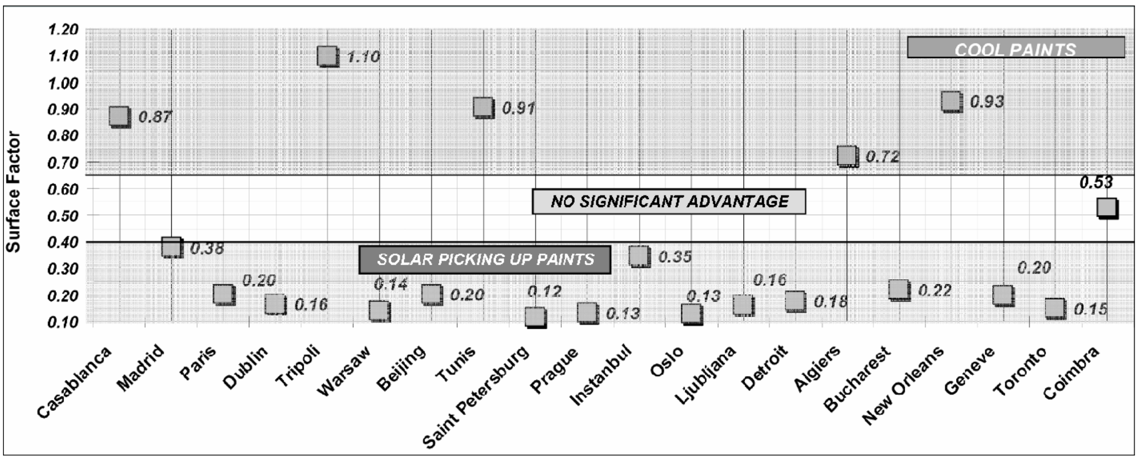


*Figure 3.6.9 – Prediction of the most useful external coatings using SF criterion for various climatic conditions*

The criterion expressed in Table III.20 has been verified taking into consideration 20 other cities (figure 3.6.9).

The suitability of a specific external coating has been predicted simply through the use of SF method, as reported in figure 3.6.9; the results have then been confirmed using the building energy dynamic simulations (figure 3.6.10). To obtain the results in figure 3.6.9, the climatic data files of IWEC [42] or TMY2 [43] have been used.

By simply calculating SF and considering the criterion of table III.20, therefore, the most energy-useful coating types can be identified without using software codes. The SF-indicator might, thus, be an useful design tool for architects and environmental consultants; it represents, in fact, an immediate and simple method for choosing the most energy-useful external coatings for the building envelope as a function of the outdoor climatic conditions. The emerged previsions concord well with the energy simulation results reported in figure 3.6.10.

Obviously, when SF assumes values distant from the zone of no significant advantage (0.40 < SF < 0.65), the suitability of a specific coating becomes even more evident. This is clear in figures 3.6.9 and 3.6.10; it is noticeable that for high SF, (Tripoli, Tunis and New Orleans), the suitability of cool paints is significant, while for very small SF values (Saint Petersburg, Oslo and Toronto) low solar reflective and low infrared emissive coatings are recommended. In moderate climatic conditions, e.g. in Coimbra, the difference between various coatings is marginal.

Of course, in the future the method will require further verification in order for it to become statistically significant. It has, in fact, been found that the SF criterion leads to uncertain results in very particular climates e.g. in the San Francisco Bay area where the specific climatic conditions, influenced by the cold water of the Pacific Ocean and by the cold northeast winds, are not typical of the climatic region (California).

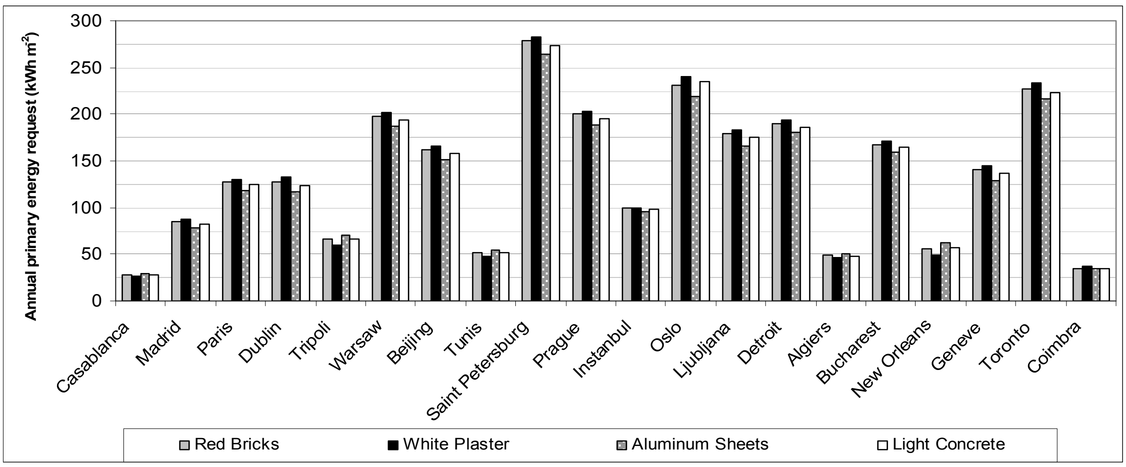


*Figure 3.6.10 – Yearly specific primary energy requests for various cities*

Note that the results are referred to a specific kind of dwelling characterized by lightweight structures and poor thermal insulation (*i.e. the social housing districts*). It follows, therefore, that energy refurbishments could be started easily and cheaply by simply painting the building envelope.

d) LIMITED USE AND VARIOUS MANAGEMENT CRITERIA OF THE HEATING AND COOLING SYSTEMS

Until now, no attenuation in the daily use of the heating and cooling systems has been considered. In fact, according to consolidated calculation methods for the energy audit of residential buildings (*design and asset rating, as provided by EN ISO 13790:2008 [44]*), fixed values of the indoor air set-point temperatures have been considered, not variable during the day but only seasonally. Therefore, the considered working criterion for the heating and cooling systems is the following summarized:

- in winter, start up of the heating system whenever $T_{INDOOR} < 20$ °C;
- in summer, start up of the cooling system whenever $T_{INDOOR} > 26$ °C.

This choice guarantees a simple and conventional method of comparison between different buildings, even if usually variable indoor air temperatures are provided during the day in the real use (*tailored rating, as described in EN ISO 13790:2008 [44]*).

In this section, the annual primary energy requests have been evaluated considering 3 new operating conditions (scheduling 25 %, 50 %, 75 % - table III.21), different from those described above (scheduling 100 %). Passing from scheduling 25 % to scheduling 75 %, the heating indoor set-point temperature does not vary, while the accepted indoor summer conditions become progressively more restrictive.

To verify the SF method validity also under these operative conditions, the energy dynamic simulations have been carried out considering the climatic zones, previously analysed, where the energy convenience of an external coating was not so clear. As reported in table III.19 and figure 3.6.8, this occurred for:

- Athens → light energy suitability with the use of white plaster;
- Naples → marginal differences between energy demands on varying the radiative characteristics of coatings;
- New York → energy suitability with the use of aluminum sheet.

The new results (figure 3.6.11) guarantee a satisfactory verification of the method and since neither in these "border line" situations do the results vary, it may be presumed that in clearer climatic conditions the same results can be obtained.

Table III.21: Different operative conditions for the heating and cooling systems

| | *Scheduling 75%* | *Scheduling 50%* | *Scheduling 25%* |
|---|---|---|---|
| *Heating* | 16°C between 23.00 ÷ 6.00 and 8.00 ÷ 16.00<br>20°C between 6.00 ÷ 8.00 and 16.00 ÷ 23.00 | | |
| *Cooling* | 27°C between 8.00 ÷ 24.00<br>29°C between 24.00 ÷ 8.00 | 27°C between 13.00 ÷ 24.00<br>29°C between 24.00 ÷ 13.00 | 27°C between 19.00 ÷ 24.00<br>29°C between 24.00 ÷ 19.00 |

For Athens, white plaster results suitable (table III.19) and this is also verified if the operational modalities of the systems are varied (figure 3.16.11), even if the energy demands become less different with limited use of the systems.

For Naples, table III.19 has not shown any one external coating has a clear advantage over the others, and the same result has been found in this new analysis (figure 3.6.11).

As regards New York, both in the previous study (table III.19) and in the new analysis (figure 3.6.11) aluminum panels result energetically preferable.

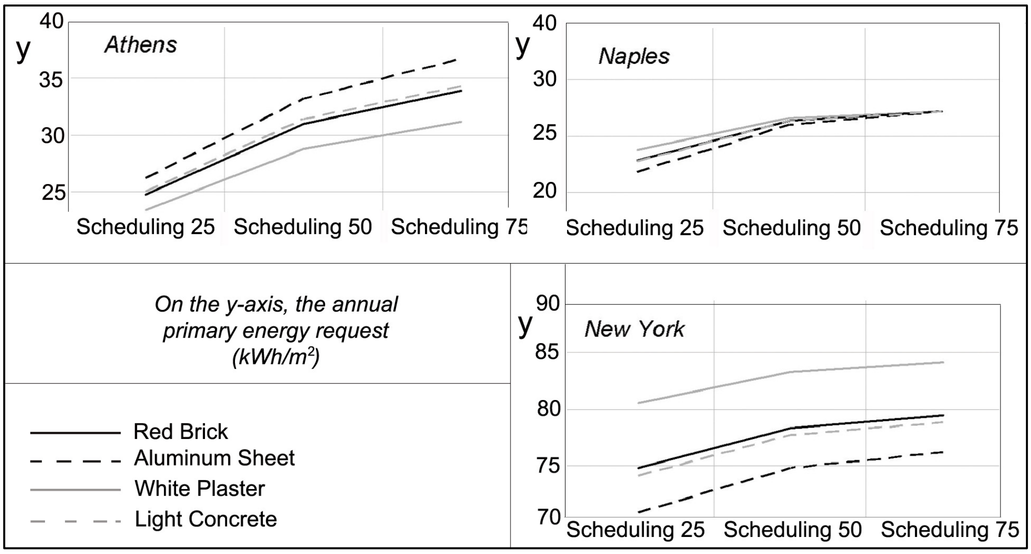


*Figure 3.6.11 – Yearly specific primary energy requests for 3 cities, considering different kinds of external coating and various operative conditions of the systems*

In this way, the validity of the SF criterion has also been verified under reduced operative conditions. In reality, SF has been constructed taking into consideration important climatic characteristics (degrees-day and summer solar radiation). Even with reduced use of the heating and cooling systems, therefore, the SF factor and criterion of table III.20 can be suitably adopted in order to minimize annual energy demands.

Note that, passing from scheduling 100 % to scheduling 75-50-25 %, for the three abovementioned cities a reduction of around 45-60 % occurs for the annual primary energy demands.

In the next section, the conventional scheduling 100 % is again considered.

### 3.6.3 Thermal inertia and energy requests for summer cooling: effects of the ventilation

In this analysis, the effects obtainable by varying the thermal inertia of the vertical walls (but maintaining the same transmittance) are examined. The results previously obtained refer to buildings with light walls characterized by low attenuation factor and low time lag effect of the summer thermal wave (CEN, 2007); therefore, in summer, the maximum external thermal load and the peak of cooling energy demand are near.

The Italian Presidential Decree 59/2009, as better described in the Chapter 2, imposes that in all the climatic zones except F (degrees-day > 3000), if the maximum solar irradiance results higher than 290 W/m$^2$, the superficial mass of building envelope opaque components must be at least 230 kg/m$^2$ for new constructions. Presently, also the verification of the dynamic thermal transmittance is admitted (*$Y_{12}$ < 0.12 W/m$^2$K with reference to the vertical wall, < 0.20 W/m$^2$k for the roof*).

On the contrary, the wall until now considered is characterized by lightweight materials (hollow brick, 600 kg/m$^3$), with a thermal mass equal to only 156 kg/m$^2$.

As shown in figures 3.6.12 and 3.6.13 (see curves relative to hollow bricks), in summer the highest internal surface temperatures are registered for the aluminum coating, with maximum values at around 9 p.m., therefore with a time lag of 7 ÷ 9 hours compared to the maximum external thermal load. This result is due also to the effect of the internal sources (lighting equipments and people presence), higher in the evening. As regards the white plaster, the maximum internal surface temperatures occur at around 11 p.m., and result lower (of about 2 °C).

On varying the composition of the wall (filled bricks - density 1850 kg/m$^3$ - instead of hollow ones), the superficial mass of the wall becomes 481 kg/m$^2$.

Note that the filled bricks have a higher conductivity, so that, in order to leaving unchanged the transmittance without varying the wall thickness, it was necessary to increase the thickness of the thermal insulation (rock wool). The thermal insulation layer was placed first on the external side (coat insulation) and then on the indoor side, to evaluate its influence and its best location in the retrofitting re-qualifications.

From figures 3.6.12 and 3.6.13 it can be also inferred that, although the attenuation and the time lag of the thermal wave are very effective in order to operate a reduction of the daytime energy requests, during the night they induce a higher thermal load. The same results have been calculated, in the section 3.3, also for new buildings.

Thus, during the night, the cooling system has to balance these higher indoor loads, requiring more energy to maintain indoor T = 26 °C, compared to the wall with light mass. In the figures 3.6.12 and 3.6.13, the areas subtended by the curves are a measure of the energy demand.

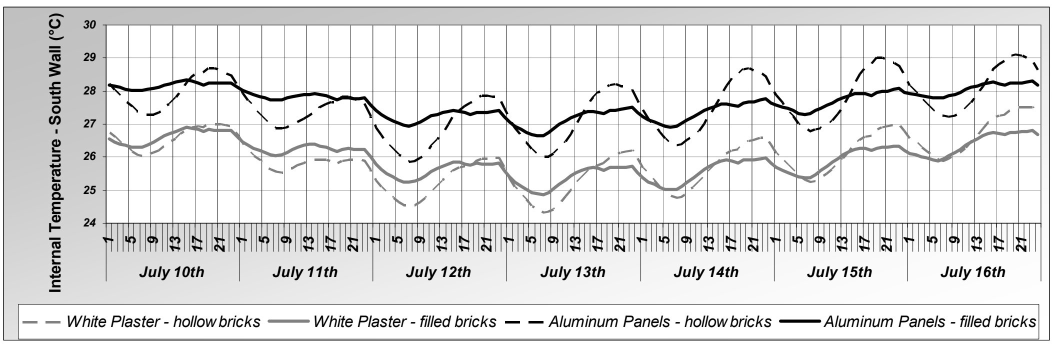


*Figure 3.6.12 – Internal surface temperatures of the south wall for some summer days*

With reference to the whole cooling season, the inner surface temperature mean value is almost independent of the wall mass. In fact, for the entire season, the wall, more or less heavy, show temperature trends described by sinusoids more or less large, with a borderline case of flattening on a constant average value (i.e. *very high time constant of the building envelope*).

It means that the seasonal thermal requests are the same, for both the cases with and without inertia: therefore, without a carefully designed ventilation system, there aren't energy advantages with the use of massive wall, if the apartments are equipped with cooling plants working also in the night. This result is verified in figure 3.6.14: fixing a constant ventilation rate (1 air-change, connected to the natural ventilation and infiltration), the energy needs are very similar using the walls with low and high mass, respectively. Very light differences are caused by modelling boundary conditions.

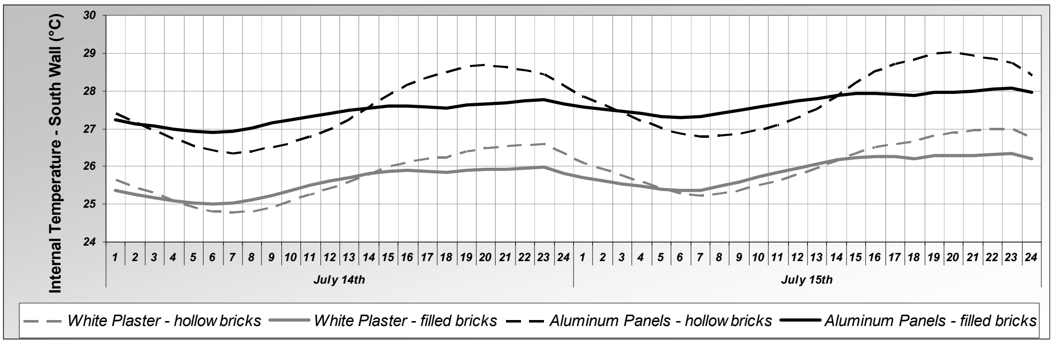


*Figure 3.6.13 – Internal surface temperatures of the south wall on July 14th and 15th*

A high inertial wall represents an advantage only in the absence of cooling system. In fact, this solution guarantees lower diurnal indoor air temperatures (limiting discomfort), while in the night higher temperature values don't cause large penalties, being lower the metabolic activity (the human body releases less heat thus making a lower ΔT between the skin and indoor temperatures acceptable). Moreover, nocturnal indoor T values are generally less than 28 °C and thus acceptable.

The use of massive walls is convenient also in buildings without persons during the night (offices, shopping malls), where the target is the reduction of only diurnal cooling loads. For these applications, cooling systems are used only for the daytime, so it is possible obtaining useful energy savings with the adoption of massive building envelopes (*this will be better shown in the next chapter*).

As regards air-conditioned dwellings, an inertial wall results very useful only when night ventilation is adopted. As evident in figure 3.6.14, by raising the number of nocturnal air changes, significant savings of primary energy for cooling are obtained. Note that this is true in climate zone characterized by an inversion of the heat flow through the wall, passing from day to night (*in Naples, $T_{EXTERNAL\ AIR}$, in summer night, is generally minor than 26 °C, and also the cool sky determines a radiative cooling effect*).

These energy savings occur because night ventilation makes it possible to cool the structures effectively through the heat exchange between warm massive walls and cool and free incoming air from outside.

This strategy becomes less suitable with low thermal inertia walls because the nocturnal cooling also occurs without any ventilation since the heat flow is directed from indoors to outdoors. On the contrary, as regards the massive structures, in the night the thermal flux is still incoming because the walls release the energy stored during the day.

Increasing the number of nocturnal air changes (up to a value function of the heat released which depends on the temperature of the wall's inner surface) can usually be carried out by employing mechanical ventilation.

In Figure 14, the energy demand due to extraction fans has also been adequately considered (*also converting the electric energy in primary one*) by evaluating the pressure head and the volumetric flow rate. Insulation position and amount of nocturnal air changes are influential as regards both the white plaster and the aluminum external coatings.

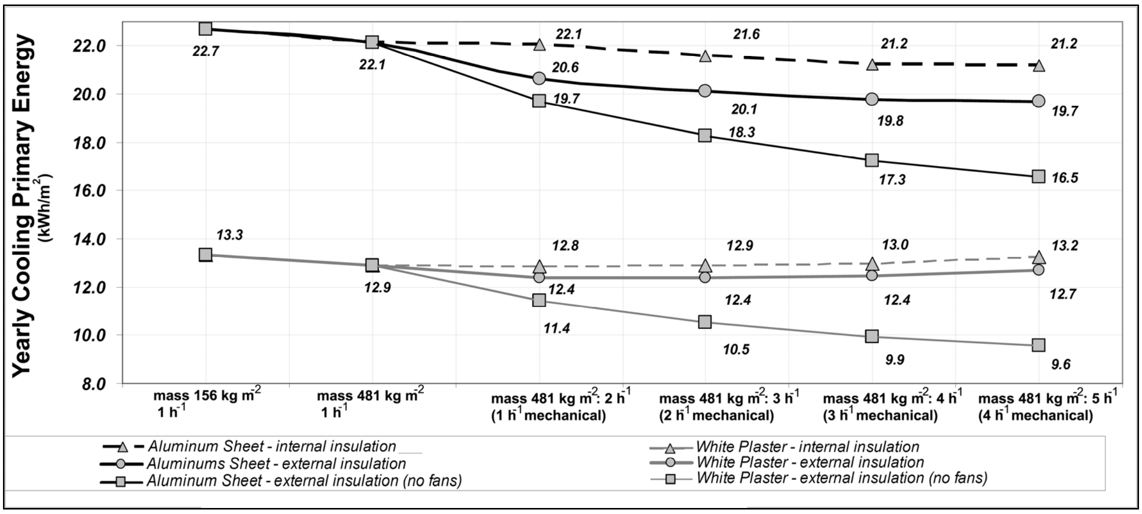


*Figure 3.6.14 – Specific primary energy requests for summer cooling as a function of indoor air change number and superficial mass of the wall, for two exterior surface coatings*

The suitability of the nocturnal ventilation is evident particularly for a low-emissive wall (which has accumulated a considerable amount of radiant energy): with 5 air changes, a maximum seasonal energy reduction of about 25 % has been obtained (in the presence of natural night ventilation, i.e. no fans), compared to the case with only 1 air change. By using mechanical night ventilation the energy reductions diminish because of the electric energy required by the fans. This aspect is important when the external coating is highly reflective and highly emissive (white plaster) so that the stored energy is less; in this case, the fan energy demands could be penalizing.

Over 5 hourly air changes, there is no advantage since the net energy demands are very similar or higher compared to 5 ACH, while the probable risk of air drafts occurs. As regards this, it has been verified that up to 5 air changes, indoor air speed results, on average, lower than 1 cm s-1 for bedrooms, so avoiding even local discomfort conditions. The average speed presents “safety” values even in the most critical spaces (corridor), where the air passage section is small.

As regards the insulation position, the internal insulation results energetically less advantageous (figure 3.6.14); this can be qualitatively justified evidencing that the thermal exchange between fresh air and internal wall is more effective in absence of the internal insulation, that represents a "barrier" to this heat transfer.  Furthermore, also other problems, related to the vapour condensation in summertime could happen insulating the internal part of the wall.

Other simulations have shown that, as regards the cooling energy demands, the diurnal ventilation becomes greatly disadvantageous if used in the presence of massive walls, so reducing substantially the building thermal inertia effects. In fact, in the same conditions as in figure 3.6.14, considering 4 diurnal air changes per hour (+ 1 natural), the seasonal energy demands for cooling become much higher compared to the case of 4 nocturnal air changes (+ 1 natural), as follows:

a) white plaster, internal insulation: + 39% (13.2 kWh/m$^2$ → 18.3 kWh/m$^2$);
b) white plaster, external insulation: + 40% (12.7 kWh/m$^2$ → 17.8 kWh/m$^2$);
c) aluminum panels, internal insulation: + 28% (21.2 kWh/m$^2$ → 27.1 kWh/m$^2$);
d) aluminum panels, external insulation: + 30% (19.7 kWh/m$^2$ → 25.7 kWh/m$^2$).

The electric energy required by fans for mechanical ventilation has still been taken into account. While an adequate night ventilation determines benefits for the walls with high inertia, especially if low-emissive, diurnal ventilation induces extra energy demands especially for the white wall; in fact, the diurnal ventilation cancels the benefits achievable using a "cold wall" while in the case of aluminum $T_{SOL\text{-}AIR}$ is so high that the diurnal ventilation load is less penalizing.

Finally, and only for aluminum coatings, in figure 3.6.15 the wall internal surface temperatures are reported for some summer days; the curves related to internal and external insulation, without any mechanical ventilation, are overlapping. Also in figure 3.6.15, the significant energy saving related to an adequate nocturnal ventilation can be inferred for both internal and external insulation. In fact, considering 5 hourly air changes, during a significant period of the day the internal surface temperature of the wall is less than 26 °C, and it means that, unless endogenous heat gains, the cooling system is turned off with consequent energy savings. In any case, during the whole day the surface temperatures are significantly lower compared to the cases with one air change (natural ventilation); this is indicative of a structure cooling, useful in order to achieve energy savings both at night and in the day.

Moreover, although the night peak temperature results lower for the internal insulation case (with 5 air changes), globally, the subtended area is smaller for the solution with external insulation: it means less energy is required by the cooling system. This is coherent with results in figure 3.6.14.

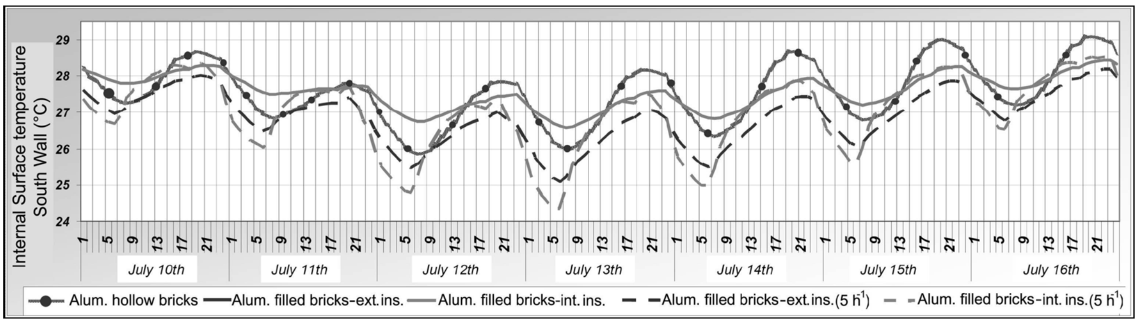


*Figure 3.6.15 – Internal surface temperatures for some summer days, considering aluminum coating and different values of wall mass and ventilation rate*

### 3.6.4 CONCLUSIONS: LIGHT COST IMPROVEMENTS FOR RESIDENTIAL BUILDINGS

In this section, an example of energy re-qualification of social housing building has been studied; this kind of building is representative of the reinforced concrete constructions almost widespread in the European city suburbs.

The analyses have been carried out using hourly dynamic energy simulations and by evaluating the incidence of various factors on the energy demand for winter heating and summer cooling, particularly for a typical Mediterranean climate (Naples – South Italy).

As regards the external coatings of the vertical walls, their solar reflectance and far-infrared emissivity influence these energy demands. For Naples, in winter, low solar reflective and/or low infrared emissive external coatings (for example, aluminum panels), due to free heat gains, are energetically more suitable (-27 %) than cool paints (high solar reflectance and high infrared emissivity - for example, white plaster). On the contrary, cool paints offer much better energy performances in summer (-70 %). Considering the whole year, aluminum panels result energetically more suitable than cool paints (-4.3 kWh/m$^2$, i.e. -7 %). On the other hand, cool paints are suitable for reducing the summer cooling peak load (-25 %) in these climatic conditions or when there isn't any cooling system for the building. These coatings determine lower summer indoor temperatures. Intermediate results have been obtained for red bricks and light concrete.

These advantages are more and more interesting when referred to the whole group of popular housing buildings in the city: considering 85′000 houses, the use of aluminum sheets leads to yearly primary energy savings of around 36′550 MWh (3140 TOE) and 7500 tons of $CO_{2\text{-}EQ}$ avoided. Contrariwise, the use of white plaster leads to an electric power saving of 25 $MW_{ELECTRIC}$, as well as to the summery reduction of: urban peaks of electricity; urban heat islands; discomfort in not conditioned houses; cooling system size.

Moreover, a simple innovative climatic index (SF – Surface Factor) has been proposed, useful in order to identify the best external coatings from the point of view of energy as a function of the outdoor climatic conditions. In the presence of heating and cooling systems in the building, for the cities with high solar irradiation and/or low winter degrees-day (SF > 0.65), cool paints are more suitable, while the opposite results have been obtained for cold climates (SF < 0.4). Tenuous relationship between energy efficiency and radiative characteristics of the coatings has been obtained with 0.4 < SF < 0.65 (for example, for Naples). Therefore, simply calculating SF, it becomes possible to identify the most energy-useful coating type without using software codes. In this way, the SF-indicator might be a useful design tool for architects and environmental consultants. Then, the approach based on the Surface Factor has been verified for many cities with different climates also considering reduced working conditions of the systems. The energy used has been evaluated in these various working conditions too.

Finally, the influence of building envelope thermal inertia on summer cooling energy demands has been evaluated measuring the simultaneous effects of the wall mass, surface radiative characteristics and indoor ventilation and it has been found that the number and the time of day of the air changes significantly influence the cooling energy needs. For climatic zones in which the summer outdoor temperature during the night is less than indoor, high thermal inertia walls have been shown to be suitable from an energy point of view only when coupled to night ventilation (better if natural). Night ventilation is particularly useful for massive and highly charged (low-reflective and/or low-emissive) building envelopes. For example, for low-emissive walls in Naples, 5 nocturnal air changes lead to a seasonal energy reduction of up to 25 % (in the presence of natural ventilation, i.e. no fans), compared to the case with only 1 air change.

Over 5 air changes, there is no energy advantage while the probable risk of air drafts occurs. In the absence of night ventilation, the energy needs are very similar using walls with low or high superficial mass if the cooling system is also active in the night.

As regards the diurnal ventilation, it is strongly penalizing if used in the presence of massive walls, making the building thermal inertia effects inefficacious. For example, considering 4 diurnal air changes per hour (+ 1 natural), the seasonal energy demand for cooling become much higher (up to 40%) compared to the case of 4 nocturnal air changes (+ 1 natural).

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# Chapter 4:

# Passive and low energy cooling of Office Buildings in several European climates: comparison of various strategies and possible couplings

## 4.1 INTRODUCTION: THE INTERNATIONAL CONTEXT ABOUT THE BUILDING ENERGY EFFICIENCY

In the last years, all the European States have been interested by a large spread of air-conditioning systems, due to the extensive commercialization and low-prices of the split and fan-coil units. In particular, the large use of air-conditioners is determining, as reported in the introduction of the European Directive 2002/91/EC, a significant growth of the electric energy consumptions and the related pollution phenomena, above all with reference to the south-Europe countries. The same EPBD, thus, strongly suggests the adoption and the design of passive-cooling solutions, in order to limit or nullify the use of air-conditioning system for the summer space cooling.

In this chapter, some different solutions for the passive cooling are studied and compared, with reference to small office buildings; this kind of application becomes particularly critic in summertime, being very elevated the endogenous heat gains and, at the same time, good comfort conditions are required to guarantee satisfactory work places under the environmental wellness point of view. Today are quite spread and well-known the techniques to improve the energy performances of the building in wintertime, while, in the hot period, very often the only one solution adopted consists in the use of active cooling systems.

The traditional building envelope solutions, useful to reduce the thermal energy losses in winter (*low-thermal transmittance values of the structures*), with reference to applications characterized by elevated internal loads, do not induce a good building performance in summertime, avoiding the dissipation of the endogenous heat gains.

The presented study evaluates the performance obtainable using 4 kind of passive solutions (*nighttime ventilation, roof movable insulation, movable insulation of the vertical walls, ventilation through the use of earth tube*), starting by the model of a small office building.

The case-study has been modelled considering high efficient building structures (for the winter period), according to both the German Standard (*EnEV 2007*) and the Italian prescriptions (*Legislative Decree 192/2005 and Presidential Decree 59/2009*).

The analyses concern, above all, the summer performances, evaluating the most adapt passive cooling solutions with reference to specific heat gains, exposure and positions of various thermal zones. The studies have been carried out considering both the presence of a cooling system (*evaluation of the primary energy requirements in summertime*) and without active systems for the temperature control (*evaluation of the thermal level trends inside the office spaces*). All the studies have been conducted considering various European climates.

Finally, on the basis of the obtained results, the coupling of the most effective solutions has been simulated, in order to present the most useful configuration of the building, with reference to both the climatic seasons.

The analyses have been carried out through the use of well-adapted codes for the dynamic energy simulations and hourly climatic weather data.

The European *Energy Performance of Building Directive (*2002/91/EC) established Guidelines to contain the energy consumptions due to the building sector, requiring a general framework of methodologies (demanded to the CEN – *European Committee for Standardization*) apt to permit a standardized calculation of the total energy use of the buildings.

During the 2008, the European Commission also presented a set of proposals to fight the climate change; the so-called 20-20-20 target proposes, within the 2020, 20% reductions of GHG emission, 20% savings as regards the energy demand, and 20% increasing of renewable energy use. Furthermore, during the December 2008, the European Parliament approved also the "*Climate-Energy Package*"; the ambitious target would transform the Europe into a low-carbon continent.

In the preface, the EBBD accounts that "*the residential and tertiary sector, the major part of which is buildings, accounts for more than 40 % of final energy consumption in the Community…*". Therefore, achieving only a 30% in the reduction of the building energy requests, more than half of the 20-20-20 energy reduction target could be easy obtained. The EPBD has to be transposed, within some months, in the various national legislations.

The EPBD came into force in January 2003; the main topics consist in the reduction of the building energy requests, taking into account the climate conditions, the indoor needs and the local peculiarities, the technical and economical effectiveness of the improving solutions for the energy containment. The Directive was emanated under the purpose of orienting the building construction activity towards a concept of energy efficiency, declined in the specific contexts, national and regional (*an exhaustive description of the EPBD is reported in the Chapter 1 of this study*). In particular, the EPBD Directive, in the article 4, imposes that "*Member States shall bring into force the laws, regulations and administrative provisions necessary to comply with this Directive at the latest on 4 January 2006*".

In the followings, the main prescriptions presently into force in Germany and Italy are briefly described, so that can be better understood the reasons and the targets of the carried out analyses. Then, the effects of the new energy prescriptions on the energy performances of office buildings have been investigated.

As regards the modelling boundary conditions, the main characteristics were selected respecting the German and Italian regulations, chosen because of well expressive of the various European climatic conditions.

## 4.2 REGULATIONS AND ENERGY EFFICIENCY PROGRAMMES IN GERMANY AND ITALY

### 4.2.1 THE GERMAN PRESCRIPTIONS REGARDING THE SUMMER PERFORMANCES

Many principles of the EPBD has been transposed into national legislation by the EnEV (*EnergieEinsparVerordnung*) - Decree on Energy Saving (in force since February 2002) and through the Law on Energy Savings (EnEG) starting by September 2005 (2nd version).

The first regulations, introduced in order to contain the building energy consumptions in Germany, have been enacted in the '70s, after the Kippur War and the consequent oil crisis, interesting the whole Europe in 1973. The first Heat Conservation Provision WSchVO (*Wärmeschutzverordnung*) came into force in 1977 (*in the same year, in Italy, the Law 373 was enacted).* The target of this German regulation was to limit the heat losses through the building envelope. New versions of these prescriptions were released in 1982 and in the middle of '90s, regarding only the new constructions, therefore excluding any mandatory action regarding the existing building re-qualifications.

With the new law in force starting by 1 January 1995 (*Wärmeschutzverordnung 1994)*, the accepted maximum limit, with reference to the building heating energy requirement, equal to 150 kWh/m$^2$a and valid starting by 1982 (200 kWh/m$^2$a in the first law of 1977) was reduced to 100 kWh/m$^2$a.

During the 2002, while the European Parliament and Commission emanated the EPBD Directive, the German Government approved the new regulation about the energy savings as regards the building sector. The EnEV 2002 introduced new restrictive legal measures for an efficient use of energy, considering both the aspects of necessary reductions of the energy demand and the cut-off of the $CO_2$ emissions.

A new main rule was attributed to the re-qualifications of the existing buildings, interested by a strictly regulation about the energy performance of particular components (*building structures or heating systems*) when substituted or renovated.

The EnEV 2002 imposed the calculation of the required primary energy (*and relative limit values*), not only with reference to the indoor space heating, but also as regards the domestic hot water production. The energy need calculation considers both the thermal requirement of the building (*heat dispersions*) and the energy losses due to the heating system inefficiencies (*energy losses due the heat generation, distribution, emission and regulation*).

As regards the calculation methodologies, the EnEV is based on the use of several technical standards, among which results particularly important the DIN 832 (derived from the European EN) - *Calculation of the heating energy requirement of buildings*. Typical German boundary conditions are contained in the DIN V 4108-6 - *Calculation of the annual heating and annual heating energy requirement of buildings* - useful to implement adequately the European methods; this technical standard provides two different calculation methods, seasonal or monthly. Finally, the standard DIN V 4107-10 - *Characteristic values for heating systems* - reports simplified graphic procedures or accurate calculation methodologies, in order to evaluate the heating system efficiency.

During the 2004 the EnEV regulation was revised. Today is in force the last version – EnEV 2007 – that introduced important news in the building energy efficiency regulation. The energy performance certificates have been introduced also for the existing buildings, when interested by sale or renting. The energy calculation can be evaluated on the basis of energy consumption or demand; in the public building the energy certificate has to be exposed and it should contain recommendations for the improvements of the energy performances in case of retrofits.

Other significant changes concern the introduction of mandatory inspections of the heating system and air-conditioners, the evaluation of energy requests for the summer cooling and also for the artificial lighting. *Note that this last calculation is mandatory only with reference to non-residential building.*

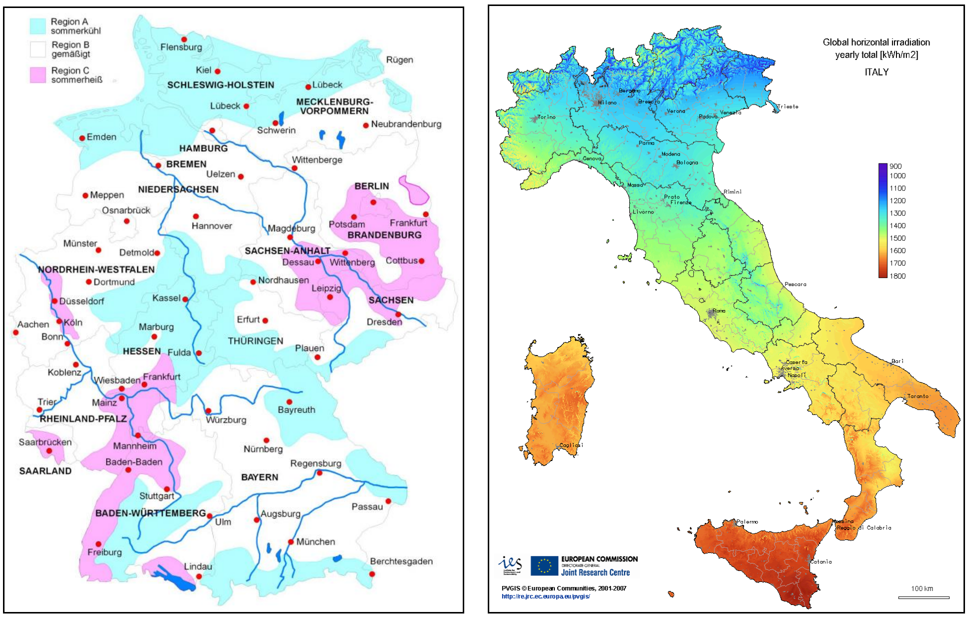



*Figure 4.2.1 – German and Italian summer maps: In Germany, the warmest conditions are for the South-West and Middle-East Lands (Baden Württemberg and Brandenburg); in Italy, the solar radiations raises moving in the South direction*

The EnEV prescriptions, regarding the maximum values of the building envelope thermal transmittance, minimum values for the heating systems energy efficiencies and, above all, about the maximum value assumable by the energy performance index – EP (kWh/m$^2$a), expressing the primary energy needs for the space heating, represent mandatory verifications in order to achieve the building permit.

With reference to the summer period, the building envelope has to guarantee comfortable temperatures in the indoor environment. Verifications about the summer building performance are not required when the temperature should necessarily to be low (< 19°C), for example in store-rooms. In this case, none summer verifications and limits in using the A/C are mandatory.

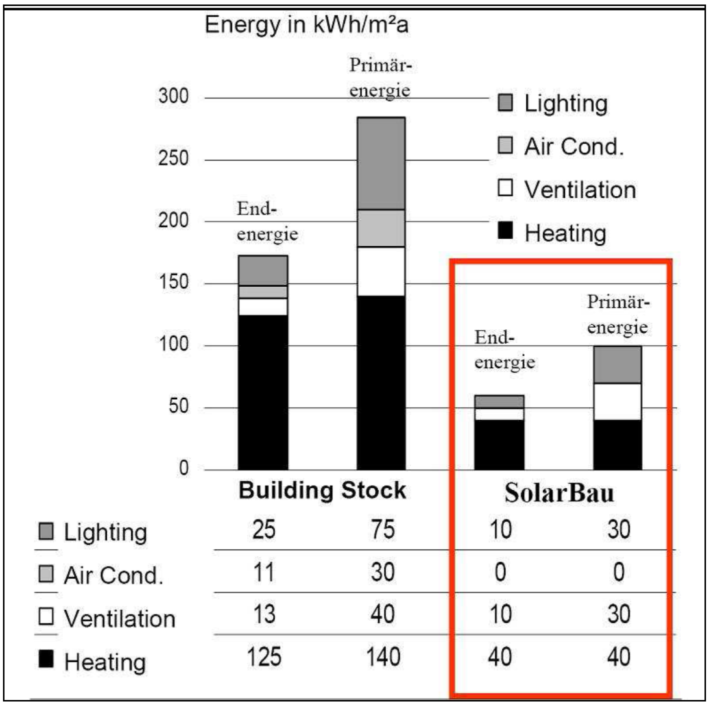
With reference to the typical buildings of the civil sector (*houses, offices, tertiary*), where the indoor T can be > 19°C and when the window area exceeds 30% of the entire building shell, a summer performance verification is required, carried out according to the methods contained in the German technical standard DIN 4108-2:2003-4. This verification imposes that a factor S (*dependent on the window area, building envelope surface, characteristics of the glasses, exposures, presence of shading systems*) has to result lower than a $S_{MAX}$ index, that, instead, is related to the climatic region (figure 4.2.1, left side), solar thermal transmittance of the glass, presence of a significant nighttime ventilation of the building.

Besides these mandatory prescriptions, on the same time the German Government promoted good example programs, in order to spread the energy efficiency concepts.

The most important funding program is the EnOB – *Energieoptimiertes Bauen*. The German Federal Ministry of Economics and Technology (BMWi) funds this research project, that promotes high energy efficiency building where, sustaining moderate construction costs and hardly reduced operational needs, high quality life, environmental comfort, reduced $CO_2$ emissions and low-energy demands are achieved. The project concerns several research areas, about new buildings or refurbishment of exiting ones, as regards new architectural concepts, engineering technologies and materials.

While the EnEV prescriptions represent legal minimum performances that should be respected, the EnOB proposals represent admirable examples of efficient constructions or energy oriented refurbishments.

The EnOB research project includes several thematic areas, among which the most important sectors regard the new buildings – EnBau (*Forschung für Energieoptimiertes Bauen, i.e. energy-optimised new buildings*) and the existing building energy re-qualification EnSan (*Energetische Sanierung, i.e. energy-oriented refurbishment*).




| | Building Stock | | SolarBau | |
|---|---|---|---|---|
| Lighting | 25 | 75 | 10 | 30 |
| Air Cond. | 11 | 30 | 0 | 0 |
| Ventilation | 13 | 40 | 10 | 30 |
| Heating | 125 | 140 | 40 | 40 |

*Figure 4.2.2 – German building stock and EnOB targets for the new construction (source: FBTA – Karlsruhe University)*

Presently, the EnBau project involves about 30 new buildings, designed, built and monitored, with the aim to reduce the end and primary energy consumptions around the 50% compared to the energy requirements imposed in the EnEV 2007 regulation. The involved constructions are above all commercial and office buildings. For the participation in the EnBau program, the total primary energy for heating, air-conditioning, lighting and the building ventilation has to be minor than 100 kWh/m$^2$ a (*max 40 kWh/m$^2$a the heating demand*) and the building should require no active cooling (*see figure 4.2.2*).

About the EnSan project, presently it involves about 25 buildings, residential and commercial ones, renovated with the target of a hard reduction of the energy needs. In particular, the EnSan program requires that the end and primary energy requirements are reduced of about 30% compared to the EnEV 2007 limits for the new constructions. As it results simple to understand, the purposes are very ambitious, so that advanced refurbishment concepts and technologies are strictly required.

Today, the 90% of the German building stock has no insulating layers, and, therefore, in wintertime the heating needs are very high (meanly, around 200 kWh/m$^2$a). Thus, the potential savings are very high, with possible reductions even larger than 70-80% in the heating energy consumption. Of course the refurbishments have to be cost-effectiveness, so that, even if the final target consists into the "*3 liter house*", in a first time should be acted the most effective (*under the technical and economical point of views*) energy oriented restoration actions. The targets of EnSan project are various, among which the main one is the development of strategies to improve drastically the energy performances of existing buildings, so that, in the future, these techniques could be spread into the building market, to diffuse new solutions a new technical culture for energy effective refurbishments.

In addition to the main cited programs (*EnBau and EnSan*), the EnOB projects is structured also with other research areas: EnBop (*Energetische Betriesoptimierung - energy-oriented operation optimisation*), LowEx (*Niedrig-Exergie Technologien - Low-Exergy Technologies*), ViBau (*Vakuumisolation im Bauwesen - Vacuum Insulation in the Building Trade*).

The building constructions or renovations participating in the EnOB projects are partially funding by the German Government, in order to sustain the extra-costs due to the high quality design processes and consultancies, investments for new technologies, cost for the monitoring equipments. About this last point, in fact, a 2-year monitoring activity is established to verify the reached targets for the funded projects.

### 4.2.2 THE ITALIAN PRESCRIPTIONS REGARDING THE SUMMER PERFORMANCES

As reported in the Chapter 1, the first national legislation aimed to induce, for the new construction, energy savings relatively to the energy demand for the building heating, was the Law n° 373/1976, issued after the first international energy crisis that raised the oil price. Then, in the early '90s, the Law n° 10/91 extends the topic of 373/76, introducing minimum efficiency requirements also for the heating system. The Law 10/91, implemented by Presidential Decree 412/93, was a good law scarcely applied, introducing, some years before the EPBD (2002), not only the concept of energy efficiency of the integrated system-building plants, but also the energy certification of the buildings.

The Italian Law 10/91 imposed the calculation of the indexes Cd (*volumetric heat loss coefficient*), FEN (*normalized energy need*) and $\eta_G$ (*overall seasonal energy efficiency ratio of the heating systems*). The main technical standards, applied to verify the legal prescriptions, were the Italian UNI 10344 - *Building heating - Energy requirements calculation method* (in the follow substituted with the cited EN 832) and the UNI 10348 - *Building heating - Heating systems efficiency - Calculation method*.

Presently are in force the prescriptions introduced by the Legislative Decrees 192/2005, 311/2006, 115/2008 and the recent Presidential Decree 59/2009 and Ministerial Decree 26.06.2009. The new verifications concern the opaque and transparent building envelope thermal transmittances, the efficiency ratios of the technical equipments, the performance energy index for the winter heating (EP index) and the thermal requirements in summertime. The EPi, expressed in kWh/m$^2$a or in kWh/m$^3$a, represents the main performance indicator and it should be less of an appropriate limit value, based on the winter degree-days of the regions (*in Italy there are 6 climatic homogenous areas*) and varied on the basis of the S/V – surface-to-volume ratio.

In the future, analogues indicators to evaluate the energy efficiency in other uses (*electricity needs, air conditioning in summer, lighting*) will be defined in the same terms of the EPi, in order to provide the global energy performance certificate.

Recently (Summer 2009), the Italian legislation went over the long "*transitory phase*", started exactly 4 years ago, having the Italian Institutions released, during the July 2009, 2 important decrees, already described in the previous chapters: i.e. the Presidential Decree 59/2009; the Inter-Ministerial Decree 26.06.2009. These last legal acts fully implemented and defined the new regulations about the building energy efficiency.

During the transient regime (*Annex I of Decree 192/2005*), as regards new constructions and major renovations, the performances of the opaque and transparent structures should be verified through the verification of the thermal transmittances of the building shell. Furthermore, as regards the heating system efficiency, it should result higher than a minimum limit value. Instead, the global performance of the building-plant systems was evaluated through the EPi, that concerns the primary energy necessary to provide the winter heating of the building. The mandatory verifications were diversified depending on kind of building or kind of action, so that in some cases it is possible to avoid the EP calculation (*established, for this, the limit value*) or increasing the limit value of the building envelope thermal transmittance.

Other prescriptions regarded the mandatory use of renewable energy sources to produce part of the hot water demand and in order to integrate the electric energy supply with photovoltaic systems.

Globally, today the legislation results well defined about the evaluation of energy efficiency for the winter period (*considering that also the classification of the performances in the energy certificate is been recently defined*). On the other hand, as regards the other energy uses, the present state of art is quite approximate, first of all with reference to the aspects connected to the summer performance of the building envelope and of the air-conditioners.

In a first period (*but only for few months*), in order to reduce the summer cooling peak loads, the concepts of thermal-wave time lag (S) and attenuation (fa) were introduced into the Italian laws (*Ministerial Decree 27.07.05*) supported by the European technical Standard EN 13786. Today these indexes are substituted by the verification of the thermal mass (*predictive of thermal capacity and thermal inertia*) of the building envelope that, in the climatic regions characterized by an elevated value of the summer radiation, has to be at least 230 kg/m$^2$. Alternative, the Presidential Decree 59/2009 imposes periodic thermal transmittance $Y_{IE}$ lower than 0.12 W/m$^2$K.

Moreover, the Legislative Decree 192/2005 and the Presidential Decree 59/2009 impose the use of window shading devices or glasses with low-solar transmission factors; furthermore, only a qualitative verification about the correct exposure and as regards a careful use of the building natural ventilation potential are required by the Italian laws.

Table IV.1: Maximal stationary thermal transmittance values imposed by the laws in Germany and Italy (*in grey, the more restrictive value*).

| ***U**$_{values}$* ***(W/m$^2$ K)*** | *Germany (EnEV 2007)* | *Italy (Annex I, Decree 192/2005)* |
|---|---|---|
| External opaque walls | 0.35 – 0.45 | 0.35 – 0.72 |
| External windows and glass-door | 1.70 | 2.00 – 4.60 |
| Glasses | 1.50 | 2.20 – 5.00 |
| Roof | 0.30 | 0.31 – 0.42 |
| Basement on the ground | 0.25 | 0.36 – 0.74 |

Table IV.2: Maximum values of the primary energy requirements for the heating of the building in Germany and Italy. The values are expressed in kWh/m$^2$ a.

| EnEV 2007 | |
|---|---|
| S/V | |
| *> 3001 Kd* | |
| ≤ 0.2 | 66.0 |
| 0.3 | 73.5 |
| 0.4 | 81.1 |
| 0.5 | 88.6 |
| 0.6 | 96.1 |
| 0.7 | 103.6 |
| 0.8 | 111.2 |
| 0.9 | 118.7 |
| 1.00 | 126.2 |
| ≥ 1.05 | 130 |

| Italian Legislative Decree 192/2005 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| S/V | Climatic Zone | | | | | | | | | |
| | A | B | | C | | D | | E | | F |
| | *until 600 Kd* | *from 601 Kd* | *until 900 Kd* | *from 901 Kd* | *until 1400 Kd* | *from 1401 Kd* | *until 2100 Kd* | *From 2101 Kd* | *until 3000 Kd* | *over 3001 Kd* |
| ≤ 0.2 | 9.5 | 9.5 | 14 | 14 | 23 | 23 | 37 | 37 | 52 | 52 |
| ≥ 0.9 | 41 | 41 | 55 | 55 | 78 | 78 | 100 | 100 | 133 | 133 |
| *The surface-to-volume ratio (S/V) represents the ratio between the amount of surface that close the heated volume and the gross heated volume of the building. The assumed value, depending on the shape of the building, influences the heat losses both in winter and in summertime. The degrees-day, instead, are expressive of the winter weather conditions in a particular climate. In the tables, analogue conditions are evidenced. Considering that in Germany, normally, there are more than 3000 Kd, for low S/V, the Italian law is more restrictive (52 kWh/m$^2$a vs. 66 kWh/m$^2$a); instead, with reference to elevated S/V ratio (≥ 0.9), the imposed limits are similar (around 130 kWh/m$^2$).* | | | | | | | | | | |

## 4.3 OFFICE BUILDING: CASE-STUDY, CHARACTERISTICS AND TYPICAL BOUNDARY CONDITIONS

The base case, considered as reference to compare the analyzed passive cooling solutions, is in the followings described. It represents a very well insulated building, with heating and cooling systems quite efficient. The building, represented in figure 4.3.1, consists in a 2-floor construction, extended in the west-east direction, with several south-exposed office rooms. On the north side, two open space offices are located (*1 per floor*), with a meeting room at the ground level. The indoor space was divided in 6 different thermal zones, as represented in figure 4.3.1. The building presents a surface of 413 m$^2$ per each floor (globally, 816 m$^2$), with an overall heated volume of 3300 m$^3$.

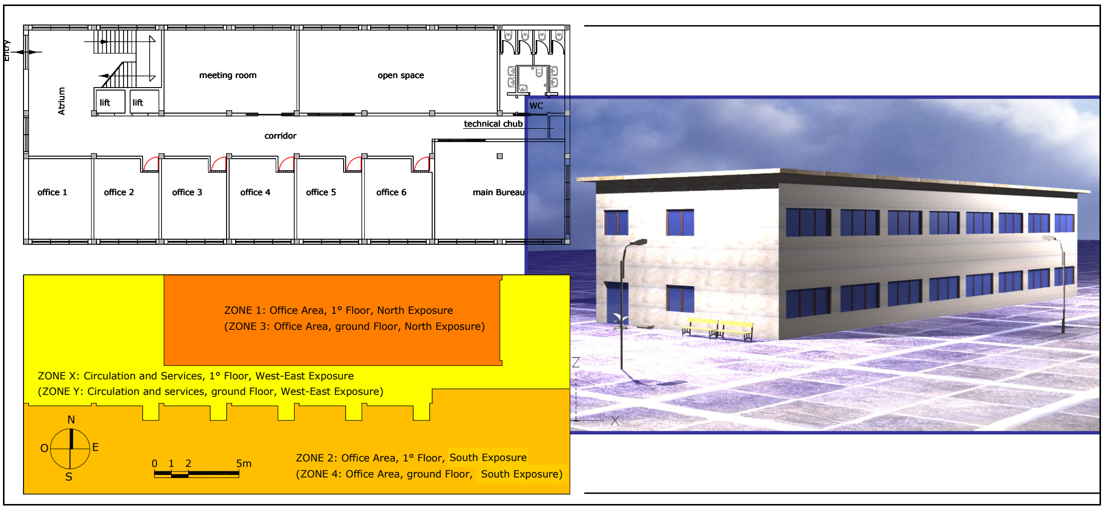



*Figure 4.3.1 – The modelled building; planimetry, thermal zones and volumetric scheme*

| **DIMENSIONS OF THE OFFICE BUILDING** | | | |
|---|---|---|---|
| Length (N-S direction) | 12.8 m | Width (E-W direction) | 32.30 m |
| Height | 8.0 m (2 floors) | Plant area and Volume | 413 m$^2$ - 3304 m$^3$ |
| **BOUNDARY DESIGN CONDITIONS** | | | |
| Climatic file and data | File IWEC | Occupancy (design)* | Maximum 65 Workers |
| Metabolic Index | 1.5 met per person | Infiltration ventilation 0.5 Vol/h<br>Ventilat. to Air freshness 6 L/s person .,e.g. 21.6 m$^3$/h person | |
| Artificial lighting (design)* | Maximum 10 W m$^{-2}$ | Other installed electric equipments (design)* | Maximum 12 W m$^{-2}$ |
| $T_{SUMMER-SET-POINT}$ (13 h - 5 days/week) 26 °C<br>(Cooling during when no occupancy occurs) | | $T_{WINTER-SET-POINT}$ (14 h - 5 days/week) 20 °C<br>(16 °C during no occupancy period) | |
| $U_{WINDOW}$ | 1.1 W m$^{-2}$ K$^{-1}$ | $U_{VERTICAL-OPAQUE-STRUCTURES}$ | 0.29 W m$^{-2}$ K$^{-1}$ |
| $U_{ROOF}$ | 0.17 W m$^{-2}$ K$^{-1}$ | $U_{BASEMENT-FLOOR}$ | 0.29 W m$^{-2}$ K$^{-1}$ |
| Surface to volume Ratio | 0.47 m$^{-1}$ | Electric energy cost | 0.18 € kWh$^{-1}$ |
| HEATING: System global efficiency: | 0.83 | Natural Gas cost | 0.65 € Nm$^{-3}$ |
| COOLING: Seasonal Energy Efficiency Ratio. | 3.0 Wh Wh$^{-1}$ | Electrical to primary energy conversion coefficient | 2.8 |
| THERMAL MASS OF THE ROOF | 469 kg m$^{-2}$ | Thermal to primary energy conversion coefficient | 1.1 |
| **** it is fixed an hourly scheduling with reference to occupancy, artificial lighting and other installed electric equipments*** | | | |

*Figure 4.3.2 – Main boundary conditions of the modelled office building*

The thermal characteristics of the building envelope are reported in figure 4.3.2, the structure layers in figure 4.3.3. The main peculiarities of the buildings are satisfactory both of Italian and German standards, such as imposed by the present regulation laws.

The modelled heating system modelled consists in an all-water system; a water gas boiler with heat recovery from smokes provides the warm water to fan-coil units, located in the office spaces. According to the European standards EN 15316, the following efficiency ratios are individuate for the heating sub-system devices:

- heat generation: water gas boiler with heat recovery from smokes – $\eta_G = 0.99$;
- heat distribution: un-insulated pipes within the internal walls – $\eta_D = 0.92$;
- heat emission: fan-coils – $\eta_E = 0.98$;
- environmental regulation: each thermal zone controlled – $\eta_C = 0.93$.

The overall system seasonal efficiency ratio, with reference to the heating system and including all sub-technical systems (*electronics, transport, storage, distribution and emission losses*) results $\eta_{OVERALL} = 0.83$. The auxiliary energy, in this case-study, has been not considered.

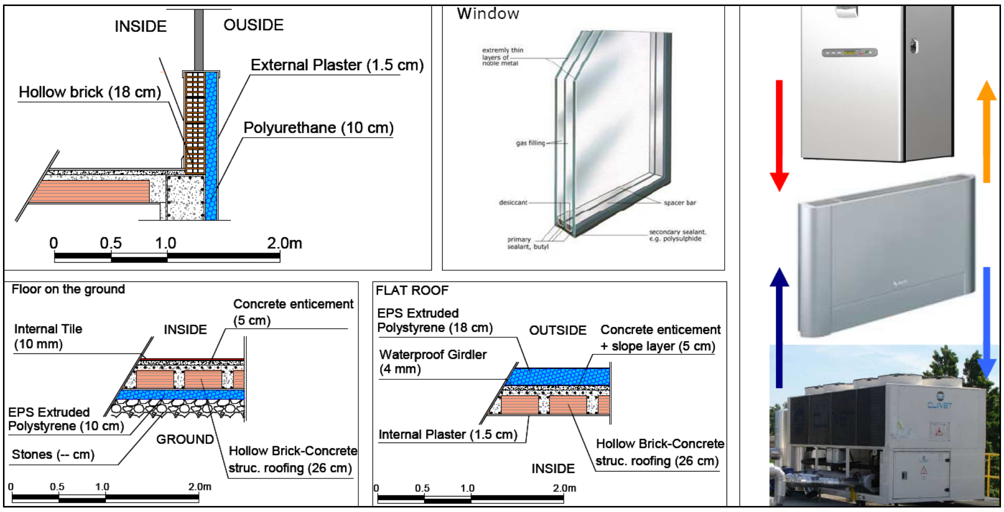


*Figure 4.3.3 – The building structures and the heating and cooling systems*

The same fan-coil units, in summertime, provide the indoor environment cooling; of course, in this case, an electric water chiller is necessary to provide the refrigerant fluid. Considering the same technical sub-systems of the heating plant, about these the same energy efficiency ratio has been considered. Therefore, the only difference, of course, concerns the heat generation systems. The modeled water chiller has an Energy Efficiency Ratio (EER) of 3.60 $Wh_{THERMAL}/Wh_{ELECTRIC}$, evaluated in nominal design conditions. As regards the seasonal use of the cooling system in summertime (*figure 4.3.3*), the Seasonal Cooling System Energy Efficiency Ratio (SEER) has been calculated and it results equal to 3.00 $Wh_{THERMAL}/Wh_{ELECTRIC}$.

The modelled characteristics, about the thermal behaviour of the building envelope and relatively to the efficiencies of the designed heating systems induce very efficient performances in wintertime (*as detailed in the followings*), with quite fair requirements with reference to the heating needs of the building.

In summertime, as before described, the German and Italian present regulations impose quite simplified verifications, so that, not always these prescriptions, even if satisfied, can guarantee good performances (*i.e. low cooling need and/or comfortable temperatures*) of the building during the warm season.

The modelled building presents a transparent surfaces of 146 $m^2$, with respect to a whole building shell of 1550 $m^2$, and a total vertical surfaces of 722 $m^2$; the transparent building envelope, therefore, represents the 9% of the whole exposed surfaces and the 20% considering only the vertical ones. In these conditions, the German EnEV 2007 imposes no summer verifications. Although the calculations are not necessary, in this study these evaluations are anyway carried out, in order to demonstrate that, even if satisfied, this kind of prescriptions does not assure satisfactory results.

The verification method, contained in the German Standard DIN 4108-02, imposes the evaluation of the S factor, as expressed in the following equation 1:

$$S = \sum \left( A_W \cdot g_j \cdot F_{C,j} \right) / A_G \qquad (1)$$

where:

$A_W$ = total window surfaces;

$g_J$ = solar transmittance through the glasses;

$F_C$ = Correction factor, depending on the shadings;

$A_G$ = Plan surface of the building.

**Tabelle 12.4: Zuschlagswerte $S_x$ verschiedener Standortrandbedingungen, Bau- und Betriebsweisen, nach [R9].**

| Zeile | Gebäudelage und Beschaffenheit | Zuschlagswert $S_x$ |
|---|---|---|
| 1.1 | Gebäude in Klimaregion A | 0,04 |
| 1.2 | Gebäude in Klimaregion B | 0,03 |
| 1.3 | Gebäude in Klimaregion C | 0,015 |
| 2.1 | Leichte Bauart: ohne Nachweis von $C_{wirk}/A_G$ | $0{,}06 \cdot f_{gew}$ |
| 2.2 | Mittlere Bauart: 50 Wh/(K · m²) ≤ $C_{wirk}/A_G$ ≤ 130 Wh/(K · m²) | $0{,}10 \cdot f_{gew}$ |
| 2.3 | Schwere Bauart: $C_{wirk}/A_G$ ≥ 130 Wh/(K · m²) | $0{,}115 \cdot f_{gew}$ |
| 3.1 | Erhöhte Nachtlüftung mit n ≥ 1,5 $h^{-1}$ bei leichter und mittlerer Bauart | + 0,02 |
| 3.2 | Erhöhte Nachtlüftung mit n ≥ 1,5 $h^{-1}$ bei schwerer Bauart | + 0,03 |
| 4 | Sonnenschutzverglasung mit g ≤ 0,4 | + 0,03 |
| 5 | Fensterneigung 0°-60° gegenüber der Horizontalen | $- 0{,}12 \cdot f_{neig}$ |
| 6 | Nord-, Nordost- und Nordwest-orientierte Fenster mit Neigung > 60° und Fenster, die dauernd vom Gebäude selbst verschattet sind | $+ 0{,}10 \cdot f_{nord}$ |

mit:

$f_{gew} = (A_w + 0{,}3 \cdot A_{AW} + 0{,}1 \cdot A_D) / A_G$

$A_w$ = Fensterfläche in m² (ermittelt nach Rohbaumaßen)
$A_{AW}$ = Außenwandfläche in m²
$A_D$ = wärmeübertragende Dach-/Deckenfläche in m²
$A_G$ = Nettogrundfläche des Raumes in m²

$f_{neig} = A_{w,neig}/A_G$ = Fensterfläche (geneigt) bezogen auf die Nettogrundfläche

$f_{nord} = A_{w,nord}/A_{w,gesamt}$ = Fensterfläche nach Zeile 6 bezogen auf die gesamte Fensterfläche eines Raumes

*Figure 4.3.4 - Coefficients reported by the German Standard DIN 4108-02*

As imposed by the EnEV 2007, S must result lower than a $S_{MAX}$, calculated as reported in the equation 2:

$$S_{MAX} = \sum \Delta S_X \qquad (2)$$

with:

$\Delta S_X$ = various terms related to the climatic regions, window exposure, night-ventilation, weight of the building (see figure 4.3.4).

In the examined case-study, S results 0.0847 and, even considering the worst German climatic Region (*i.e. building located in the "Klimaregion C"*), $S_{MAX}$ results equal to 0.102. Thus, it was verified that $S < S_{MAX}$.

Therefore, according to the present German legislation, this building satisfies the EnEV 2007 prescriptions about the summer environmental over-heating.

The same verification was been carried out also adopting the Italian standards. Naples was characterized by a summer solar irradiance, on the horizontal plane (*in the month with the highest solar radiation*), equal to 315 W/m$^2$. Being this value > the 290 W/m$^2$, the Italian Legislative Decree 192/2005 and the Presidential Decree 59/2009 impose that the building structures must have a thermal mass > 230 kg/m$^2$ (*without specifying if also the windows have to be computed*). Note that with reference to the evaluation of the mass of the structures, no internal and external plasters have to be considered. In the case-study, even computing the windows, it results:

- vertical opaque walls: 240 kg/m$^2$ > 230 kg/m$^2$ → verification satisfied;
- roof structure: 380 kg/m$^2$ > 230 kg/m$^2$ → verification satisfied;
- basement floor: 412 kg/m$^2$ > 230 kg/m$^2$ → verification satisfied.

Also considering the new, alternative, method proposed into the Decree 59/2009*,* the building envelope result satisfactory. In fact, this new regulation imposes reduced value of dynamic thermal transmittance for the building envelope ($Y_{12}$):

- opaque wall: $U_{DINAMIC\text{-}VALUE}$ ($Y_{12}$) must result lower than 0.12 W/m$^2$K;
- roof structure: $U_{DINAMIC\text{-}VALUE}$ ($Y_{12}$) must result lower than 0.20 W/m$^2$K.

In figure, 4.3.5 the periodic thermal transmittance of the building vertical wall has been calculated. Really, the same verifications have been carried out also for the other building envelope structures.

The evaluated the dynamic thermal transmittance of this building is quite reduced (0.013 W/m$^2$K), so it results perfectly regular also with respect to this verification.

As regards the time lag effect (S), it results higher than 13 hours (*with a suggested one of 8-9 hours*); moreover, quite satisfactory is also the attenuation factor ($f_a$), resulting of 0.077, while the suggested one is about 0.15.

Thus, in both the cases (*German EnEV and Italian Decrees 192/2005 and Decree 59/2009*), even if in the reported summer verifications the worst boundary conditions have been considered (*elevated solar radiation, climatic region, restrictive law interpretation*), the carried out verifications give positive results, i.e. the building guarantees (*according to the present laws*) good summer performances.

*Really, this is not true; and it will be shown in the next paragraphs of this study.*

| LAYER | Layer description | $\lambda$ (W/m K) | $\rho$ (kg/m$^3$) | c (J/Kg K) | R (m$^2$ K/W) | s (m) | $\delta$ (m) | $\xi$ (dimensionless) | C (kJ/K m$^2$) | Time (s) |
|---|---|---|---|---|---|---|---|---|---|---|
| Indoor Liminar convection/radiation | | | | | 0.13 | | | | | 86400 |
| 1 | Internal plaster | 0.58 | 1600.00 | 840.00 | 0.03 | 0.015 | 0.11 | 0.14 | 20.16 | |
| 2 | Hollow Brick-Concrete struc. roofing ($\lambda_{eq}$) | 0.74 | 1400.00 | 840.00 | 0.35 | 0.260 | 0.13 | 1.98 | 305.76 | |
| 3 | Concrete enticement + slope layer | 2.50 | 2000.00 | 840.00 | 0.02 | 0.050 | 0.20 | 0.25 | 84 | |
| 4 | Waterproof Girdler | 0.17 | 1200.00 | 840.00 | 0.02 | 0.004 | 0.07 | 0.06 | 4.032 | |
| 5 | EPS Extruded Polystyrene | 0.04 | 35.00 | 1340.00 | 5.14 | 0.180 | 0.14 | 1.26 | 8.442 | |
| 6 | material | no | 0.00 | 0.00 | 0.00 | 0.000 | 0.00 | 0.00 | 0 | |
| 7 | material | no | 0.00 | 0.00 | 0.00 | 0.000 | 0.00 | 0.00 | 0 | |
| 8 | material | no | 0.00 | 0.00 | 0.00 | 0.000 | 0.00 | 0.00 | 0 | |
| 9 | material | no | 0.00 | 0.00 | 0.00 | 0.000 | 0.00 | 0.00 | 0 | |
| 10 | material | no | 0.00 | 0.00 | 0.00 | 0.000 | 0.00 | 0.00 | 0 | |
| Outdoor Liminar convection/radiation | | | | | 0.04 | | | | | |
| TOTAL | | | | | 5.734 | 0.51 | | | 422 | |

| | |
|---|---|
| **M (kg/m$^2$)** | **468.8** |
| **U (W/m$^2$ K)** | **0.174** |
| **$F_{DECREM.}$ (attenuation)** | **0.077** |
| **$Y_{DYNAMIC}$ (W/m$^2$ K)** | **0.013** |
| **$C_{INNER\ SIDE}$ (kJ/m$^2$ K)** | **7.4** |
| **$C_{EXTERNAL\ SIDE}$ (kJ/m$^2$ K)** | **155.0** |
| **Time Lag (h)** | **13.09** |
| **Time Lag (minutes)** | **785.24** |

*Figure 4.3.5 – Calculation of dynamic thermal parameter (periodic transmittance, time lag effect, attenuation factor) according to EN Standard 13786/2008*

## 4.4 The considered passive cooling strategies: illustration and technical reviews about these

In this paragraph, the modelled solutions for the reduction of the cooling needs of the building are presented. In particular, 4 kinds of cooling strategies are studied and compared:

- roof movable insulation,
- nighttime ventilation,
- vertical wall movable insulation,
- ground cooling through earth-to-air heat exchanger.

About this last strategy, the ground cooling has been simulated several times, in order to optimize, meanly for the 4 cities, the best working criteria. The following description of any kind of solution adopted and analyzed contains a brief review of the scientific literature state of art.

### 4.4.1 Roof Movable Insulation

The movable insulation of roof is a passive cooling solution working under the radiant cooling phenomena. Each surface emits a radiation into a spectrum of wavelengths that, at the ordinary temperatures of building surfaces, are in the long-wave range (infrared). During the summer night, the net radiative flux interesting the building envelope surfaces induces heat dissipation and a consequent cooling of the building structures. Normally, in fact, the main view factor interesting the building structures is verified with the sky (*characterized by low temperatures*) so that the net radiative flux is directed toward it.

During the day, the high solar radiations peaking up on the building structures, on the contrary, causes an elevated heat gain, being partially absorbed by the surfaces that raise their temperatures (*increasing the heat conduction inside the lived spaces*).

Therefore, a useful radiant cooling can be obtained only during the nighttime, while, during the diurnal hours, it is necessary to protect the external building surfaces by the solar radiation (*increasing their albedo, using shading systems, adopting elevated massive structures to increase the thermal inertia of the opaque envelope*).

The net radiative flux between the sky and exposed building surfaces depends on several factors, among which the most important are:

- sky temperature;
- sky emissivity;
- sky conditions;
- surface emissivity;
- surface temperature;
- external ambient temperature;
- wind conditions;
- humidity conditions.

Santamouris [1, 2] well and easily explains how these boundary conditions influence the potential cooling effects of a radiative system, underlining that the radiant potential is fully used when, during the nighttime, the opaque structures result charged (*usually this happens when massive structures are adopted*), because heated by the summer diurnal radiation. Otherwise, in presence of easy and light structures (*i.e. no stored thermal energy*), the cooling effects can be annulated, and, if the ambient air is contradistinguished by thermal level higher than the internal ones, further conduction heat gains can interest the building structures.

Givoni [3] reunites in 3 macro-groups the several radiant options to provide the building structure cooling:

a) high mass roof with movable insulation;
b) unglazed water collector;
c) lightweight metallic radiator that cool the ambient air.

This last one solution has to be accurately designed, in order to reduce the thermal absorptance during the daytime, to increase the conduction heat transfer and to emit enough thermal energy during the nighttime. About it, the metallic material could offer good performances as regards the thermal conductivity, but it requires adapted painting in order to provide also low absorptance and, above all, high infrared emissivity, such demonstrated by Bagiorgas and Mihalakakou [4].

Actually, each kind of solutions can be diversified in several technical configurations. In this chapter, for examples, it will be analyzed the performance obtainable using the first configuration: *radiant cooling effect, obtained by means of the removing, during the nighttime , of the roof thermal insulation*.

A high thermal capacity can be obtained both using high concrete building structures (*elevated mass and, therefore, elevated thermal capacity*) or water pond layers on the roof, that, being the water characterized by an elevated specific heat capacity, result well adapted in storing the diurnal thermal energy.

This passive cooling strategy initially was coupled to water pond layers, so that, during the day, the thermal capacity of the fluid (*high specific heat of the water = 4.19 kJ/kg K*) provides the storage of high quantity of solar radiant energy incident on the building roof.

Erell *et al*. [5] simulated a reference building in Sevilla (Spain) equipped with a roof pond in order to provide passive cooling. The water pond has a covering insulation during the daytime. The results show energy savings of 45-55%, reducing hardly the cooling loads and the operating period of the HVAC system.

Givoni [3], studying radiative and convective heat transfer phenomena, shows that, in order to be very effective, the thermal mass has to be discharged during the night. Therefore "*in order to serve as a cooling system, the roof as to be insulated from the sun and hotter ambient air during the daytime hours….and if combined with operable insulations it becomes an efficient radiator/storage cooling element*".

Santamouris, in "*Advances in Passive Cooling*" [6], reports some numerical and experimental examples of massive roof coupled with movable insulations. Some experimental buildings were realized (California, Texas, Arizona) both with water pond or heavy concrete layers used as high inertia elements. The monitoring activities and the numerical simulations confirm that are influent, about the obtainable saving potential, of course the sky temperature, the solar irradiation, the outdoor air temperature, but also the conditions of the sky (*clean, covered or overcast*) and the wind speed on the roof. This last event influences strongly the convective thermal exchanges both during the day and during the night.

The movable insulation cooling potential was deeply studied by Nahar, Sharma and Purohit [7], that experimentally built 7 identical test-cells roofed with different passive cooling solutions. The passive solutions investigated consist in:

1. a cool painted roof;
2. fixed thermal insulation on a concrete roof,
3. a water pond layer upon a traditional ceiling (to store the diurnal heat gains) with a top layer of movable insulation panels;
4. evaporative strategies to cool the roof surface;
5. broken white glazed tile pieces over the roof;
6. use of vacuum insulating materials;
7. roof covered with a local (Indian) thermal insulating material (*called "Sania"*) used over the huts in the arid regions.

The best performances, as regards the indoor temperature reductions, have been obtained using the evaporative cooling strategy, but very useful results are achieved also with the white glazed tiles and the water pond with movable insulating panels.

Analogues studies were conducted by Dilip Jain [8], that compares typical methods of roof passive cooling in India; the comparison was carried out considering a simple base case without insulations, a roof with insulating material on the inner side of the structures, evaporative cooling solutions above the roof and a water roof pond with movable insulation panels. The numerically obtained results are then validated also through well-appropriated experiments and these show that, with reference to unconditioned buildings, the roof pond with movable insulation is very useful, inducing the best indoor comfort conditions in arid regions.

In this study, it is not provided the water layer, because the roof structure is very massive, so that 18 cm of movable extruded polystyrene are positioned on the top of the roof, in external position, as represented in figure 4.4.1.

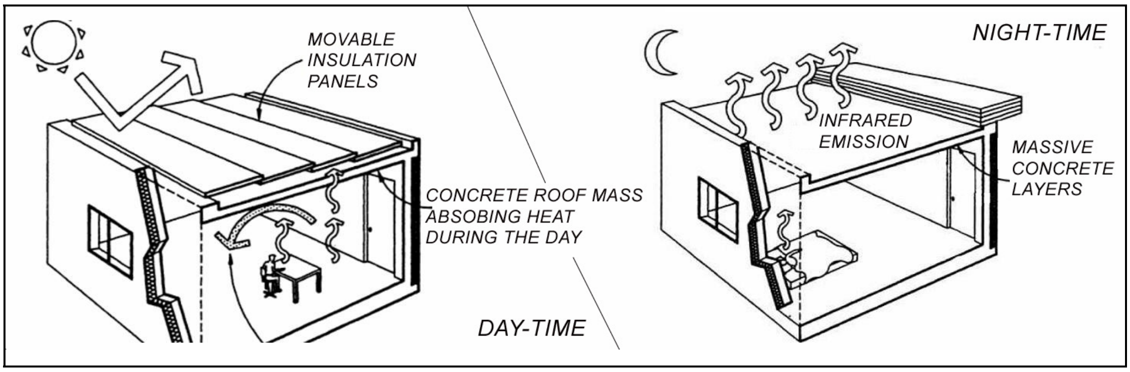



*Figure 4.4.1 - The functional schemes in summertime (source: elaboration of a Givoni example [3])*

The mobility of these panels could be easy obtained through a simple mechanical system that operates the movement of the panels in the first hours of the night, overlapping the insulating sheets on the roof external cornice. Using metallic tracks, in the morning first hours the insulating panels slide on the roof, in order to cover its entire surface.

About the scheduling of the insulation movement, it was modelled that, in the period $16^{th}$ June – $15^{th}$ September, from 7.00 in the morning until 20.00 in the evening, the insulation panels cover all the roof surface, while, in the remaining night hours, the concrete heavy structures result sky-exposed. The thermal transmittance of the roof, during the summer day, is so defined:

- summer diurnal hours: $U_{\text{STACTIONARY VALUE}} \rightarrow 0.17\ W/m^2K$;
- summer nocturnal hours: $U_{\text{STACTIONARY VALUE}} \rightarrow 1.35\ W/m^2K$.

This scheduling was chosen because it induces, meanly in the 4 climatic conditions considered (*i.e. Naples, Stuttgart, Berlin and Oslo*), the best performance both in reducing the cooling load in air-conditioned office buildings and in containing the indoor diurnal thermal levels with reference to naturally ventilated buildings.

### 4.4.2 NIGHTTIME VENTILATION

Balaras [9] investigated the role of the thermal mass, able to mitigate the summer indoor temperatures, reducing the peak cooling load and then determining a higher comfort. Furthermore, the author noted that an elevated thermal inertia becomes very important particularly during the intermediate seasons, when the large variations of external climatic conditions during the 24 hours can be mitigated inside the lived spaces. Moreover, an elevated thermal mass becomes very useful when coupled with well-designed nighttime ventilation, when the summer outdoor air temperatures are usually lower than the indoor ones, so that it is possible discharging the heated heavy structures of the envelope (*and thus the building results again ready to store energy during the following day*).

As already shown in the Chapter 3, Kolokotroni [10] has carried out similar studies in UK refurbished offices. The author noted that, when the indoor spaces are ventilated during the night, in the following days the indoor temperature results lower, above all in the first hours of the working time (*this results will be full confirmed in our studies*).

Givoni [11, 12] monitored the indoor conditions inside several buildings with different mass levels in south-California, on varying the night ventilation rates. The obtained results show that the night free cooling is characterized by an high cooling potential in order to free cool building envelopes characterized by elevated mass.

Even if is quite accepted the usefulness of the night ventilation to discharge the heat stored by massive structures, the potential of this kind of passive cooling solutions has to be carefully estimated. Geros *et al.* [13] investigated the night ventilation potential, both in conditioned buildings and in buildings without active cooling systems, in 10 urban canyon of the Athens region. The analyses show the potential of this passive cooling strategies, in specific location characterized by lower wind and air stagnancy (*i.e. urban canyon*), where these adverse boundary conditions determine a significant reduction in the obtainable performances. The effectiveness of night ventilation is quite reduced where the microclimatic external conditions are affected by morphological and particular contextual conditions. Therefore, besides the mean outdoor temperatures, also the specific urban environment has to be carefully considered, in order to avoid an overestimation of the cooling potential of this strategy.

The same question was posed by Parker *et al*. [14], who underline the potential of natural nighttime ventilation in hot-arid climates, where the coupling of high thermal inertia, and nocturnal thermal discharging of this can reduce both the temperature swings during the day and the cooling loads that the HVAC system has to balance.

The same authors explain that, although theoretically the potential of nighttime ventilation is very high, the urban context can drastically reduce it, when, for examples, some adverse conditions happen (*no wind, local obstructions, nearby buildings*). Furthermore, Parker underlines that the whole potential of nighttime ventilation is achieved when the building structures are characterized by an elevated thermal capacity; otherwise, if the building is a lightweight one, no significant benefits are achieved, being the structures already cooled during the night hours, by means of simple heat transfer conduction phenomena.

Finally, the indoor diurnal temperatures of massive buildings are lower compared to light building ones, while during the night the opposite effect occurs. Enclosures able to store energy, shifting and attenuating the heat transmission to the indoor environment, become therefore useful to reduce the temperature fluctuations of the lived spaces: it means lower thermal levels during the maximum external thermal load, but also higher temperatures during the night.

The behaviors of massive building envelopes have been well investigated by Henze *et al.* [15]: the attenuation of the indoor temperature swings, obtained using high thermal inertia building envelopes, can induce energy savings, if in the indoor environment control the new criteria about the thermal adaptative comfort are applied. On the contrary, if a fix set-point temperature is maintained using a cooling system (*and it happens often in the south-European conditioned buildings, e.g. Italy, Spain and Portugal*), the use of high mass structures do not induce energy savings.

Thus, massive envelopes are well adapted when the use of the building is in the central period of the day. As regards the residential constructions, the nocturnal free cooling and other techniques of mass activation become necessary to limit the thermal discomfort or/and reduce the night cooling loads, as reported by Shaviv *et al.* and Cheng with Givoni [17, 18].

Also this kind of passive cooling strategy has been investigated in this Chapter, with reference to the case-study building before presented. The building envelope presents quite massive structures: a mixed brick-concrete layer characterizes the roof and the basement. Also the vertical wall, according to the European typical construction technologies, presents a brick stratum. Thus, considering the high potential of the simulated building in storing thermal energy during the summer diurnal hours, the night ventilation seems a well-adapted passive cooling strategy. Considering that it is an office building (*no occupancy during the night hours*), also many air-changes can be designed during the nocturnal hours, being not significant the nighttime overcooling.

With reference to the 4 considered climatic conditions (*Naples, Stuttgart, Berlin and Oslo*), 4 ACH were considered and simulated during the nights. It means about 11230 $m^3$/h of night ventilation (3.12 $m^3$/s), that can be easy obtained naturally. In fact, the simulated office building is characterized by a relevant amount of opening windows (see figure 4.3.1). This has been thought also in order to consent the variation of the microclimate by the hosted workers.

The night ventilation was adopted between 12.00 pm to 7.00 am, each day in the period $15^{th}$ June – $15^{th}$ September.

### 4.4.3 MOVABLE INSULATING PANELS FOR THE VERTICAL OPAQUE WALLS

Even if the movable insulating layer for roof structures are well-known in the scientific literature and in the constructive practice in hot climates (*although this solution is not commonly used*), the movable insulation for the opaque vertical roof is substantially an unknown strategy; some applications, in particular technological solutions, can be seen in the Trombe-Michel walls (figure 4.4.2). This kind of building solution is used above all in wintertime, when the south-facades are interested by an appropriate solar radiation useful to obtain natural and free solar heat gains.

The system is constituted (from the external to the internal layers) by a glazed surface, an air gap, a black painted massive wall (*the wall is painted black to increase its solar absorptance*). The solar radiation, crossing the glazed surface, heats the black wall that, partially, conducts the thermal energy inside the building, partially heats the air inside the gap. This air, entering in the low zone of the gap, when heated, comes back into the room in the upper zone (figure 4.4.2-a), being the airflow movement induced by the natural convection (stack effect).

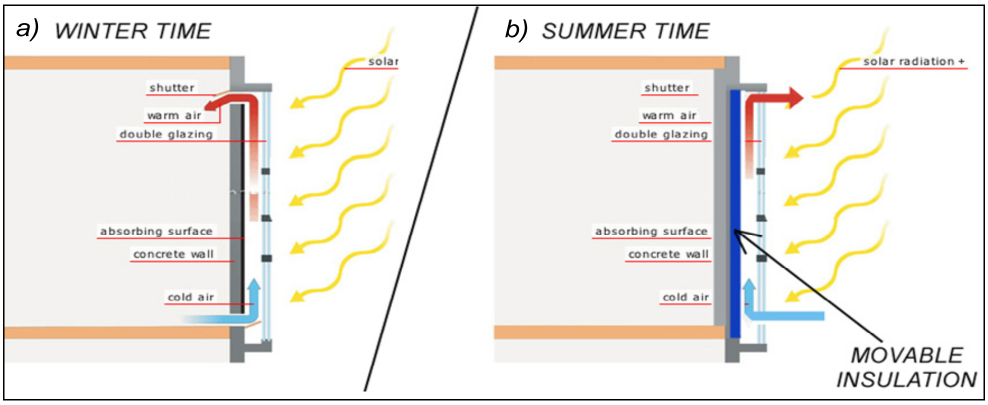



*Figure 4.4.2 - Trombe Wall functional schemes, in both winter (a) and summer (b) time.*

The role of movable insulation panels, on the external side of the black wall (exposed to the solar radiation) guarantee no heat dissipation during the nighttime hours in wintertime, while in the summer season these limit the over-heating of the black wall.

Anyway, in summertime is also useful designing opening slots in the glass façade, so that the external air enters into the gap through the low opening, cools the gap, and then it is rejected to the external environment (see figure 4.4.2-b).

The functioning of the Trombe wall can be regulate using both electrical movable dampers (i.e. to open and close the openings situated on the glazed curtain - *in summer* - and on the black wall - *in winter* - ), or also providing mechanical movable insulations.

As already explained about the movable insulation of the roof, during the summer night hours the movable insulation can be removed to increase the heat dissipation from the indoor environment towards the external ambient.

Another strategy of vertical movable insulation is commonly used to vary the thermal resistance of the windows, above all in wintertime. Well-exposed windows, principally on the south-façade of the building, guarantee significant heat gains in moderate climate during the winter diurnal-hours. For examples, about the 4 analyzed city, results:

- Naples: January mean irradiation on the vertical plane south-exposed → 2530 Wh/m$^2$;
- Stuttgart: January mean irradiation on the vertical plane south-exposed → 1250 Wh/m$^2$;
- Berlin: January mean irradiation on the vertical plane south-exposed → 1090 Wh/m$^2$;

- Oslo: January mean irradiation on the vertical plane south-exposed → 644 Wh/m$^2$.

Therefore, significant benefits can be achieved designing correctly the window amount and their characteristics in wintertime. Anyway, even if during the diurnal hours, useful heat gains can be achieved (*and they results higher than the heat losses for conduction phenomena*), during the nighttime 2 penalizing phenomena occur:

- the first one is represented by the relevant heat dissipations from the inside environment to external one, due to the indoor-outdoor temperature difference;
- the second one, instead, is represented by nocturnal radiation between the indoor space and the sky.

In order to reduce both these thermal losses, the covering of the transparent window surface adopting appropriate thermal insulating materials can be quite convenient.

The same principle of the night insulation of the windows was initially adopted to improve the environmental conditions of greenhouses. Then, basing on an elementary physical principle (*raising the thermal resistance of the transparent envelope when there is no solar radiation*) it was extended also to the residential and civil applications (figure 4.4.3).

In summertime, closing the window with insulating panels during the diurnal hours (*modulating the amount of natural lighting such as required inside the indoor space*) induces positive effects in reducing the cooling load of the buildings and, when this is no-conditioned, this operation results also useful to improve the indoor thermal conditions. In this case, the movable insulation of the windows works as a shading device for the transparent surfaces. During the night hours, instead, when usually the outdoor climatic conditions induce a thermal flux from inside towards the outside, reducing the thermal resistance of the window (*removing the insulations*) could make better the thermal condition of the indoor space (*reducing the cooling loads*).

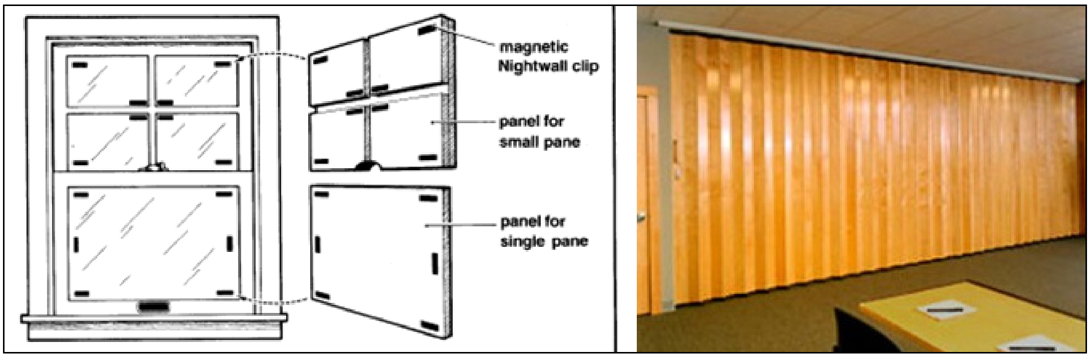



*Figure 4.4.3 - Movable insulating panels for windows: scheme and application*

The same principle can be adopted for the opaque wall. In fact, if at the upper floor of the building, important energy savings and better comfort conditions can be achieved cooling the structures during the nighttime, removing the roof thermal insulating panels, the same effect can be applied to the vertical walls.

In particular, removing the insulation by the vertical opaque walls, during the summer night hours, a significant radiative cooling effect would discharge the heated envelope.

Of course, the cooling effect will result reduced compared to the benefits achievable reducing the thermal resistance of the roof (above all as regards the north-exposed facades). This is due to 2 main reasons:

1. the different amount of stored thermal energy (much higher for the roof);
2. the different view factor with the sky (two times higher with reference to the horizontal structures).

In particular, not only the solar radiation on the vertical surface is minor compared to the radiation interesting the horizontal surface, but also the view factor between vertical wall and sky is reduced (0.5), so that the potential cooling cannot be very elevated. Anyway, this kind of solution could be applied at each floor of the building (*not only at the last one*) as represented in figure 4.4.4.

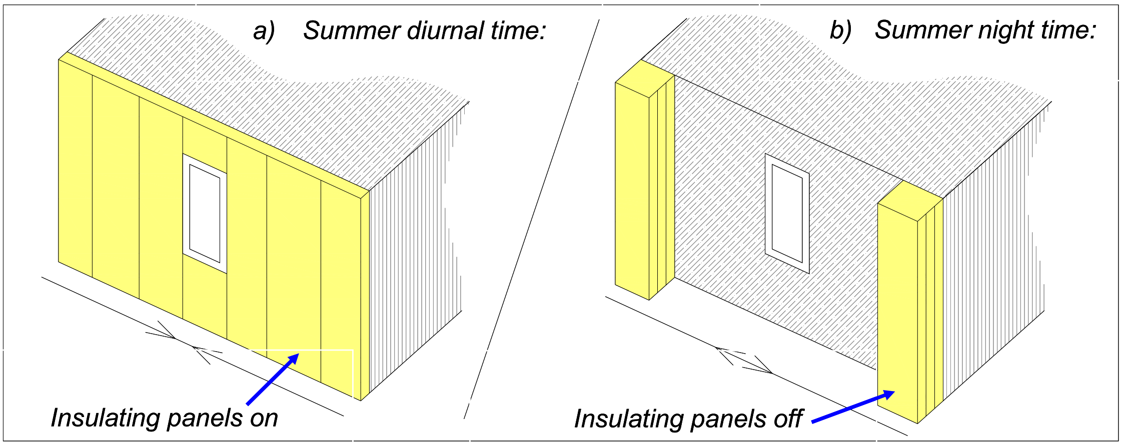



*Figure 4.4.4 – Vertical wall movable insulating panels: functional schemes*

Therefore, despite we are conscious that this strategy can offer not always excellent results, the potential achievable effects have been analyzed in the followings.

Under the technological point of view, the system works at the same way of the roof movable insulations. Using the same tracks usually adopted to build the external insulation of the building, a simple mechanical systems can be designed to overlap the insulating panels in some part of the vertical wall (*for example near the outside exposed pillar surfaces, as represented in figure 4.4.4*).

The modeling criterion, as regards the vertical movable insulations for the simulated office building, is in the following lines summarized. In the period 15$^{th}$ June – 15$^{th}$ September, this scheduling interests the 10 centimetres of polyurethane panels posed on the exterior side of the opaque vertical walls: in the night hours, between 7.00 pm and 07.00 am, the insulation panels are moved off, so that the thermal transmittance of the opaque structures changes in this way:

- summer diurnal hours: $U_{STACTIONARY\ VALUE} \rightarrow 0.29\ W/m^2K$;

- summer nocturnal hours: $U_{STACTIONARY\ VALUE} \rightarrow 1.05\ W/m^2K$.

The movable insulation has been modelled with reference to all the perimetrical walls of the building, so that the cooling effect can be obtained in each thermal zone. The effect of this kind of passive cooling solutions will result very different depending on the analysed building thermal zones (south- or north- exposed).

### 4.4.4 EARTH-TO-AIR HEAT EXCHANGERS

The earth-to-air heat exchangers, in the followings shortly called EAHX, represent a technical solution fit to reduce, in both winter and summertime, the ventilation loads of the building. These exchangers work under a quite simple physical phenomena: the ground temperature do, in both the climatic season, more convenient the use of the earth as cold or warm sink, so that pre-heating or pre-cooling the external air through a thermal exchange with the ground induces significant energy savings. In particular, well using this thermal exchange, it becomes possible to reduce, or sometimes to nullify, the necessary enthalpy drop, commonly obtained by means of HVAC systems.

The ground temperature, at a certain depth (*normally about 5 – 8 meters under the ground level*) remains quite constant throughout the year. The soil temperatures and thermal distribution depend on several factors, among which the structures and the physical properties of the ground, its covering (snow, lawn) and the climate interferences (*such as the wind intensity, the solar radiation, humidity ratio and rainfall [18, 19, 20]*). The influence of each of this parameter is quite difficult to quantify.

The earth-to-air heat exchangers are usually characterized by a metallic, plastic or concrete tubes placed underground; the choice of the correct depth, as explained in the followings, strongly affects the systems performances. The ventilation airflow, crossing the buried pipes, is preheated in wintertime and cooled in summer (*see the working schemes in figure 4.4.5*). The principle was empirically discovered already several centuries ago, starting by some interesting experiments in the ancient Persia; then, other examples were applied also in the Greek architecture of pre-Christian Era.

Normally the air circulation through the horizontally buried pipes is guaranteed using electric fans. This aspect represents one critical design topic, being the pressure drop within the pipes strongly influent on the energy efficiency of the EAXH. In particular, this low-energy strategy induces a thermal energy recovery from the ground; when the pressure drops are not minimized (→ *i.e. powerful fans are required),* the paid mechanical (electric) energy do ineffective the use of this strategy. Of course, when this application is used integrated in a ventilation system, the energy consumption of the fans does not represent a new energy requests (*even if is in this case, the electrical energy request becomes surely higher compared to a traditional ventilation system*).

There are several technological variations of the passive thermal recovery by means of buried pipes. In particular, can be identified two macro-groups of earth tubes: a) open-loop EAXH; b) closed-loop EAXH.

In the first case (*investigated in this study*), the external airflow, crossing the pipes, is directly supplied into the indoor environment (figure 4.4.5). With reference to close-loop solutions, contrariwise, both the inlet and the outlet are located within the indoor space [3].

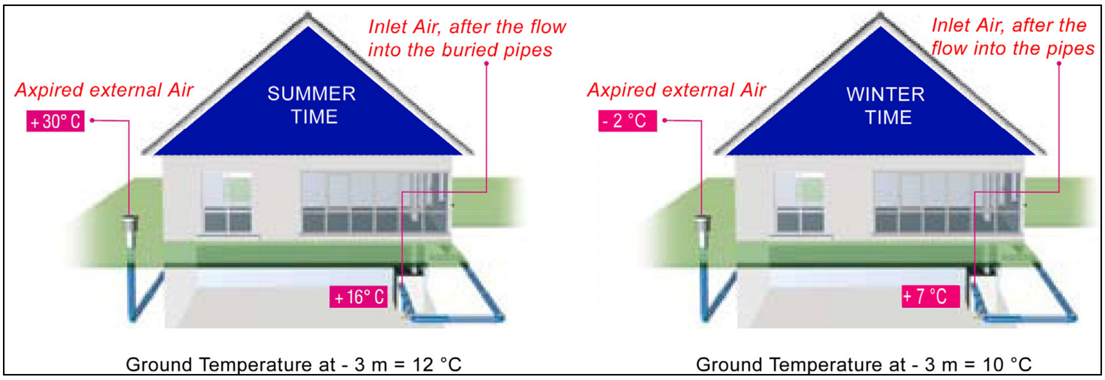



*Figure 4.4.5 - Simplified schemes of the summer and wintertime EAHX functioning*

Traditional applications use pipes normally in the range 30 – 60 m as regards the buried length, typically posed at 2 ÷ 4 m under the ground level. The diameters of the pipe can vary in the range 8 ÷ 20 cm; the buried pipes are located in horizontal position. In summertime, when the external humid air is characterized by a relevant amount of moisture, condensation phenomena inside the pipes are frequent. For example, drawing on a psychometric chart typical external outdoor conditions in warm summer climate (*Germany and Italy included*), at the conditions 32 °C for the temperature and 65% about the RH, corresponds a condensation temperature of about 24.5 °C. Considering the ground typical temperature, in these climates and at these depths, is in the range 8 ÷ 15 °C, then the formation of liquid is very probable.

Therefore, considering the typical problems deriving from the water stagnancy in the air ducts (*fungi, bacteria und also legionella risks*), it is very recommended an exact minimum slope of the tubes (at least 2°).

In order to assure a good quality for the inlet air, in addition to a correct inclination of the pipes to drain the condensed water, also a regular cleaning, a non-toxic bactericidal treatment of the tubes (*e.g. deposing silver ions*) and well-adapted air filters are necessary. Moreover, in order to optimize the heat exchange between the crossing air and the ground, corrugated tubes should be used.

About the EAHX design tool, a mathematical model to simulate the performances of single buried tubes was developed by Mihalakakou and then also experimentally validated [21, 22, 23, and 24].

Zhang and Haghigat [25] underline the critical accordance among physical model based on empirical correlation, computational fluid dynamic tools and experimental data. In particular the authors refer about significant discrepancy among several different numerical codes; the critical aspect is represented by the lacking of parameters and other accurate boundary conditions (*pipe wall temperatures, local average convective heat transfers*), without using previously CFD simulations. Zhang and Haghigat tried to solve the problem, proposing a complete and reliable group of CFD studies to derive, for typical EAXH applications, the necessary input parameters. On the other hand, the authors propose a 1-dimensional physical model based on some assumptions:

a. thermal properties of the air inside the tube are constant and the fluid is incompressible;
b. airflow inside the tube is steady state and mono-dimensional;
c. the duct is divided in several sections, each characterized by constant value about the air temperature;
d. the tube surface temperature is not affected by the airflow thermal level;
e. on the duct surface, no latent heat transfer occurs.

Using these assumptions and the developed physical model, the numerical results was compared with a measured field in a Norwegian application. The results show that the model becomes more reliable along the tube, while in the start sections (near the pipe inlet) there is a significant discrepancy between the 1-D model and the CFD results. The CFD simulation gave results very well correspondent to the measured values.

Berkert *et al*. [26], instead, underline the lack of optimization criteria and well-adapted software. Depth, length and cross-section of the tubes influence the heat exchange, the achievable benefit and also the pressure drop that, on the contrary, induce different amount of required fan electrical power.

These authors developed the computer tool GAEA [26], based on 3 main physical assumptions and relative mathematical modeling conditions:

a. the earth temperature around the tubes depends on the deep layer ground temperature, and, during the using time, it depends also on the air thermal level inside the tube;
b. as regards the external air temperature, its trend can be represented with a sinusoidal function;
c. the thermo-dynamic transformation of the air through the pipes is evaluated dividing the tube in 100 segments and considering each of these as characterized by a constant thermal level.

The comparison between experimental data, achieved by Albers [27] and the simulation carried out using the Berkert's tool was really satisfactory. The results of the validation are reported in figure 4.4.6-b. Being GAEA well validated, in the followings of this study, some boundary conditions to model and optimize the EAHX (*using EnergyPlus [28]*) have been chosen after some analyses based on the GAEA model.

About the achievable advantages induced by these systems, the earth tubes are simple, characterized by an elevated potential, and require low maintenance. Pfafferot [29] underlines that, while in wintertime is usually necessary an air post-heating process, through the use of an heating systems (*see figure 4.4.5, right side*), in summertime, if the thermal behaviors of the building are satisfactory, it is possible guarantee comfort conditions also without an active post-cooling of the EAHX outlet air [29].

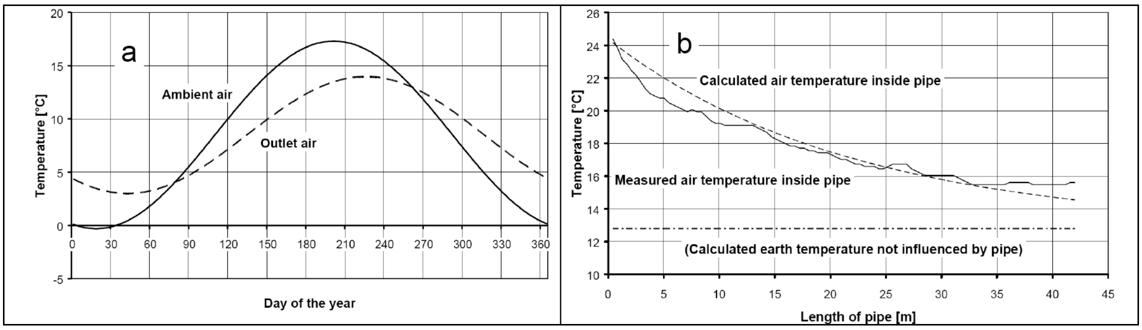



*Figure 4.4.6 - GAEA model: a) air temperature before and after the heat exchange inside the buried pipe; b) calculated and measured air temperatures along the earth tube heat exchanger (source: [26])*

In the following analyses, the EAXH was simulated to operate both energy savings in summertime within air-conditioned building and to reduce the indoor temperatures in naturally ventilated offices. In particular, the following investigations have been carried out:

1) how much the use of an earth-to-air heat exchanger reduces the needs of the active cooling, fixing an indoor temperature set-point;
2) if it is possible, adopting well designed earth tubes, the obtainment of thermal comfort conditions inside natural-ventilated office buildings, and so without the use of active cooling.

Three typologies of regulation have been considered. In fact, as shown in the previous review about these systems, the balance between the saved thermal energy and the (extra) electrical energy required (*higher pressure drops compared to a traditional ventilating system, i.e. higher fan size, or, in absence of ventilating systems, the electrical energy required by the fans*) represents the a key-aspect.

Therefore, the potential of the EAHX has to be correct identified, using well-adapted simulation systems, so that it can be possible both the choice of the best design conditions (*length, depth, cross-section dimensions, materials*) and the best scheduling and regulation criteria. *In this section, common boundary conditions are considered; in the paragraph 4.7, a deep study regarding the influence of the design choices has been reported, with reference to the Italian climates.*

The importance of appropriate control strategies is also underlined in [30] to avoid unwanted air heating in summer (*e.g. when during the evening hours the outdoor temperature is cooler than the earth tube surfaces*) or un-desired cooling effect in wintertime (*when, in moderate climate, during the day sometimes the air temperature can be also higher than 15 °C*).

Some introductory analyses, referred to the 4 climates considered (*i.e. Naples – south-Europe, Stuttgart – central-Europe, Berlin – central-Europe Germany, Oslo – north-Europe*) chosen as representative of all European weather conditions, have been carried out to design correctly the earth-to-air heat exchanger. The system characteristics, quite typical for this kind of application, are described in table IV.3.

Table IV.3: main design characteristics of the modelled earth-to-air heat exchanger

| | *Whole Office Building* | | |
|---|---|---|---|
| | *Zones 1 and 3* | *Zones 1 and 3* | *Zones Y and X* |
| Design Volume rate (each zone) | 2 x 0.096 $m^3/s$ | 2 x 0.144 $m^3/s$ | 2 x 0.088 $m^3/s$ |
| Design Volume rate (building) | 2361 $m^3/h$ | | |
| Earth tube type | Fan positioned on Exhaust position *(so, no air temperature increase through the fan)* | | |
| Specific pressure loss | 30 Pa/m | | |
| Total pressure loss | 1150 Pa | | |
| Fan Total Efficiency | 0.7 | | |
| Tube length | 50 m | | |
| Tube depth under the ground | 3.00 m | | |
| Tube thickness | 5 mm | | |
| Tube material | PVC ( thermal conductivity of 0.16 W/mK) | | |
| Pipe radius | 165 mm | | |
| Soil condition | Heavy and Damp | | |
| Electrical energy absorbed by the fans | 1250 W | | |

As regards other boundary conditions (i.e. average soil surface temperature, amplitude of soil surface temperature, phase constant of soil temperature), these have been defined using the various data reported by Pfafferot *et al*. [30], or using the numerical values calculated by means the "*Calculation of Soil Temperature*" developed by the U.S. Department of Energy [31].

However, all input data have been accurately selected, evaluating their coherence with respect to those reported in the scientific literature. After the choice of the mean best functioning period of the system in summertime, three design options have been compared in each climate conditions:

a) EAHX base case – the ventilation of the building (about 22 $m^3/h$ person, i.e. 1 ACH) is achieved always supplying into the building the outlet airflow coming from the buried tubes;
b) in summertime the EAXH works between 8.00 in the morning until 18.00 in the afternoon. In the first hours of the day (5.00 – 8.00 am) and in the evening (18.00 – 21.00) the cooling effect is obtained by means of natural ventilation (with a consequent saving of the energy required by the fans; even in this case, the ventilation amount is of about 1 air-change/hour);
c) the third operational mode is represented by an EAHX running for the whole working time (8.00 – 19.00). This kind of strategy, as shown in the following study, will induce the best performances.

The physical phenomena that govern the heat exchanger between the ground-tube surface and the crossing air are quite simple to simulate, adopting the above mentioned strategies (*quite stationary analyses carried out dividing in several segments the tube length*). The main problems and critical aspects concern the exact evaluation of the ground temperature. Therefore, in this research, this aspect has been carefully studied, using several parameters and scientific tools to correctly model the temperature gradient underground.

A satisfactory result is shown in figure 4.4.7, where can be seen a very good accordance between the trends reported by Pfafferot [30] and the ground modelled in this study.

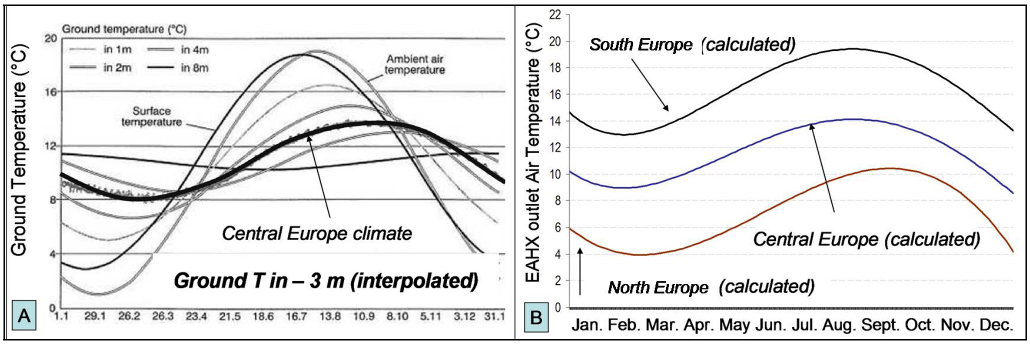



*Figure 4.4.7 – Comparison (and validation) between literature data [30] (graph A) and values derived from the mathematical model adoption (graph B)*

The central line of the graph B and the thick one of the graph A show a quite good accordance, above all considering that the first one represents the EAXH outlet air temperature, while the second one reports the ground thermal level. The correspondence results quite satisfactory, above all considering that is perfectly reasonable, anyway, a sensible difference in the calculated parameters (*left: ground temperature; right: air inlet by the EAHX*), being these not the same. In the comparison of figure 4.4.7, this difference results of about 1.0 – 1.5 °C, the same order of magnitude evaluated by Berkert *et al*. [26].

The graph 4.4.7.A reports the ground thermal level, as cited by Pfafferot for middle European climate.

Once measured a quite satisfactory reliability of the implemented physical model, the results obtainable using this kind of passive solution strategy for the modelled building (*in the 4 climatic conditions considered*) are in the following described.

## 4.5 The analysed case study: methods, weather data, sky and ground model: algorithms and calculations

In this section, some simulation boundary conditions are illustrated to understand the adopted methodologies. Each numerical analysis can be useful to identify limits and potentiality of a possible applicable solution, and, when it is not correctly accurate, this powerful instrument becomes misleading.

About the numerical methods, the procedure of the BEPS - Building Energy Performance Simulation has been applied. The numerical code used is EnergyPlus, developed by the U.S. Department of Energy [28]. The mass, momentum and energy heat transfers through the building and the environment are solved adopting the CTF methods, considering the Conduction

Transfer Functions enough accurate for this kind of study, because this research doesn't analyze moisture formation or condensation, solving exclusively the sensible heat transfer phenomena. In fact, the modeled building and plants are evaluated neglecting the indoor humidity control, so that the latent heat exchange was not calculated.

Furthermore, the significant complexity of the building and its several thermal zones did to expensive (*under the computational point of view*) and not accurate (*too many interactions to find the convergence*) solution algorithms based on the ConFD methods (*i.e. Conduction Finite Differences*).

The used code is an integrated simulator, based on various resolution methods (*implementing, in the same time, Blast and DOE-2 algorithms*). EnergyPlus works solving simultaneously all the main parts of the controlled volume: building, HVAC system and other plant. This code was used because it provides appropriate feedbacks among the various sub-systems. This methodology requires a greater computational work, but the reliability of the solutions is quite better than the results achievable using sequential simulation method [28].

In the studies here reported, each carried out simulation was extended to the whole year, providing 30 mass and energy balances for each hours (30 time step/h). The chosen convergence limits are usual for this kind of application.

The four considered climate data (*Naples, Stuttgart, Berlin, Oslo*) are based on the ASRHAE IWEC weather files. This detail is quite important to underline the reliability of the simulations, above all about the radiative heat transfer phenomena between the building and the sky. The weather data implement information about the estimated solar radiation, by means of an hourly calculation based on the earth-sun geometry and on hourly weather parameters. The well suitability of this kind of information is obtained because these data contain information regarding the cloudiness, based on several years of measurements.

The American Society of Heating, Refrigerating and Air-Conditioning Engineers (*ASHRAE, Inc., Atlanta, GA, USA*) developed the IWEC source data. These data files have been then converted in a set of data usable by EnergyPlus. The sky temperature for the long-wave exchange interesting the building surface is calculated starting by the IWEC weather files, considering the horizontal IR intensity. The code computes the sky temperature and its emissivity as function of the sky condition (*clear, cloudiness, overcast)*, the air dry bulb temperature, the dew point temperature.

Crawley *et al.* [32] reported an interesting study about the climatic information derived from different several weather data used in the most common building-energy simulators. These authors underline the necessity of a correct estimation of the solar and sky radiation in order to evaluate exactly the overall building performances, about the natural and artificial lighting point of view, the physical expansion and contractions of the structures, the thermal transfers through the building envelope. At the same time, similar accuracy is required also for the wind conditions. The new data format file (*.epw*), developed by these authors and used in EnergyPlus, provides very accurately simulations, adding several new data fields into the weather data format compared to the traditional weather files, above all with respect to the infrared sky model.

As represented in figure 4.5.1, the EnergyPlus (*E/E in the graph, where the first E indicates EnergyPlus, the second E represnts ESP-r last version*) weather data files are quite full of information about the parameters that determine the heat exchange between the building and the sky. These influent factors are: wind speed, wind direction, infrared sky temperature, solar radiation – global – diffuse – normal, illuminance, cloud amount and sky conditions, visibility, ground conditions). In particular, as cited by Crawley *et al.* *"...the infrared sky field allows the programs (EnergyPlus) to calculate the effective sky temperature for re-radiation during nighttime...".*

This deepening about the radiative heat transfer phenomena was been considered a necessary specification in this study. In fact, two of the considered cooling strategies (*roof and wall movable insulation*) are totally based on the night radiation. Therefore, a study on the reliability of the model was considered necessary.

With reference to the four considered cities, the main weather data characteristics are described in table IV.4.

| **Data Element** | **DOE-2** | **BLAST** | **ESP-r** | **E/E** |
|---|---|---|---|---|
| Location (name, latitude, longitude, elevation, time zone) | X | X | X | X |
| Data source | | | | X |
| Commentary | | | X | X |
| Design conditions | | | | X |
| Typical/extreme periods | | | | X |
| Data periods | | | | X |
| Holiday/Daylight Savings | | X | | X |
| Solar Angles/Equation of Time Hours | | X | | |
| Degree Days | | X | | X |
| Year | X | X | X | X |
| Month | X | X | X | X |
| Day | X | X | X | X |
| Hour | X | X | X | X |
| Minute | | | | X |
| Data source and uncertainty flags | | | | X |
| Dry bulb temperature | X | X | X | X |
| Wet bulb temperature | X | X | | X |
| Dew point temperature | X | | | X |
| Atmospheric station pressure | X | X | | X |
| Humidity ratio | X | X | | X |
| Relative humidity | | | X | X |
| Enthalpy | X | | | |
| Density | X | | | |
| Wind Speed | X | X | X | X |
| Wind Direction | X | X | X | X |
| Infrared Sky Temperature | | X | | X |
| Solar Radiation (global, normal, diffuse) | X | X | X | X |
| Illuminance (global, normal, diffuse) | | | | X |
| Sky cover (cloud amount) | X | | | X |
| Opaque sky cover | | | | X |
| Visibility | | | | X |
| Ceiling height | | | | X |
| Clearness (monthly) | X | | | |
| Ground temperatures (monthly) | X | | | X |
| Present weather observation and codes (rain, snow) | | X | | X |
| Precipitable water | | | | X |
| Aerosol optical depth | | | | X |
| Snow depth | | | | X |
| Days since last snowfall | | | | X |

*Figure 4.5.1 – The EnergyPlus weather data formats compared to the other climatic data. In grey are evidenced the data that provide a correct evaluation of the building-sky radiative heat exchanges (source: E+ users documentation)*

Table IV.4: main aspects of the considered city climate conditions

| | *Winter Degrees-Day (base 18 °C)* | *Winter design Temperature (°C) 99% DBT ASHRAE* | *Summer design Temperature (°C) 99% DBT ASHRAE* | *Monthly average solar maximum daily Radiation (Wh / m²)* |
|---|---|---|---|---|
| **Naples** | 1364 | 1.9 | 33.1 | 6797 |
| **Stuttgart** | 3338 | -10 | 29.2 | 5638 |
| **Berlin** | 3156 | -9.2 | 29.9 | 5109 |
| **Oslo** | 4171 | -14.5 | 26.8 | 5378 |

As regards the validation of E+ in European climates, several literature sources report different comparisons between numerical analyses and experimental data, mainly by means of comparative analyses between models and real text cells. About this, only one study is here mentioned, in particular because it is referred to evaluations similar to those reported in this research.

Olsen and Chen [33] carried out a study about the potential energy savings of several different systems for a new building realized in UK (London). In particular, this paper is cited because it regards the same arguments analysed in our study (among which natural ventilation and night cooling). The second paragraph of the cited paper is entirely dedicated to the E+ validation with experimental data. The validation of E+ is carried out comparing the numerical prediction with the experimental data provided by the IEA (International Energy Agency) for several small test rooms built near London.

The results are very satisfactory, so that Olsen and Chen affirm: "*…the prediction matches the measured room temperature very well….*".

The last aspect of the engineering references that we would like to describe, in order to well explain the modeling methods and the solving procedures, regards the evaluation of the temperature gradient under the soil, amplitude, phase constant and all the other parameters that influence the working and the effectiveness of an earth-to-air heat exchanger.

As above mentioned about the earth ube, it is particularly important well modeling this kind of passive cooling solution strategy. In fact, through the EAXH use, relevant savings of thermal energy can be obtained, spending a certain amount of mechanical energy. Considering the exergetic qualities of these 2 kinds of energy, it is necessary a very correct design of the system so that significant conveniences, energetic, thermodynamic and economic can be achieved.

First of all, it must be exactly identified the soil structure and its moisture content. In fact, the heaviness and the humidity rate of the ground influence the thermal diffusivity and its conductivity; at the same way, also the water absorption coefficient and the evaporation fraction become influent. In fact, all these parameters vary the amount of heat transferred from the surrounding soil to the air mass flowing within the buried pipes.

In the carried out simulations, the boundary conditions were inferred considering several literature sources [24, 30] and calculation software [26, 28, 31]. In particular, the wind influence on the soil temperature was calculated starting by the weather data files, such as the convective heat transfer coefficient, approximated by the Krarti [34] correlations. The same bibliographic reference was used by the code to evaluate the hemispherical emittance of the ground surface and the radiation constant; instead, the absorption coefficient and the albedo depend on soil cover and moisture contents. Defined all the other soil characteristics and behaviors, the heat transfer between the ground, the buried pipe and the air flowing inside this are determined defining first of all the air kinetic viscosity and its thermal conductivity.

Then, simply, the convective heat transfer is calculated as function of the Reynolds and Nusselt correlations. The initial conditions of the inlet air temperature are imposed equal to the external environmental air thermal level.

The main coefficient and parameters that concur to model and to define the earth tube efficiency are represented in figure 4.5.2 and in the following summarized:

- <u>tube properties</u> *(size, length, thermal conductivity, thermal diffusivity, cross section, depth, air velocities inside the pipe, distance between the pipes and between the tube and the undisturbed ground)*;
- <u>soil properties</u> *(materials, content of water, covering, shadows, thermal conductivity, absorption coefficient, albedo, amplitude of the soil surface variation, average soil surface temperature, phase constant of the soil, soil profile temperature)*;
- <u>climatic data</u> *(solar radiation, sky temperature, wind velocity above the ground surface, air external condition about temperature and humidity, radiation constant, sky hemispherical emittance)*;
- <u>air conditions inside the pipe</u> *(kinetic viscosity, thermal properties, phase constant, mass flow rate, air velocity along the tube)*.

| Variable | Description | Units |
|---|---|---|
| $A_s$ | amplitude of the soil surface temperature variation | (°C) |
| $C_a$ | specific heat of air | (J/kg°C) |
| $h_c$ | convective heat transfer coefficient at the inner pipe surface | (W/m$^2$°C) |
| $h_s$ | convective heat transfer coefficient at the soil surface | (W/m$^2$°C) |
| $k_{air}$ | thermal conductivity of the air | (W/m°C) |
| $k_p$ | pipe thermal conductivity | (W/m°C) |
| $k_s$ | soil thermal conductivity | (W/m°C) |
| $L$ | pipe length | (m) |
| $m_a$ | mass flow rate of ambient air through pipe | (kg/s) |
| $r_a$ | relative humidity | |
| $R_c$ | thermal resistance due to convection heat transfer between the air in the pipe and the pipe inner surface | (°C/W) |
| $R_p$ | thermal resistance due to conduction heat transfer between the pipe inner and outer surface | (°C/W) |
| $R_s$ | thermal resistance due to conduction heat transfer between the pipe outer surface and undisturbed soil | (°C/W) |
| $R_t$ | total thermal resistance between pipe air and soil | (°C/W) |
| $\Delta R$ | radiation constant | (63W/m$^2$) |
| $r_1$ | inner pipe radius | (m) |
| $r_2$ | pipe thickness | (m) |
| $r_3$ | distance between the pipe outer surface and undisturbed soil | (m) |
| $S_m$ | average solar radiation | (W/m$^2$) |
| $S_v$ | amplitude of the solar radiation | (W/m$^2$) |
| $t$ | time elapsed from beginning of calendar year | (days) |
| $T_a(y)$ | air temperature of the pipe at the distance y from the pipe inlet | (°C) |
| $T_m$ | average soil surface temperature | (°C) |
| $T_{ma}$ | average air temperature | (°C) |
| $t_0$ | phase constant of the soil surface | (sec; days) |
| $t_{0a}$ | phase constant of the air | (sec; days) |
| $T_{va}$ | amplitude of the air temperature | (°C) |
| $T_{z,t}$ | ground temperature at time t and depth z | (°C) |
| $T_{z1,z2,t}$ | soil profile temperature at time t, averaged over depths between $z_1$ and $z_2$ | (°C) |
| $u$ | wind velocity above the ground surface | (m/s) |
| $U_t$ | overall heat transfer coefficient of the whole earth tube system | (W/°C) |
| $V_a$ | average pipe air velocity | (m/s) |
| $z$ | depth of the radial center of pipe below soil surface | (m) |
| $z_1$ | upper bounds of some vertical profile in soil | (m) |
| $z_2$ | lower bounds of some vertical profile in soil | (m) |
| $\alpha_s$ | soil thermal diffusivity | (m$^2$/s; m$^2$/days) |
| $\beta$ | soil absorption coefficient (= 1 – soil albedo) | |
| $\varepsilon$ | hemispherical emittance of the ground surface | |
| $\varphi_I$ | phase angle between the insolation and the air temperature | (rad) |
| $\Phi_s$ | phase angle difference between the air and soil surface temperature | (rad) |
| $\upsilon$ | kinetic viscosity of air | (m$^2$/s) |
| $w$ | annual angular frequency (=1.992 x 10$^{-7}$ rad/s) | |

*Figure 4.5.2 – Properties, coefficients and parameters that influence the performance of an earth-to air-heat exchanger (source: E+ users documentation)*

Finally, the correlation to estimate the air conditions along the tubes has been determined using the Jacovides and Mihalakakou [35] equations, which evaluate the heat transfer between air and soil as the amount of heat losses characterizing the air along the tube.

## 4.6 Discussion of the numerical analyses carried out considering significant European climates

In this section, a comparison among the different passive cooling solutions, in the 4 considered climate conditions, has been carried out, as regards both the winter and summer times. About the analysis methods, the European Standards for the EPBD consider 3 different deepening levels, depending on the scope of the simulation (figure 4.6.1). In this Thesis, being the study relative to an optimization of the energy performances, of course the most detailed method (*operational rating evaluation*) has been considered.

The analyses regard above all the summer performances. A brief introductory analysis has been carried out also about the winter energy requirements, in order to underline that the thermal behaviors of a building are deeply different in cold or warm situations. About the winter analyses, the studies have been carried out considering the energy requirements necessary to maintain the indoor air at a fixed set-point value (20 °C).

In summertime, instead, the analyses have been conducted considering both a fully air-conditioned environment (*indoor temperature equal to 26 °C during the working hours*) or leaving the indoor an indoor temperature free-running (i.e. naturally ventilated building), and studying if the indoor thermal level trends can guarantee a satisfactory thermal comfort inside the working spaces.

| Kind of evaluation | Kind of Input Data | | | This method is valid or suggested for |
|---|---|---|---|---|
| | USE | Weather | Building | |
| Standard Rating | Standard | Standard | Design | Permit to build, energy certification or qualification of the design |
| Asset Rating | Standard | Standard | Real | Energy certification or qualification (Energy Label) |
| OPERATIONAL RATING | DETAILED | HOURLY WEATHER DATA | AS MUCH DETAILED AS POSSIBLE | ENERGY OPTIMIZATION, EVALUATION OF INVESTMENTS AND ACHIEVABLE BENEFITS |

*Figure 4.6.1 – Kinds of energy evaluation and relative scopes (source: CEN)*

### *a) Wintertime*

The comparison among the energy performance obtainable on varying the passive cooling solutions has effects, of course, only in the summer period. Therefore, relatively to the wintertime analyses, only the base case building has been evaluated. Actually, the simulations investigated also the winter performances obtained using the other building configurations, but, of course, the same results of the base case have been obtained. In fact, all the analyzed solutions work only in summertime, except the earth-to-air heat exchanger that determines energy savings also in winter. This aspect will be analyzed in the second part of this chapter (*paragraph 4.7*).

In wintertime, the modeled building envelope induces quite good performances, with yearly specific energy requests quite low with reference to all the 4 cities considered. Typical external air temperatures are reported in figure 4.6.2.

In particular, about the building thermal requests (*and thus, not considering the energy losses due to the inefficiencies of the heating systems*), the energy requirement to keep the indoor space at 20 °C during the winter diurnal working time results:

- Naples: mean value of the building = 1.7 kWh / m$^2$ year;
- Stuttgart: mean value of the building = 23.4 kWh / m$^2$ year;
- Berlin: mean value of the building = 26.7 kWh / m$^2$ year;
- Oslo: mean value of the building = 43.6 kWh / m$^2$ year.

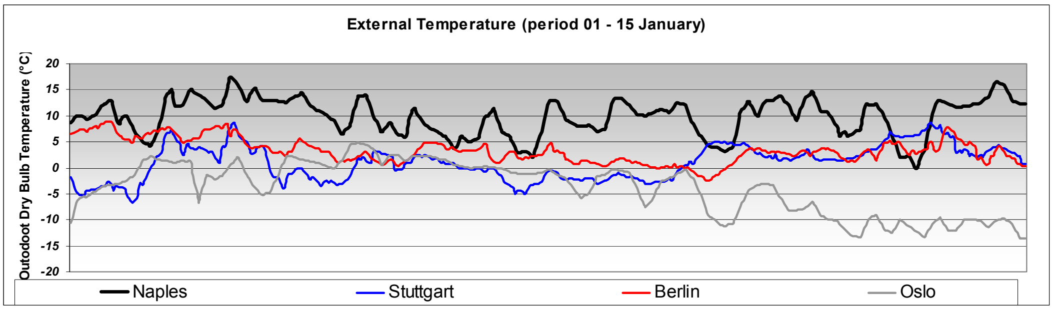



*Figure 4.6.2 – Wintertime: typical outdoor air temperature for the considered cities*

The results on varying the thermal zones are reported in figures 4.6.3 and 4.6.4, respectively with reference to the thermal and end energy requests.

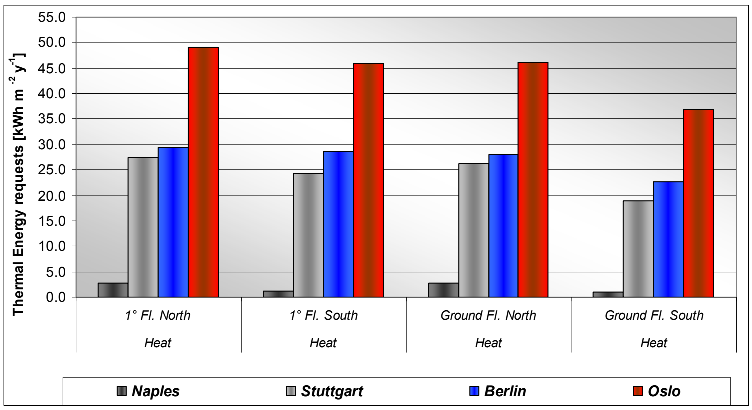



*Figure 4.6.3 – Wintertime: building thermal energy request for the 4 city considered*

As previously defined, the overall seasonal energy efficiency ratio of the heating system ($\eta_G$) is estimated equal to 0.83.

Considering also the energy losses due to the inefficiencies of the heating system (*heat generations, control devices, distributions of thermal vector fluid, heat emission*), the end energy demand for the space heating has been then calculated obtained. The end energy requirements result:

- Naples: mean value of the building = 2.0 kWh / m$^2$ year;
- Stuttgart: mean value of the building = 28.2 kWh / m$^2$ year;
- Berlin: mean value of the building = 32.2 kWh / m$^2$ year;

- Oslo: mean value of the building = 52.5 kWh / m$^2$ year.

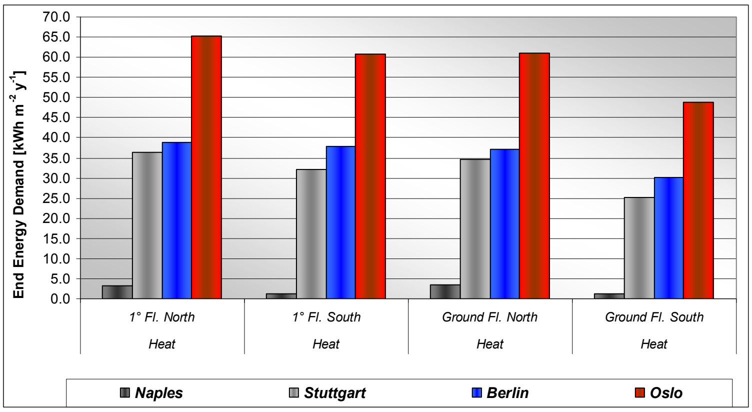



*Figure 4.6.4 – Wintertime: building-heating system end energy request for the 4 city considered*

In figure 4.6.5, with respect to other building projects funded by the EnOB program in Germany, the office building modeled in Stuttgart and Berlin have been represented.

As shown in the figure 4.6.6, in both the cases (*Stuttgart and Berlin*), the achievable performances not only results satisfactory of the EnOB targets about the wintertime energy needs (*maximum admitted thermal need = 40 kWh/m$^2$a*), but these also guarantee energy needs meanly lower compared to the average values of the building funded by the German Government.

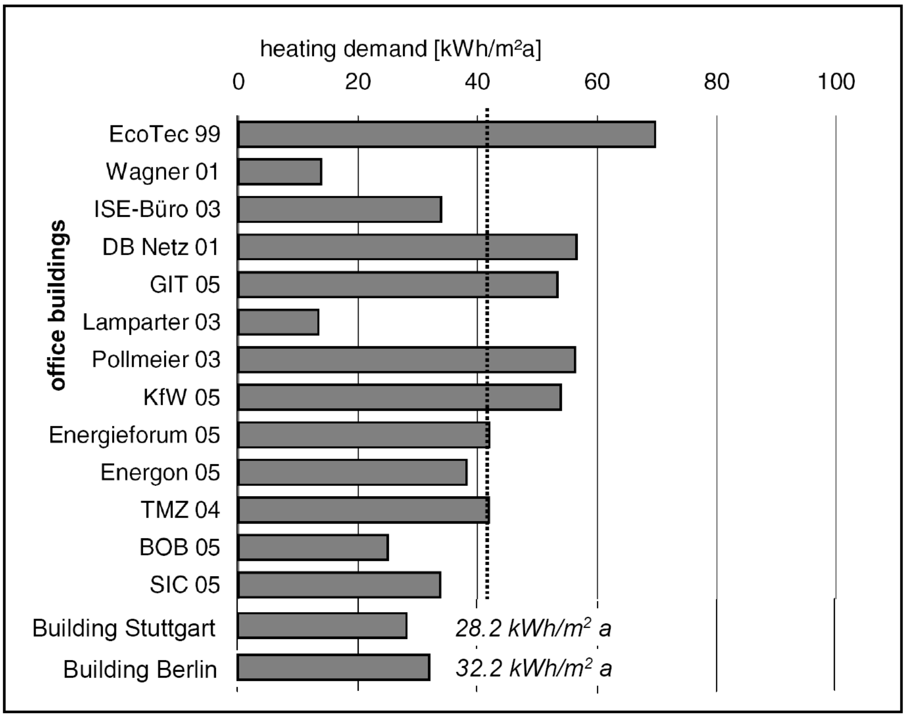



*Figure 4.6.5 – EnOB demonstration program: simulated building performances (source: modification of an EnOB original graph: www.enob.info)*

Moreover, considering also the energy conversion factor of 1.1, used to calculate the primary energy needs starting from the end energy demand (*and so adopting the German criteria*), the following values are obtained and represented in figure 4.6.6. Depending on the specific thermal zone, the heating primary energy requirements are detailed in figure 4.6.6, while, considering the mean value for the whole building these result:

- Naples: mean value of the building = 2.2 kWh / $m^2$ year;
- Stuttgart: mean value of the building = 31.1 kWh / $m^2$ year;
- Berlin: mean value of the building = 35.4 kWh / $m^2$ year;
- Oslo: mean value of the building = 57.8 kWh / $m^2$ year.

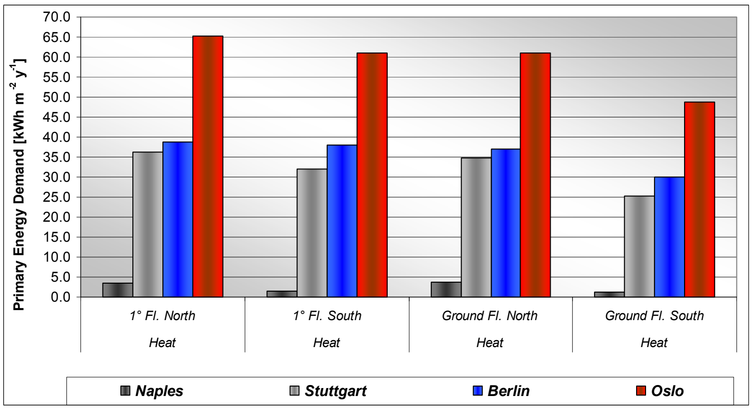



*Figure 4.6.6 – Space heating primary energy request for the 4 city considered*

The German and Italian mandatory limits, for the new constructions, considering the surface-to-volume ratio of this building (*S/V = 0.47 m⁻¹*), result:

- EnEV 2007 (*only one value for the whole Germany*), only space heating, maximum admitted value = 83.6 kWh / $m^2$ year.
- Legislative Decree 192/2005 (climatic zone of Naples), only space heating, maximum admitted value = 27.3 kWh / $m^2$ year.

The building simulated in Naples achieves, as regards the wintertime performance, very satisfactory energy requirements. The warm climate of this town, the physical characteristics and behaviors of the building envelope, the good efficiency of the heating system and the high endogenous heat gains do hardly reduced the energy needs for the space heating, so that a kind of "*passivhaus*" has been obtained.

Actually, about the technological solutions provided for the walls, the roof and the windows, the modeled building, in Naples, is quite out of order in this climate conditions. In fact (*…unfortunately…*) in this climatic region the big part of the building are realized, still now, without any kind of thermal insulation. In fact, the new Italian regulation imposes U values that, considering the traditional construction methods and practices of this Nation, are very reduced; considering the quite warm climate of the southern part of this country, a comparison between the thermal transmittance imposed and those implemented in the simulation code can exhaustively explains the optimal achieved performance:

- roof: $U_{\text{VALUE MODELLED}} = 0.17\ W/m^2K$ ($U_{\text{VALUE ACCORDING TO THE LAW}} = 0.42\ W/m^2K$);
- vertical wall: $U_{\text{VALUE MODELLED}} = 0.29\ W/m^2K$ ($U_{\text{VALUE ACCORDING TO THE LAW}} = 0.46\ W/m^2K$);
- basement: $U_{\text{VALUE MODELLED}} = 0.29\ W/m^2K$ ($U_{\text{VALUE ACCORDING TO THE LAW}} \rightarrow 0.49\ W/m^2K$);
- windows: $U_{\text{VALUE MODELLED}} = 1.10\ W/m^2K$ ($U_{\text{VALUE ACCORDING TO THE LAW}} \rightarrow 3.00\ W/m^2K$).

All the reported law values are those admitted until the end of 2009.

Furthermore, even if the simulated opaque and transparent structures are much better than the imposed ones, this not explains a primary energy requirements (*meanly 2.2 kWh/m²a*) 10 times lower than the mandatory limit (*27 kWh/m²a*). In fact, this result mainly derives by the very high internal heat gains, usually significantly elevated in office buildings (*high crowding, elevated artificial lighting, high density of information and technology equipments*).

An office built in this way, as shown in figure 4.6.7-a, would be classified in CLASSE A (*the best obtainable evaluation*) using the method provided by the "*Guidelines for the Building Energy Certification*" recently approved by the Italian Parliament (*i.e. Ministerial Decree 26.06.2009*).

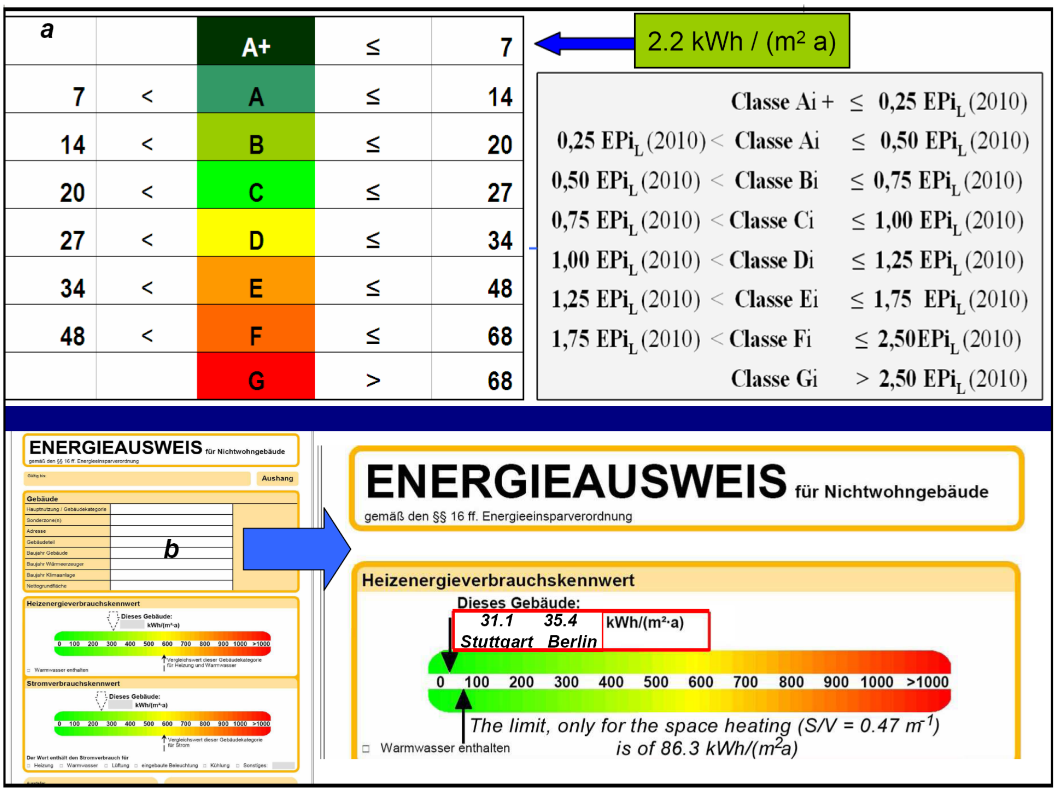



*Figure 4.6.7 – Italian (a) and German (b) building energy certificates*

Moreover, the modeled building achieves good energy performances in wintertime also in Germany, where the present regulation, already mentioned, imposes restrictive thermal behaviors for the building structure and active energy systems. Moreover, the prescriptions contained in the EnEV 2007 represent only a minimum target that must be reached (*presently, the new EnEV 2009, recently released, imposes even stricter requirements*).

As previously mentioned, in Germany the project EnOB purposes, already now, targets much more ambitious than the EnEV ones. In fact, according to the EnEV 2007, an office building, with the same geometry considered in this case-study, could be realized if the primary energy request for the winter heating results lower than 86.3 kWh/m$^2$a. On the other hand, in order to be funded by the EnOB project, the building must require, always considering only the primary energy for heating, less than 40 kWh/m$^2$a.

*It means that, even if the law in force imposes a performance index satisfactory, however it is possible, using good techniques and consolidated technologies, to achieve much better results!*

As shown in figure 4.6.7-b, the simulations carried out, respectively with reference to the climates of Stuttgart and Berlin, give results that satisfy both the EnEV limit and the EnOB requirements. In both the cases, the primary energy request for the winter heating is lower than 40 kWh/m$^2$a, resulting equal to 31.1 kWh/m$^2$a for Stuttgart, 35.4 kWh/m$^2$a in Berlin. These results are obtained considering a fixed indoor air temperature of 20 °C during the working time hours.

It is interesting to note that, while for Naples the cooling loads results so low that it is quite indifferent the incidence of the thermal zone exposure (i.e. *1° floor north, 1 floor south, ground floor north, ground floor south*), it is not the same for the German cold climate conditions. Therefore, as it easily understandable, the higher energy requests are relative to the thermal zone north-exposed, while the lower ones characterize the south-exposed spaces based on the floor.

In particular, considering the simulations carried out for the climate conditions of Stuttgart, the thermal zone 1 (*upper floor, north*) has a primary energy need of 36.3 kWh/m$^2$a, while the offices based on the floor and south exposed (*thermal zone 4*) are characterized by an energy demand of 25.2 kWh/m$^2$a, with a saving of 30%. The same event happens in Berlin, where the savings obtainable using a direct heat exchange with the soil and well orienting the offices determine a difference of – 23% (*i.e. 30.1 kWh/m$^2$a compared to 38.9 kWh/m$^2$a*).

Quite satisfactory results are achieved also in Norway, where the carried out simulations show a building energy requirement, for Oslo, around 58 kWh/m$^2$a. As regards this climate, the different exposure influences significantly the achievable performances. In fact, the different position (*contact with the soil or sky exposed roof*) and exposure (*south or north*) determine a difference of 16.4 kWh/m$^2$a (*65.2 kWh/m$^2$a in the first case, 48.8 kWh/m$^2$a in the second one*).

### b) Summertime

Therefore, designing a good building envelope and a quite efficient heating system, automatically the obtainment of satisfactory performances in wintertime can be allowed. *The same thing doesn't happen in summertime.*

In fact, the heat transfer phenomena and, in particular, the direction of the heat flux, during the warm season are quite difficult to evaluate correctly. In wintertime, the heat flux is always directed from the indoor space to the external one, without strong differences due to time, exposure or kind of external environment (*sky, outdoor air, and ground*). In summer, instead, the heat transfer mechanisms are very variable; during the day-time, the heat flux is entering into the space, while during the night, in moderate climates, the outdoor ambient is usually cooler. Furthermore, the direct contact between ground and building can induce a free cooling of the basement, while the sky-exposed roof is strongly penalized by the diurnal solar radiation with some heat losses during the night, due to the night-radiation under a maximal view factor.

These preliminary considerations are reported only to explain that, while in wintertime solutions to contain the heat losses are simple to design, being quite consolidated also a long experience and tradition about this, in summertime two penalizing events occur:

1) it results much more complicated managing the heat transfer phenomena;
2) there is no long experience and tested technologies to prevent the indoor overheating.

### 4.6.1 RESULTS OF THE PASSIVE COOLING TECHNOLOGIES APPLIED TO THE CASE-STUDY

The following studies about the bad performances of the simulated building and the comfort and energy benefits achievable recurring to passive cooling solutions are carried out in two different ways:

1) considering a fixed set-point temperature for the indoor spaces (*26 °C*), maintained using a cooling systems (*fan coils with electric water chiller*) and evaluating the energy savings obtainable recurring to the simulated passive cooling solutions;
2) leaving the indoor temperature free running, and evaluating the indoor conditions (*thermal comfort or not*) inside the working spaces, by means of the EN Standard 15251 (*see table IV.5 and figure 4.6.8*), that regards the adaptative thermal comfort criteria.

This double analysis has been considered necessary. In fact, even if the final target of the EnEV and the purposes of the EnOB program require no active cooling for the building in summer period, the particular application (*elevated endogenous heat gains*) and the considered climatic conditions (*also Naples, south-Italy, characterized by a quite hot summer*) impose necessarily the use of a cooling systems.

Of course, the target of this study is an energy optimization of the building envelope, so that the EnOB targets would be achieved for the building simulated in Germany, while for the Italian climate the maximal reduction of the primary energy used to the building cooling would be reached.

The first analyses considers, on varying the thermal zones, the energy requirements to maintain the indoor temperature at 26 °C for the whole working period, simulating the base case building, that, as shown in the previous paragraph, results satisfactory according to the German (EnEV 2007) and Italian (*Legislative Decree 192/2005 and Presidential Decree 59/2009*) legislations.

Table IV.5: Thermal Comfort conditions considering several classes and admitted ranges

| Thermal Comfort (*according to the EN 15251*) | Category I (90% acceptation) | Category II (80% acceptation) | Category III (65% acceptation) |
|---|---|---|---|
| Naples (*mean July T = ca. 25.0 °C*) | 25.0 – 29.0 °C | 24.0 – 30.0 °C | 23.0 – 31.0 °C |
| Stuttgart (*mean July T = ca. 18.6 °C*) | 22.9 – 26.9 °C | 21.9 – 27.9 °C | 20.9 – 28.9 °C |
| Berlin (*mean July T = ca. 19.1 °C*) | 23.1 – 27.1 °C | 22.1 – 28.1 °C | 21.1 – 29.1 °C |
| Oslo (*mean July T = ca. 17.5 °C*) | 22.6 – 26.6 °C | 21.6 – 27.6 °C | 20.6 – 28.6 °C |

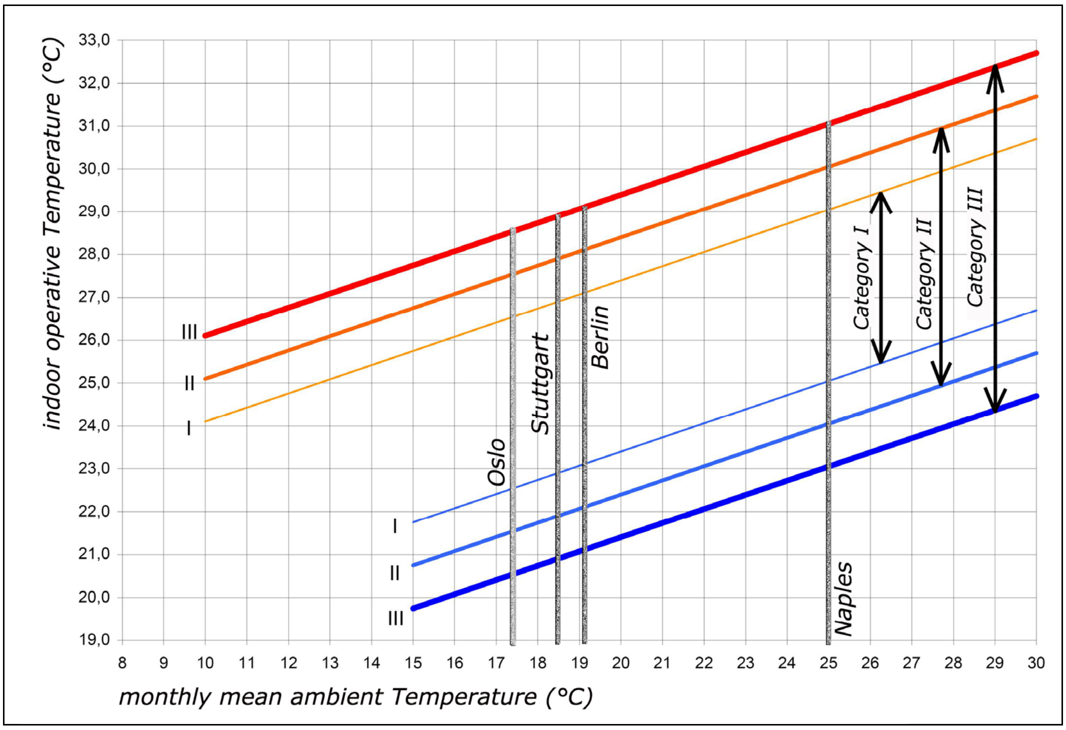



*Figure 4.6.8 – Comfort conditioned within unconditioned spaces, on varying the external thermal levels.*

In figure 4.6.9, typical summer outdoor air conditions are represented with reference to the four considered climates.

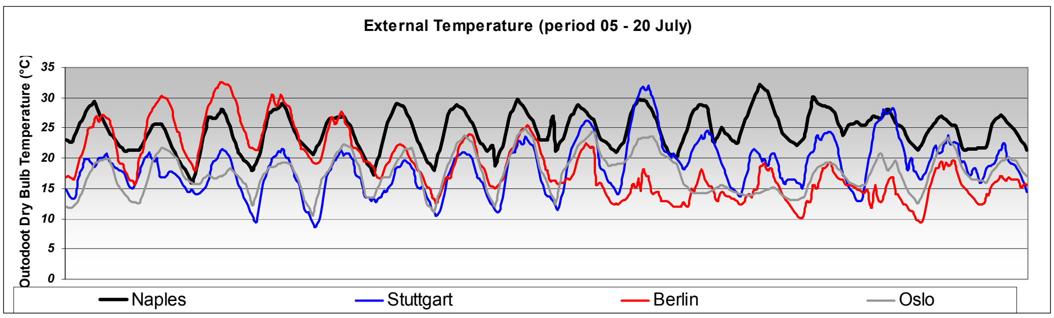



*Figure 4.6.9 – Summertime: typical outdoor air temperature in the considered cities*

As shown in figures 4.6.10 and 4.6.11, respectively referred to the thermal energy requirements and the primary energy needs (i.e. *considering the cooling system efficiency and* *the conversion factor between electric and primary energy*), the achieved performances are quite poor.

In figure 4.6.10, it can be seen that Naples, of course, requires a thermal energy demand much higher than the others cities: meanly for the whole building, the thermal energy need results equal to 59.2 kWh/m$^2$a, with respect to 24.0 kWh/m$^2$ (Stuttgart), 25.0 kWh/m$^2$ (Berlin) and 19.7 kWh/m$^2$ (Oslo).

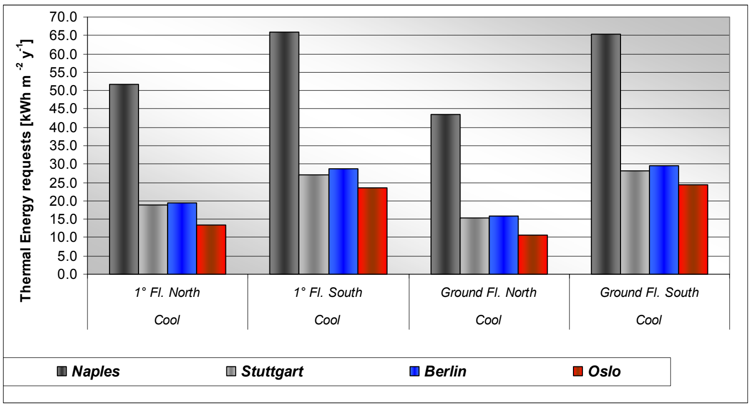



*Figure 4.6.10 – Thermal energy requests for the building cooling in the different thermal zones and relatively to the 4 cities considered*

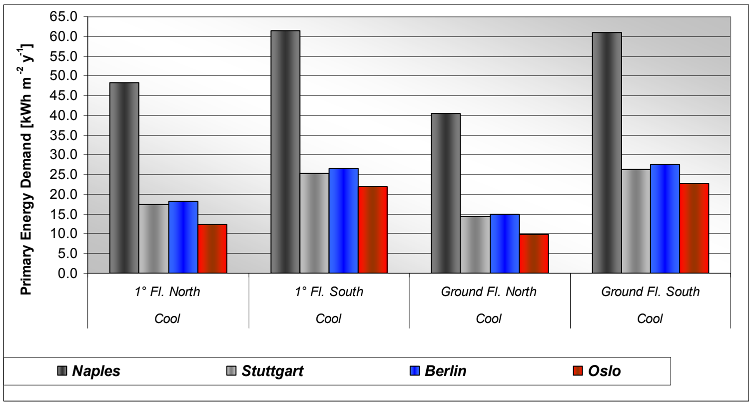



*Figure 4.6.11 – Primary energy requests for the building cooling in the different thermal zones and relatively to the 4 cities considered.*

As previously illustrated, the SEER of the modelled cooling system is of 3.0 $Wh_{THERMAL}/Wh_{ELECTRIC}$, while the conversion factor between electric and primary energy is 2.8 (*e.g.* *1* $kWh_{ELECTRIC} \rightarrow 2.8\ kWh_{PRIMARY}$).

According to the Italian recent regulation (*i.e. Presidential Decree 59/2009*), a primary energy demand of 55.3 kWh/m$^2$a (table IV.6) cannot be allowed, being the upper limit, for the Neapolitan climate conditions, about of 30 kWh/m$^2$a (*and it will not depend by the S/V factor, as exhaustively described in the Chapter 3*).

Meanly, with reference to the whole building, the end energy demands (*in this case electric energy*) and the primary energy requirements (*and so considering the cooling system* *coefficient of performance and the conversion factor between electric and primary energy*) are reported in table IV.6.

As regards Stuttgart and Berlin, although the modelled buildings result full regular according to the actual German regulation (*EnEV 2007 prescription, i.e.* $S < S_{MAX}$), as shown in the paragraph 4.3, a cooling primary energy requirement of about 23 kWh/m$^2$a is not at all satisfactory. In fact, with reference to these climatic conditions, despite it is difficult to obtain, anyway it is possible to guarantee comfort conditions adopting only passive cooling strategies (*EnOB targets*).

The same consideration is valid for Oslo, where a mean primary energy request for the summer cooling around 18 kWh/m$^2$a does no represent a fair result.

Table IV.6: End and primary energy demands for the summer cooling in the 4 cities considered

| | *End electric energy (kWh/m$^2$ a)* | *Primary energy (kWh/m$^2$ a)* |
|---|---|---|
| *Naples* | *19.7* | *55.3* |
| *Stuttgart* | *8.0* | *22.4* |
| *Berlin* | *8.3* | *23.4* |
| *Oslo* | *6.6* | *18.4* |

In the next sections, city by city, the effects obtainable adopting the passive cooling solutions described previously will be evaluated. The analyses will regard 2 significant thermal zones of the building, the ground floor north-exposed (*the less critical space in summertime*) and the upper floor south-exposed (*the worst one*). As previously underlined, the study will analyze both the presence of a cooling system and the indoor temperature free-running. In this second evaluation, the indoor comfort level will be analyzed by means of the adaptative comfort criteria included in the recent standard EN 15251.

All the investigated passive cooling solutions will be singularly compared, i.e. applied, one for time, to the described base case. The main modeling conditions are described in the paragraphs 4.4 and 4.5.

With reference to the earth-to-air heat exchanger, a first analysis, in each city, has been carried out in order to evaluate the best control strategy; in particular, as previously described, the functioning period was selected evaluating several solutions, searching the best compromise between the obtainable thermal savings and the electricity absorbed by the fans. For example, considering the first period of June, even if the use of the EAHX determines thermal advantages (due to the heat exchange with the soil) these thermal recovery do not balance, in Oslo, the electric energy required by the fans. This is due to the low ΔT (ambient air – soil), so that the thermal exchange results quite limited.

As regards the ventilation systems, exhaust fans have been considered. The fan electrical absorption results:

- zones 1-3 (*offices, total area 83 m$^2$*): 2 extraction fans, each absorbing 165 $W_{ELECTRIC}$;
- zones 2-4 (*offices, total area 152 m$^2$*): 2 extraction fans, each absorbing 265 $W_{ELECTRIC}$;

- zones X-Y (*corridors, each one equal to 137 $m^2$*): 2 extraction fans, each absorbing 160 $W_{ELECTRIC}$.

The selected period runs from 15th June until the half of September (93 days). As regards the daily working of the EAHX, three control strategies have been considered:

a) the ventilation of the building is achieved always supplying into the building the outlet airflow coming from the buried tubes → the earth tube works 15 hours/day;
b) the EAXH works between 8.00 in the morning until 18.00 in the afternoon. In the morning (5.00 – 8.00 am) and in the evening (18.00 – 21.00) the air cooling effect is obtained by means of natural ventilation → the earth tube works 10 hours/day;
c) the EAHX runs between 8.00 in the morning until 19.00 in the afternoon (*i.e. for the whole working time*) → the earth tube mechanical ventilation works 11 hours/day.

The description of the results follows.

**Naples**

As shown in table IV.7, about the earth tube control strategy efficiency, the 1st and the 3rd solution guarantee the same performances. In fact, even if the first control strategy determines higher thermal savings (*higher heat losses and free cooling of the outdoor air crossing the buried pipes*) the third solution requires reduced electric consumptions, due to the minor working hours.

Table IV.7: Naples: Primary Energy requirement for the space cooling (kWh/$m^2$ a) on varying the earth tube control strategy

| | 1st floor north | 1st floor south | Ground floor north | Ground floor south |
|---|---|---|---|---|
| *1st strategy* | 39.4 | 49.6 | 33.2 | 48.9 |
| *2nd strategy* | 49.4 | 64.7 | 41.4 | 64.6 |
| *3rd strategy* | 39.8 | 50.5 | 33.2 | 49.6 |
| ***No earth tube*** | **48.3** | **61.6** | **40.5** | **60.9** |

The results reported in table IV.7 consider the energy absorbed by the fans, converted in primary energy. Considering the high quality of the electricity (*high exergetic energy*), this last solution was chosen and compared with the other 3 passive cooling strategies adopted, i.e. nighttime ventilation, roof movable insulation and wall movable insulation (*a deeper analysis, in the paragraph 4.7, will analyzes the effect of an extended use of the earth tube*).

A first analysis considers the 4 different thermal zones (*the corridors have been studied but not reported*), evaluating the higher energy savings achievable in summer. The simulated building is provided with a cooling system.

In figure 4.6.12, the thermal energy requests for the summer cooling have been represented, on varying the adopted passive cooling solution. Generally, the south-exposure of the building is more penalizing compared to the north one. This is quite evident also because of the great insulation of the basement, that partially cancels the heat losses between the building and the fresh soil, so that the contact with the ground is not so influent.

Considering the whole seasons, the best results are obtained well-designing an earth-to-air heat exchanger, and this strategy is more efficient where there is not a high picking up solar radiation (*ground floor*). Instead, as regards the 1st floor sky exposed, the roof movable insulation represents a very useful solution, in order to discharge the roof mass heated during the day-time.

In reducing the thermal loads, the natural nighttime ventilation is more effective than the roof movable insulation about the office space situated not at the last floor. This is quite obvious, considering that the maximal potential of the roof movable insulation is, of course, referred to the sky-exposed rooms.

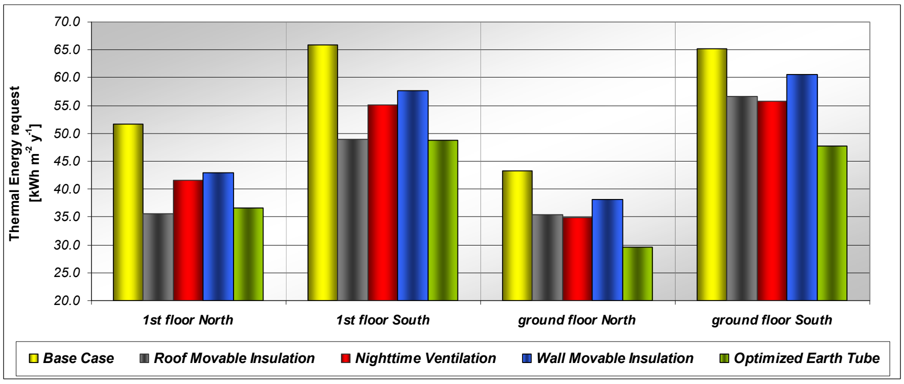



*Figure 4.6.12 – Thermal energy requested by the different thermal zones on varying the adopted passive cooling solution (Naples)*

The lower thermal loads results for the north-exposed thermal zone, adopting the earth tube ventilation: in this way, the thermal energy need of the zone was reduced to 29.6 kWh/m$^2$a, compared to the 43.3 of the base case (-32%).

For all the analysed thermal zones, the movable insulation of the vertical walls does not induce satisfactory results; actually, compared to the base case, thermal savings of about 5 – 10 kWh/m$^2$a can seem not negligible; really, the technological complexity of the systems and the poor convenience of the achievable performances do not suggest this solution.

In terms of primary energy (*figure 4.6.13*) the obtained results are a little bit different. In fact, in this case the best performance globally is achieved recurring to the nighttime natural ventilation and to the movable insulation of the roof; although also the earth tube induces very good performances in reducing the indoor heat gains, above all during the day-time, this solution requires a not negligible electric consumptions. Therefore, computing also this energy cost, globally this kind of passive cooling strategy is not the preferable solution.

The histograms represented in figure 4.6.13 suggest the following coupling: last floor of the building with movable insulation of the roof and basement and intermediate levels provided with nighttime ventilation. This both strategies provide the discharge of the heated thermal masses during the night, working in different ways: the nighttime ventilation, in fact, cools the opaque structures by means of convective heat exchanges, while the roof movable insulation determines a significant night radiative cooling among the charged concrete layers and the cool sky. Dividing the analyses for each considered thermal zone (figure 4.3.1), and choosing the best passive cooling strategies studied, results:

- zone 1 (*north-exposed, 1st floor*): adopting the roof movable insulation the summer primary energy request is equal to 33.1 kWh/m²a, while the base case requires 48.3 kWh/m²a (savings around 31%);
- zone 2 (*south-exposed, 1st floor*): adopting the roof movable insulation the summer primary energy request is equal to 45.7 kWh/m²a, while the base case requires 61.6 kWh/m²a (savings around 26%);
- zone 3 (*north-exposed, ground floor*): adopting the nighttime ventilation the summer primary energy request is equal to 32.5 kWh/m²a, while the base case requires 40.5 kWh/m²a (savings around 20%);
- zone 4 (*south-exposed, ground floor*): adopting the earth tube ventilation the summer primary energy request is equal to 49.6 kWh/m²a, while the base case requires 60.9 kWh/m²a (savings around 19%).

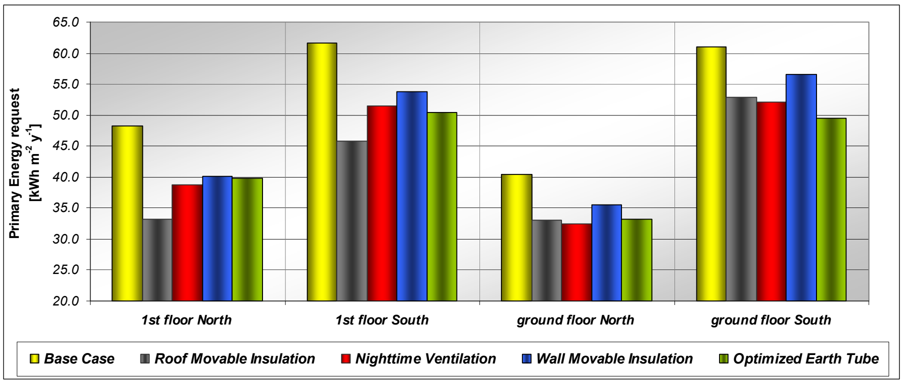



*Figure 4.6.13 – Primary energy requested by the different thermal zones on varying the adopted passive cooling solution (Naples)*

In the next paragraph, the best coupling of passive cooling strategies will be provided, in order to reduce, as much as possible, the summer thermal needs of the building.

In a second analysis, the simulated case-study building is not equipped with the cooling system. In figure 4.6.14, the indoor temperature trends are reported for the warmest period of the whole summer season. The figure represents what happens inside the thermal zone 2 (*the most critical one, figure 4.6.14 up)* and 3 (*characterized by the lowest summer cooling load, figure 4.6.14 down*). The analyses have been carried out considering the adaptative comfort criteria described in the technical standard EN 15251 as regards naturally ventilated buildings.

Considering the limit reported in the figure 4.6.8 and in the table IV.5, in this climate region no thermal comfort is possible during the working time without an air-conditioning systems. In the warmest zone of the building (zone 2), in July only the first working time hours (*between 8.00 and 9.00 am*) are comfortable adopting the nighttime ventilation, so that only the 9% of the working time is partially thermally satisfactory (Category III).

A little bit better the situation characterizing the ground floor north-exposed, where, usually until the 11.00 am, almost comfort conditions (*temperatures lower than 30°C*) are obtained recurring to the nighttime ventilation strategy; thus, in this second case, about the 35% of the working time guarantees thermal comfort conditions (Category III, *i.e. 65% acceptation*).

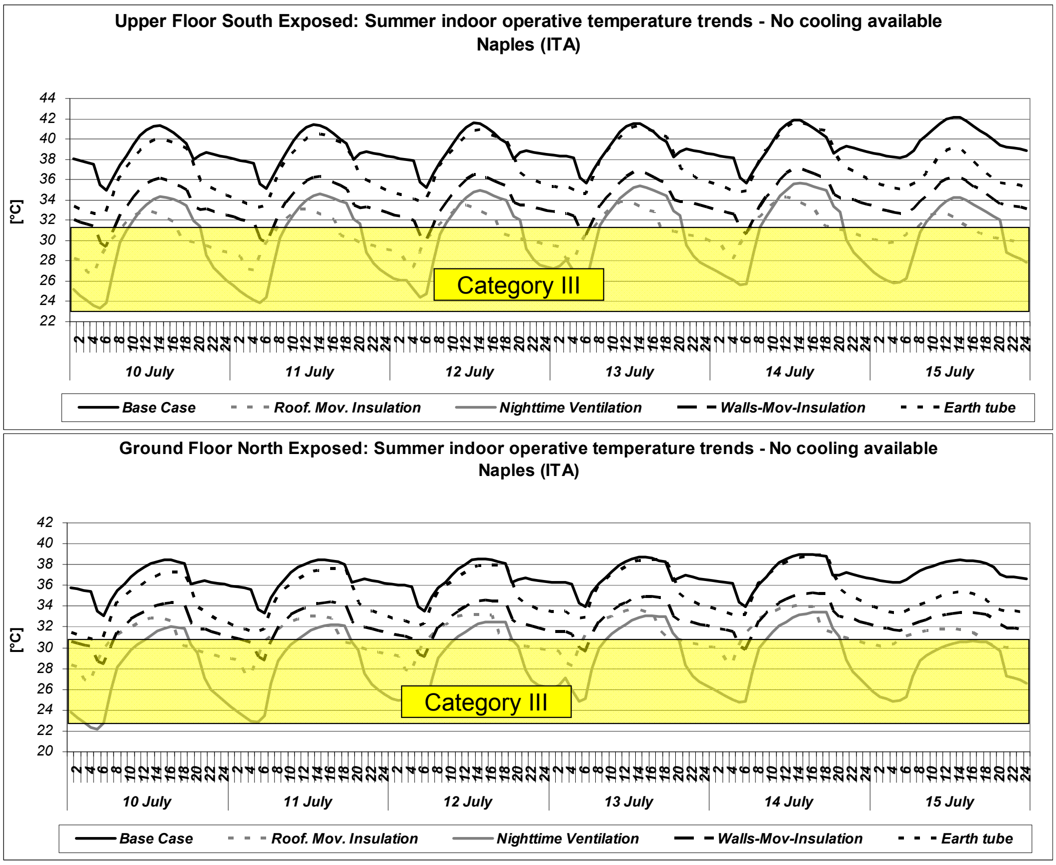



*Figure 4.6.14 – Office building simulated in Naples: indoor temperature trends in July and comfort conditions according to EN 15251 (up: thermal zone 2; down: thermal zone 3)*

The other solutions do not guarantee any thermal comfort in this period; in particular, the earth tube performances results poor, even if seasonally this represents a good strategy. It means that the heat exchange between the outdoor air and the buried pipes is not so effective in the warmest period of the year in this climatic region, even if, considering the whole summer, this results a good solution.

This particular results can be easily explained with reference to figure 4.4.7, where is quite clear that in July the ground temperature at – 3 m is equal to 18-20 °C and so the potential cooling of the outdoor air is quite limited. For this climatic conditions, the maximal potential of the earth-to-air heat exchange is achieved in June, when the soil temperature at the pipe levels is around 16 – 17 °C, providing, in this way, a total balancing of the ventilation load and a significant contribute in reducing the total summer thermal loads. Anyway, the best performances of the earth-to-air heat exchanger will be achieved in the other climatic regions analysed, as understandable seeing figure 4.4.7 and consulting the paragraph 4.7.

Finally, the Energy Efficiency Ratio (EER) of the earth-to-air heat exchanger has been analyzed, in 2 different ways:

- the maximum EER has been calculated considering the instantaneous heat losses achievable (*before and after the air flowing in the buried pipes*), compared to the fan energy consumptions (equation 3); this represents the design COP obtained with reference to a warm day of July:

$$EER_{DESIGN} = \dot{m} \cdot c \cdot \left(T_{external-air} - T_{earth-tube-air}\right) / \, Fan_{\ electric\ request} = kW_{thermal} \, / \, kW_{electric}$$

(3)

- in a second case, the EER is calculated seasonally, comparing the energy savings achievable using the earth tube (*i.e. the cooling thermal energy recovered by the ground*) and the fan seasonal energy requests (equation 4).

$$SEER_{SEASONAL} = \left(Q_{ground\ recovered}\right) / \, seasonal\ Fan_{\ electric\ request} = kWh_{thermal} \, / \, kWh_{electric}$$

(4)

In the analyses carried out for Naples adopting the boundary conditions obtained starting by the carried out simulations, it results:

- $EER_{DESIGN}$ = 0.80 kg/s * 1.01 kJ/kg K * (32 °C – 19 °C) / 1.25 kW = 8.4 $kW_{thermal}/kW_{electric}$:
- $SEER_{SEASONAL}$ = 7675 $kWh_{thermal}$ / 1278 $kWh_{electric}$ = 6.0 $kWh_{thermal}/kWh_{electric}$.

In the followings of this paragraph, with reference to the other considered cities, it will show that the ground cooling results more convenient in the climatic region characterized by lower ground temperature (*even if, often, it means also lower external air temperature*). Anyway, considering a typical cooling system efficiency (*SEER of around 3.0 – 3.5 $kW_{thermal}/W_{electric}$*), the earth-to-air heat exchange guarantees very satisfactory performance also in the south-Italian context.

**Stuttgart**

In the table IV.8, the results of the preliminary analyses about the earth-to-air heat exchanger are reported. The control strategies and the working hours of the earth tube are the same already described for the building simulated in Naples.

Considering the electric energy required by the fans (*and then converted in primary energy*), the best solution is the third one, with savings, compared to the base case without earth-to-air heat exchange, around:

- zone 1: - 29% (saving of 5.1 kWh/m$^2$a);
- zone 2: - 27% (saving of 6.8 kWh/m$^2$a);

- zone 3: - 26% (saving of 3.7 kWh/m$^2$a);
- zone 4: - 27% (saving of 7.1 kWh/m$^2$a).

Table IV.8: Stuttgart: Primary Energy requirement for the space cooling (kWh/m$^2$ a) on varying the earth tube control strategy

| | 1$^{st}$ floor north | 1$^{st}$ floor south | Ground floor north | Ground floor south |
|---|---|---|---|---|
| *1$^{st}$ strategy* | 13.3 | 18.9 | 11.9 | 19.6 |
| *2$^{nd}$ strategy* | 20.5 | 29.0 | 17.2 | 30.1 |
| *3$^{rd}$ strategy* | 12.5 | 18.6 | 10.7 | 19.2 |
| ***No earth tube*** | **17.6** | **25.4** | **14.4** | **26.3** |

Seeing the reported results, it is evident that the more consistent savings are achieved with reference to the thermal zones characterized by the higher cooling loads. In the following studies, comparing the 4 kind of passive cooling solutions simulated, the strategy n° 3 for the earth tube control was adopted.

Despite the presence of the buried heat exchanger, in the south-exposed office rooms the thermal loads are still too high (≈ 19 kWh/m$^2$a). Thus, even if this strategy for the passive cooling induces an important reduction of the cooling system energy requirements, alone the buried pipes do not permit a completely passive cooling of the building.

In figure 4.6.15, simulating the presence of a cooling system (*with fan coils*), the thermal energy requested in summertime is diagrammed, on varying the various thermal zones.

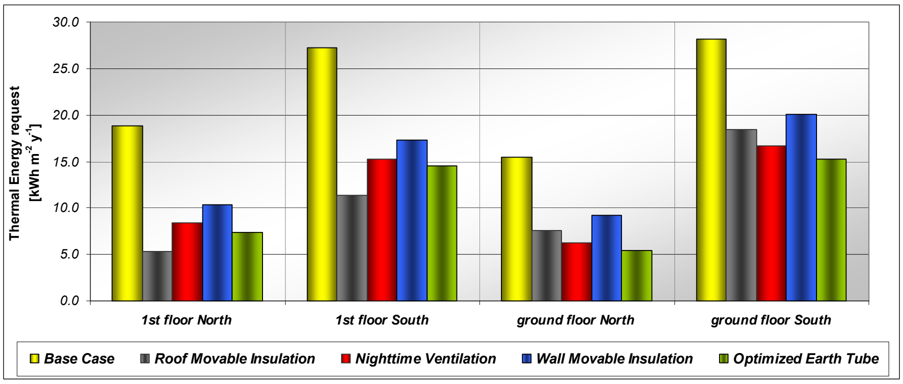



*Figure 4.6.15 – Thermal energy requested by the different thermal zones on varying the adopted passive cooling solution (Stuttgart)*

First of all, globally a great free cooling potential is quite evident.

As regards the upper floor sky-exposed, the movable insulation of the roof determines very important energy savings, with thermal needs lower than 6.0 kWh/m$^2$a for the north-exposed rooms and lower than 12 kWh/m$^2$a for the south-exposed ones. In this last case, considering that the base case requirement was around 27 kWh/m$^2$a, an energy saving higher than 55% has been achieved. In the thermal zone 1, the saving obtainable recurring to the roof movable insulation was higher than 71% compared to the base building (*roof movable insulation = 5.3 kWh/m$^2$a, base case = 18.8 kWh/m$^2$a*).

Very significant savings are obtained also using, in the right way, the earth tube and the nighttime ventilation. These 2 kind of passive cooling solutions result quite similar about the saved thermal energy, even if, as it is shown in figure 4.6.16 analyzing the primary energy needs, the nighttime ventilation will result better (*i.e. the earth tube requires an amount of electric energy for the fan running*).

As regards the thermal energy required for the building cooling, nighttime ventilation and earth-to-air heat exchange result the best solutions for the ground floor, where, of course, the movable insulation of the roof cannot induces significant performances.

In the warm climate of Naples the movable insulation of the vertical wall showed very poor results. Instead, with reference to Stuttgart, if other solutions cannot be applied, this strategy seems not so bad; of course, there are some technological complexities to solve, but globally this solution guarantees quite satisfactory performances. In fact, even if the obtainable cooling savings are poorer compared to the other passive cooling solutions, anyway savings of 44% (*zone 1*), 37% (*zone 2*), 41% (*zone 3*) and 29% (*zone 4*) are achieved with respect to the base case. Obviously, also in this case, the higher savings are obtained at the ground floor; this is quite simple to explain: in fact, with reference to the upper floor, the higher thermal gains depend by the solar radiation picking up on the roof and, using movable insulation panels for the vertical walls, it is impossible the reduction of these gains. Contrariwise, at the ground floor (*or at the intermediate ones*), the movable insulation of the walls determines, during the nighttime hours, an effective discharge of the heat charged wall concrete layer.

The earth tube ventilation requires an electric energy amount to provide the air extraction. In this study, extraction fans have been considered, in order to avoid the primary air temperature increase, due to the crossing through an intake fan. Using suppy fan, in fact, kinetic (and so thermal) energy is transferred to the crossing air, while, using extraction fans this problem is avoided, even if, of course, in wintertime some free heat gains are not achieved.

In figure 4.6.16, the achievable energy savings recurring to the adoption of the 4 considered strategies for the passive cooling are reported, in terms of global primary energy requirements for the space cooing. Of course, the earth-to-air heat exchanger was penalized because of the energy required by the fans.

In terms of primary energy, the best solution was represented by the use of the roof movable insulation, which induces very higher savings compared to all the other solutions. In particular, with respect to the earth tube adoption, the roof movable insulation induces reductions of 7.5 kWh/m$^2$a (- *60%, thermal zone 1*), 8.0 kWh/m$^2$a (- *43%, thermal zone 2*), 3.6 kWh/m$^2$a (- *34%, thermal zone 3*) and 2.0 kWh/m$^2$a (- *10%, thermal zone 4*). In this last case (ground floor south-exposed), the obtained energy saving is significantly lower, because the movable insulation of the roof can permit only an indirect cooling.

About the ground floor of the building and in terms of primary energy, the higher savings for the space cooling are obtained recurring to the nighttime ventilation, that, consisting in 4 ACH during the nighttime, could be easily obtained naturally (*i.e. without any fan electric consumption*).

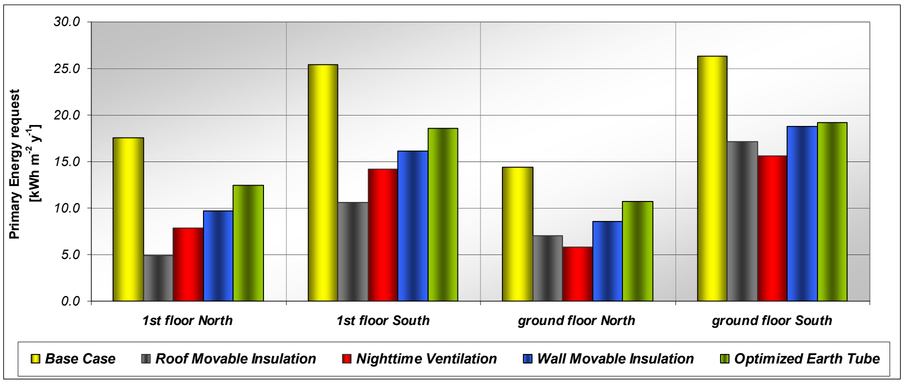



*Figure 4.6.16 – Primary energy requested by the different thermal zones on varying the adopted passive cooling solution (Stuttgart)*

At the same way already shown for Naples, a second analysis considers a not-conditioned building, evaluating the possible comfort conditions inside the spaces during the warm season. As explained in the previous pages, the EnOB program funds efficient building, establishing the requirement of no active cooling in summertime.

Seeing the results shown in figure 4.6.15, it can be understood that, admitting a high indoor thermal levels (*the adaptative new comfort criteria, e.g. the Standard EN 15251*), a complete passive cooling of the building could be possible too.

In fact, adopting the shown passive cooling solutions, the thermal energy requests to maintain the indoor spaces at 26 °C in summertime is quite reduced (6 ÷ 12 kWh/m$^2$a).

In figure 4.6.17, the indoor temperature trends are reported for the hottest period of the year, on varying the passive cooling strategies adopted and considering two thermal zones: zone 2 (*upper floor south-exposed*) and zone 3 (*ground floor north-exposed*).

Really, it can be noted that there is a change with respect to the results achieved for Naples: in fact, the warmest thermal zone results, now, the office space at the ground floor and south-exposed, with a seasonal energy request a little bit higher compared to the same exposure but at the upper floor. This happens because, considering the whole summer season, the night radiative cooling effect interesting the roof is higher than the diurnal heat gains.

About the critical space (zone 2), as shown in figure 4.6.17 (*upper graph*), the movable insulation of the roof and the nighttime ventilation provide almost always thermal comfort conditions, evaluated, by means of EN 15251 methods for naturally ventilated building (*in the range 20.9 – 28.9 °C for Stuttgart, i.e. Category III*).

In particular, during the considered 6 days (10$^{th}$ ÷ 15$^{th}$ July), as regards the working time hours, the calculated temperatures are lower than 28 °C for the great part of the time, if the roof movable insulation or the nighttime ventilation are adopted. Only in the hottest day of the year (14$^{th}$ July), in central hours of the day the indoor thermal level does not result comfortable.

The best solutions is represented by the roof movable insulation that induces quite satisfactory stability of the indoor temperatures, while the day-night excursions, derived from the nighttime ventilation adoption, are quite higher. As already shown also for Naples, in the warmest day of the summer, the earth tube is not very effective in presence of high thermal loads. This is due to the too high outdoor temperature (also 32 °C) and, principally, to the soil thermal levels around 13 -14 °C (*9.5 °C in May and June*), so that the inlet air has a reduced cooling capacity, and it results not enough for the sky-exposed indoor spaces.

By means of nighttime ventilation and roof movable insulation, all the working hours of 10th and 11th July are characterized by indoor comfort conditions, so that no residual cooling needs have to be balanced by an HVAC. Satisfactory performances are achieved also in the following days…..*and this happens during the warmest period of the year in the hottest thermal zone of the building!*

Furthermore, analysing the temperature levels inside the cooler thermal zone (*zone 3, ground based and north-exposed, i.e. the less critical zone of the building*), all the 4 passive cooling strategies guarantee, in this critical period, comfort conditions (*see figure 4.6.17, down graph*).

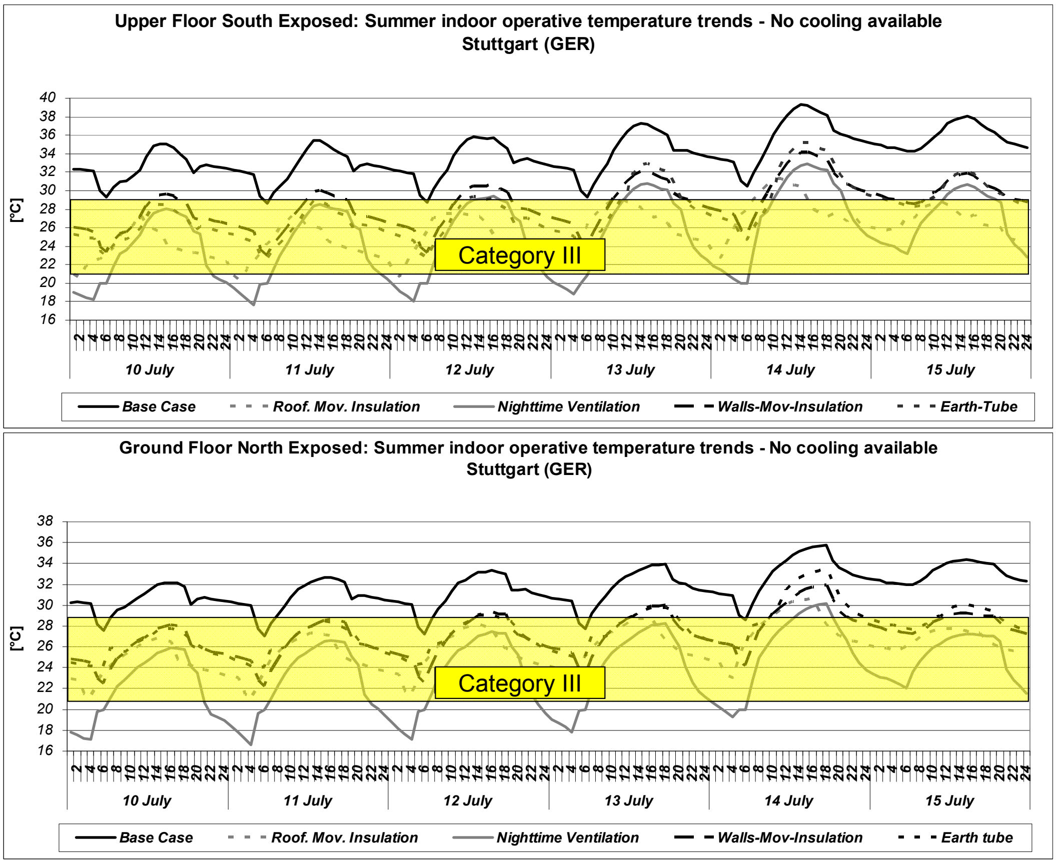



*Figure 4.6.17 – Office building simulated in Stuttgart: indoor temperature trends in July and comfort conditions according to EN 15251 (up: thermal zone 2; down: thermal zone 3)*

In particular, during the 10th and 11th July, the 100% of the working hours are characterized by indoor thermal comfort, adopting each one of the simulated passive cooling solutions.

In the hottest days, the wall movable insulation and the earth tube can drastically reduce the cooling loads, even if this is not enough. Also in this thermal zone, the nightime ventilation and the movable insulation of the roof induce the best performance (*about 90% of the time results comfortable*).

This analysis should not induce wrong suggestions: in fact, with respect to the whole season, all the analyzed passive cooling solutions guarantee optimal results. For example, in June, when the soil temperature is quite low, the buried pipes crossed by the ventilation air determine always comfort conditions during the working time, while in September, when the solar radiation becomes lower, also the movable insulation of the wall provides very appreciable performances.

Also with reference to the Baden-Württemberg climatic conditions (*i.e. Stuttgart*), the coefficients of performance of the earth tube have been evaluated, both in the warmest period of the year ($EER_{DESIGN}$) and seasonally ($EEER_{SEASONAL}$), respectively recurring to the methods already shown in the equations 3 and 4.

The $EER_{DESIGN}$ has been calculated considering the external conditions at 1.00 pm of a July central day, and evaluating the air temperature after the heat exchange inside the buried pipes. The inlet air temperature (*after the heat exchange in the earth tube*) was evaluated around 15 °C (figure 4.4.7), while the fan electric consumption is (*globally with reference to the whole building*) equal to 1250 $W_{ELECTRIC}$. Using the equation 3 results:

- $EER_{DESIGN}$ = 0.80 kg/s * 1.01 kJ/kg K * (32 °C – 15 °C) / 1.25 kW = 11.3 $kW_{thermal}/kW_{electric}$.

The obtained results are quite satisfactory, for the two following reasons:

1) the achieved results, about the temperatures of the air and the ground temperature are quite in according to the most authoritative literature and so well reliable;
2) compared to a traditional active cooling systems, the $EER_{DESIGN}$ results about 3 times higher.

As regards the Seasonal Energy Efficiency Ratios ($SEER_{SEASONAL}$), this was calculated adopted the equation 4. Using the already shown method, results:

- $SEER_{SEASONAL}$ = 5670 $kWh_{thermal}$ / 1278 $kWh_{electric}$ = 4.4 $kWh_{thermal}/kWh_{electric}$.

This value, a little bit lower than the same obtained for Naples (*about 6* $kWh_{thermal}/kWh_{electric}$) suggests that a better control and working time for the earth-to-air heat exchanger should be hypothesized. In particular, the designed system works until the half of September, when, in this climate conditions, comfort conditions are also achievable supplying directly the outdoor air inside the building.

Anyway, providing a free management of the systems (*manual control provided by the office administration, or automatic handling with an outdoor air temperature sensor to regulate the EAHX functioning*), this solution appears very useful, seeing the high value assumed by the $EER_{DESIGN}$.

**Berlin**

Also for this town, a preliminary analysis about the earth-to-air heat exchanger has been carried out, in order to choose the most effective functioning criterion. The period was always the same, fixing the working period in the temporary range 15$^{th}$ June ÷ 15$^{th}$ September. Considering the same boundary conditions such as defined for Stuttgart, about the soil structures and its thermal behaviour, with reference to the Berliner climate conditions the same 3 control strategies for the earth tube have been simulated. Also in this case, the best solution was represented by the third functioning regulation: *e.g. the buried pipe ventilation runs between 8.00 in the morning until 19.00 in the afternoon (the whole working day-time). Globally an external air amount of 1 ACH was supplied into the office.*

In table IV.9, the results of the preliminary analyses about the earth-to-air heat exchanger are reported.

Table IV.9: Berlin: Primary Energy requirement for the space cooling (kWh/m$^2$ a) on varying the earth tube control strategy

| | 1$^{st}$ floor north | 1$^{st}$ floor south | Ground floor north | Ground floor south |
|---|---|---|---|---|
| *1$^{st}$ strategy* | 13.3 | 19.6 | 11.8 | 20.2 |
| *2$^{nd}$ strategy* | 12.2 | 22.0 | 9.7 | 22.7 |
| *3$^{rd}$ strategy* | 7.9 | 13.7 | 6.9 | 14.1 |
| ***No earth tube*** | **18.2** | **26.7** | **14.9** | **27.5** |

Also for this city, the most critical space results not the office rooms at the last floor and south-exposed (*zone 2*), but the thermal zone oriented at the same way but located at the ground floor. In fact, seeing the climatic data of this city (table IV.4), the solar radiation in summertime is quite lower compared to Stuttgart (*monthly average solar maximum daily radiation = 5368 Wh/m$^2$ in Stuttgart, 5109 Wh/m$^2$ in Berlin)* while the outdoor temperature results higher for the main city of the Germany (*figure 4.6.8 and table IV.5*). In these conditions, the built roof structure (*well insulated and massive*) induces, globally, no energy penalties, being, considering the whole summer season, the night radiative cooling effect higher than the diurnal heat gains. On the other hand, the very high thermal resistance of the basement determines poor direct heat dissipation between the building and the soil, so that, globally, the exposure at the last floor of the building is less penalizing compared to the same exposure at the ground floor.

As regards the earth tube-control strategies, also for the Berlin climate the third one regulation solution appears the best one, reducing hardly the primary energy requirement to maintain the building at a fixed temperature internal values (26 °C). This analysis is expressive also of the best solution adoptable for naturally ventilated building, being the thermal comfort strictly connected to the un-balanced thermal gains within the lived spaces.

Comparing the primary energy savings (*and, thus, computing also the electric energy absorbed by the earth tube extraction fans, then correctly converted in primary energy*), the third control strategy for the buried pipe shows the best performances, inducing the following energy savings:

- thermal zone 1: saving around 10.3 kWh/m$^2$a → - 57% primary energy required;
- thermal zone 2: saving around 13.0 kWh/m$^2$a → - 49% primary energy required;

- thermal zone 3: saving around 8.0 kWh/m$^2$a → - 54% primary energy required;
- thermal zone 4: saving around 13.4 kWh/m$^2$a → - 49% primary energy required.

Thus, the higher savings are obtained for the thermal zones characterized by the higher thermal loads (*zones 2 and 4*), where, despite the computation of the fan electric absorption, the energy required can be cut of about 50% compared to the base case building. Therefore, in the next study, this third regulation strategy was adopted to compare the 4 kind of passive cooling strategies.

Considering that the results of table IV.9 have been obtained evaluating an indoor fixed thermal control at 26 °C, with the thermal energy needs very reduced (7 – 14 kWh/m$^2$a), then, admitting higher indoor thermal levels, also a full passive cooling is possible. Of course, "adaptative" comfort criteria should be considered (*i.e. according to EN 15251, for Berlin the admitted category III imposes thermal excursions inside the range 19 ÷ 28.5 °C, with reference to naturally ventilated building*).

In figures 4.6.18 and 4.6.19, the energy requirements to keep at 26 °C the indoor space have been represented, respectively considering the thermal energy needs (*no cooling system energy losses)* and the primary energy consumptions (*computation of the air-conditioning system inefficiencies and conversion factor between electric and primary energy*).

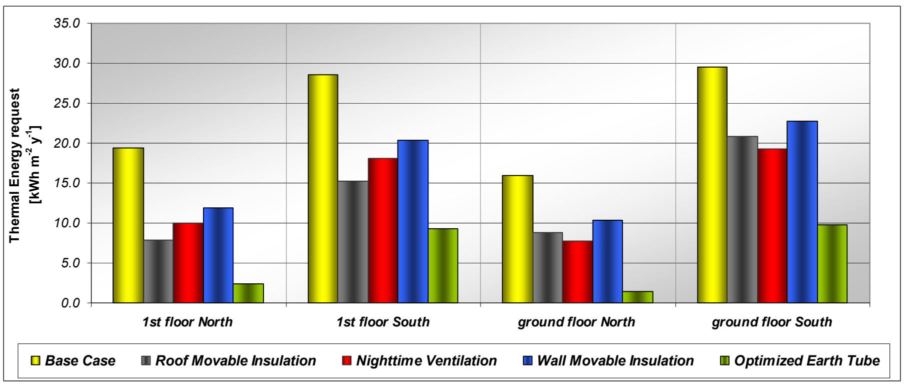



*Figure 4.6.18 – Thermal energy requested by the different thermal zones on varying the adopted passive cooling solution (Berlin)*

With reference to the thermal energy needs, the use of the earth tube cancels the cooling necessity for the thermal zone north-exposed (*less than 3 kWh/m$^2$a*), while in the other spaces (south-exposed) the cooling requests are hardly reduced (*less than 10 kWh/m$^2$a*). This means that, if the energy requirement for the fan functioning was considered not a cooling energy request but a mechanical ventilation one, the EnOB target are fully achieved by means of this passive cooling solution (*i.e. no active cooling needs*).

Although the ground heat exchange for the ventilation air represents the best solution for the passive cooling, very appreciable results can be obtained also recurring to the movable insulation of the roof and adopting the nighttime ventilation. On varying the considered thermal zones, the difference between the savings obtained adopting the buried pipes are always 5 ÷ 6 kWh/m$^2$a lower than the thermal energy requirement deriving from the application of the roof movable insulation panels or achievable adopting the nighttime ventilation.

This last 2 passive cooling strategies, as regards the thermal energy savings, result quite equivalent; in particular, the average thermal energy need of the building is around 14.6 kWh/m$^2$a (*roof movable insulation*) and 15.2 kWh/m$^2$a (*nighttime ventilation*). This results are quite good, considering the elevated heat gains (*external: high summer external temperature and significant solar radiation; internal: people, electric equipments, computers, artificial lights)*.

Also in this case, the movable insulation of the vertical walls probably doesn't result so convenient, because, although a quite good thermal energy reduction compared to the base case is obtained (*meanly: - 15.2 kWh/m$^2$a*), the aesthetic impact and, above all, the constructive difficulties can do not so simple or effective this action on the building envelope.

As regards the primary energy needs (figure 4.6.19), the absolute values of course are different with respect to the analysis regarding the thermal requests, but the design indications, previously noted, are confirmed. In fact, also computing the electric energy absorbed by the fans of the earth-to-air heat exchanger, this strategy results still a very well-adapted solution, even if, globally, very good performances are also obtained adopting the nighttime ventilation and the movable insulation of the roof (*about this last strategy, considering also the corridors, it becomes the best one*).

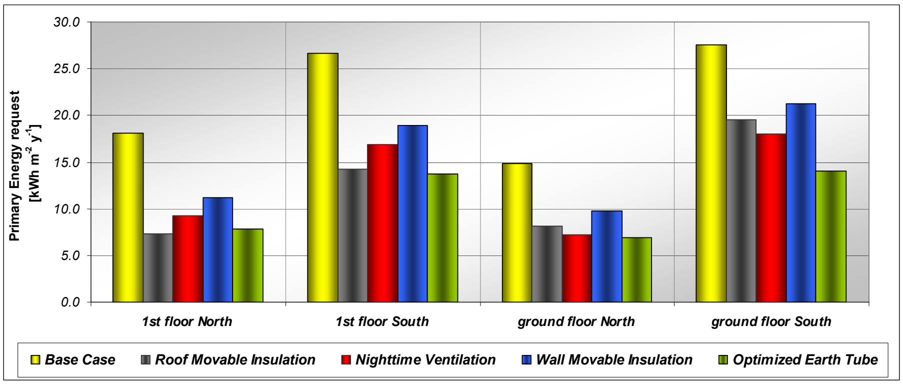



*Figure 4.6.19 – Primary energy requested by the different thermal zones on varying the adopted passive cooling solution (Berlin)*

In terms of primary energy, the base case (*meanly for the whole building*) requires 23.4 kWh/m$^2$a to maintain the indoor environment at 26 °C during the working hours (*between 8.00 am and 19.00*); considering the same boundary conditions, with reference to the analysed passive cooling solutions, the following results have been calculated:

- adoption of the <u>earth-to-air heat exchanger</u>: mean value for the building air-conditioning → 14.1 kWh/m$^2$a (*i.e. – 40% compared to the base case*);
- adoption of the <u>roof movable insulation</u>: mean value for the building air-conditioning → 13.6 kWh/m$^2$a (*i.e. – 42% compared to the base case*);

- adoption of the <u>nighttime ventilation</u>: mean value for the building air-conditioning → 14.2 kWh/m$^2$a (*i.e. – 39% compared to the base case*);
- adoption of the <u>wall movable insulation</u>: mean value for the building air-conditioning → 16.7 kWh/m$^2$a (*i.e. – 29% compared to the base case*).

These results are a little bit different with respect to the values reported in the figure 4.6.19; this happens because, with reference to figure 4.6.19, the thermal zone X and Y have been not considered. As shown in the figure 4.3.2, the 2 corridors (*zone X and Y*) present no extended sun exposed surfaces, being situated in the central position of the building area, so that the external heat gains are quite reduced (*no sun radiation on the vertical walls*). Thus, in this case, the roof movable insulation, above all at the upper floor, is largely the best solutions, providing a very effective night cooling of the only one heated structure.

As regards the thermal comfort conditions achievable without an air-conditioning system, (*and so evaluating the indoor thermal level trends leaving the indoor temperatures free running*), very interesting results can be noted, as shown in figure 4.6.20.

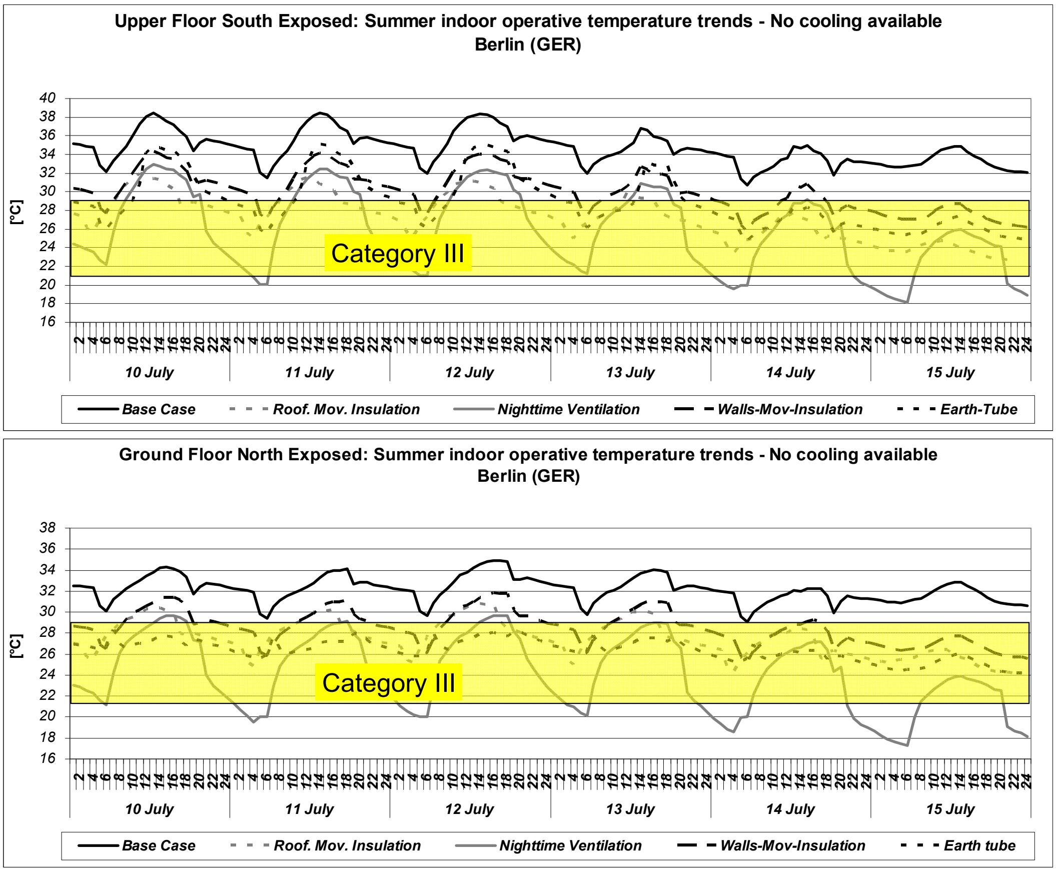



*Figure 4.6.20 – Office building simultaed in Berlin: indoor temperature trends in July and comfort conditions according to EN 15251 (up: thermal zone 2; down: thermal zone 3)*

Even in this case, the analyses are referred only to the hottest period of the year (*the central part of July*), so that some singularities can happen.

Although the summer climate conditions in Berlin are a lightly different compared to Stuttgart (*lower solar radiation, but meanly higher temperatures*), similar thermal behaviors of the building can be noted.

As regards the thermal zone 2 (*upper floor south-exposed, represented in the figure 4.6.20 up graph*), in this period the best comfort conditions are obtained using the roof movable insulations, that induces a well-adapted discharging of the roof massive layers heated during the day-time. In particular, still with reference to the dynamic comfort conditions identified by the European Standard EN 15251, the roof movable insulations guarantees comfort conditions (*Category III, i.e. 65% people satisfied*) for the 65% of the working time, with reference to the very hot 6 days considered (half July).

Quite satisfactory also the performances obtained adopting the nighttime ventilation, that guarantees, in this very critical period, thermally comfortable working time for about 45% of the diurnal hours. However, considering the whole season, the results are much better, with acceptable thermal comfort levels obtained adopting all the studied passive cooling solutions.

As regards the thermal zone 3 (*ground floor north-exposed*), as shows in figure 4.6.20 down graph, the earth-to-air heat exchange and the nighttime ventilation always provide comfort conditions in the office spaces during the working time hours. The roof movable insulation, providing only an indirect and poor cooling effect, does not confirm the same performances obtained as regards the free cooling of the upper floor cooling. Seeing the different classes about the comfort conditions, by means of the EN 15251 methods (*Berlin July outdoor temperature = ca. 19.1 °C, and so Category I = < 27.1 °C, Category II = < 28.1 °C*), in this city also comfort conditions better than Category III can be obtained, adopting the cited passive cooling solutions. In particular, for the analyzed thermal zone, the earth-to-air heat exchange, guarantees comfort Category II (*i.e. 80% acceptation*) also in the hottest period of the year (*figure 4.6.20 down graph*), resulting indoor temperatures usually lower than 28 °C.

Actually, also considering the Category I (*i.e. 90% acceptation*) requirements, during the considered warmest days, thermal levels lower than 27.1 °C can be achieved for all the working hours of the 14 and 15 July.

Considering that the investigated period is characterized by the worst conditions happening during the whole summer, the presented results are very satisfactory, and so, extending the analyses to the whole warm period (*June – September*), the shown passive cooling solutions induce very useful indoor thermal levels, without the necessity of any air-conditioning system. *It means that this EnOB target would be achieved.*

The last analysis, with reference to the Berlin climatic conditions, is referred to the coefficients of performance obtainable well designing the earth tube heat exchanger. The EERs are evaluated both with reference to the warmest period of the year ($EER_{DESIGN}$) and considering the whole summer season ($SEER_{SEASONAL}$), adopting, also in this case, respectively the methods reported in the equations 3 and 4.

With the same criteria used for Stuttgart, the $EER_{DESIGN}$ has been calculated considering the external conditions during the central hours of a July typical day (figure 4.6.9: *outdoor air temperature equal to 33 °C*) and considering the air temperature after the thermal exchange in the earth tube. The temperature of the air, after the crossing of the buried pipes, is evaluated around 15 °C (figure 4.4.7). Moreover, implementing the equation (3) results:

- $EER_{DESIGN}$ = 0.80 kg/s * 1.01 kJ/kg K * (33 °C – 15 °C) / 1.25 kW = 11.7 $kW_{thermal}/kW_{electric}$.

Also in this case, the achieved EER is much higher than the energy efficiency ratio of a quite good cooling system.

About the whole season performance ($SEER_{SEASONAL}$), this is calculated as shown in the equation 4:

$$SEER_{SEASONAL} = 8553\ kWh_{thermal} / 1278\ kWh_{electric} = 6.7\ kWh_{thermal}/kWh_{electric}.$$

This result is quite better than the same index obtained with reference to the Stuttgart climatic conditions (*about 4.4 $kWh_{thermal}/kWh_{electric}$*). In fact, although the ground temperatures at – 3 m are quite the same for the 2 cities (figure 4.4.7), the outdoor air temperature in Berlin results, in summertime, higher than in Stuttgart, considering both the values reported in figure 4.6.9 and the design conditions described in table IV.4. For these reasons, the heat exchange in the buried pipes results more effective.

**Oslo**

As regards this last city considered, the same preliminary analysis, referred to the earth tube best control strategies, was been carried out, in order to evaluate, fixing the working period (*15th June – 15th September*), the most adapt compromise between the obtainable thermal savings and the electric energy required by the fans.

As shown in table IV.10, also in Oslo the best control strategy for the earth tube is, globally, the third one, even if somewhere, where the thermal loads are reduced (*zone 3*), the most convenient control solution consists in reducing the working hours of the earth tube (*so that it runs only when the outdoor air is particularly warm*). This is quite simple to understand: in fact, when the thermal loads are low, for example during the afternoon-evening hours (*when the outdoor air is enough fresh in order to balance the internal gains, without recurring to the earth tube*), it is convenient turn off the ground ventilation.

As already noted, globally the third one control strategy continues to be the best; therefore, also in this case, this regulation method was chosen: the earth tube mechanical ventilation works between 8.00 am until 7.00 pm, and so supplying, for all the working hours, an external air amount equal to 1 ACH.

Table IV.10: Oslo: Primary Energy requirement for the space cooling (kWh/m$^2$ a) on varying the earth tube control strategy

| | 1st floor north | 1st floor south | Ground floor north | Ground floor south |
|---|---|---|---|---|
| *1st strategy* | 8.5 | 13.1 | 8.1 | 13.8 |
| *2nd strategy* | 8.2 | 18.6 | 5.7 | 19.4 |
| *3rd strategy* | 7.1 | 12.9 | 6.5 | 13.5 |
| ***No earth tube*** | **12.5** | **21.9** | **9.8** | **22.7** |

Comparing the primary energy savings, and so considering also the electric energy absorbed by the earth tube extraction fans (*opportunely converted*), adopting the third control strategy for the earth tube mechanical ventilation, the following savings are achieved with respect to the base-case building.

- thermal zone 1: saving around 5.4 kWh/m$^2$a → *i.e. - 43% primary energy required;*
- thermal zone 2: saving around 9.0 kWh/m$^2$a → *i.e. - 41% primary energy required;*
- thermal zone 3: saving around 3.3 kWh/m$^2$a → *i.e. - 34% primary energy required;*
- thermal zone 4: saving around 9.2 kWh/m$^2$a → *i.e. - 41% primary energy required.*

The results are clamorous as regards the thermal zone 2 and 4 (*the warmest ones*) where, although considering the electrical energy requested for the extraction of the air, the earth tube performances cut drastically the primary energy requirements. In fact, adopting this control strategy, the thermal energy required to maintain at 26 °C the indoor space during the working hours, results:

- thermal zone 1: thermal energy requested = 1.7 kWh/m$^2$a → - 87% compared to the base case (e.g. 11.7 kWh/m$^2$a saved);
- thermal zone 2: thermal energy requested = 8.4 kWh/m$^2$a → - 64% compared to the base case (e.g. 15.0 kWh/m$^2$a saved);
- thermal zone 3: thermal energy requested = 1.0 kWh/m$^2$a → - 91% compared to the base case (e.g. 9.6 kWh/m$^2$a saved);
- thermal zone 4: thermal energy requested = 9.1 kWh/m$^2$a → - 63% compared to the base case (e.g. 15.3 kWh/m$^2$a saved).

Therefore, if in terms of primary energy the earth tube results quite convenient, with reference to the saved thermal energy this technique is quite formidable in these climate conditions; *in other words, if the fan electrical request is considered a ventilation requirement and not a cooling one, the earth tube ventilation results the perfect passive cooling strategy.*

In the figures 4.6.21 and 4.6.22, the energy requirement to maintain at a fixed temperature values (26 °C) the indoor air has been represented, in terms of thermal energy (*figure 4.6.21*) and primary one (*figure 4.6.22*). In this second case, the energy need considers the energy losses due to the cooling system efficiency and the conversion factor between electric and primary energy.

About the primary energy requirement, the cool soil temperature of the considered city determines very good performance of the earth tube ventilation system; as shown in figure 4.6.21, this represents the best passive cooling solution in order to cancel the thermal loads in the lived space in summertime, and this happens in each thermal zone of the building.

For the north-exposed spaces, quite good results derive also using the roof movable insulation, that induces thermal energy needs (*considering a set-point temperature equal to 26 °C*), lower than 10 kWh/m$^2$a compared to the base case. This result can be obtained only at the upper floor, while the performances of this passive cooling solution become lower when the room ceiling is not sky-exposed. Contrariwise, at the ground floor, the nighttime ventilation (*by means of 4 ACH naturally obtained*) guarantees a complete passive cooling of the north-exposed offices (thermal loads < 5 kWh/m$^2$a), reducing drastically the energy needs also for the south-exposed thermal zone (*zone 4*), with an energy demand around 10 kWh/m$^2$a.

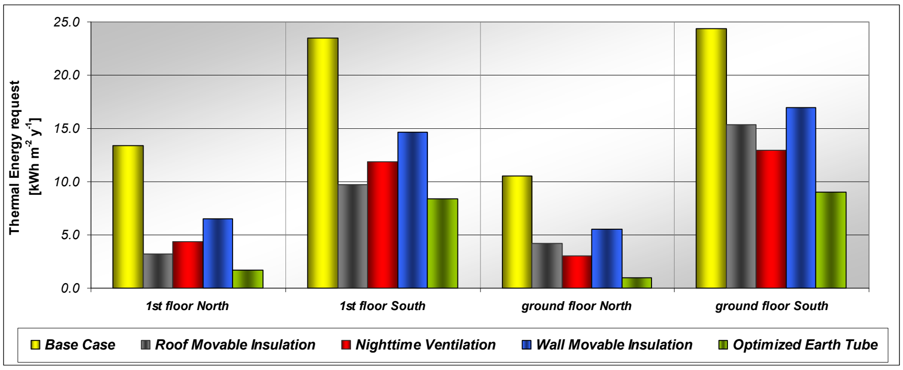



*Figure 4.6.21 – Thermal energy requested by the different thermal zones on varying the adopted passive cooling solution (Oslo)*

In figure 4.6.22 the energy requests have been evaluated in terms of primary energy. In this case, the energy required by the extraction fans of the earth-to-air heat exchanger has been computed (*i.e. 10 hours/day, 93 days, 1250 W = 1278 kWh/year for the whole building*): it means about 5.00 kWh/m$^2$a, in terms of primary energy, due to the mechanical ventilation.

Considering this electric energy request, the earth tube, although it is very useful in reducing the thermal energy needs (*the best solution in figure 4.6.21*), becomes not the preferable passive cooling strategy. In figure 4.6.22, the great performances of the roof movable insulation are confirmed for the upper floor offices (*i.e. thermal zones 1 and 2*) with primary energy requirements respectively around 3 kWh/m$^2$a and 9 kWh/m$^2$a. With reference to the ground floor rooms, the nighttime ventilation results, also now, the preferable passive cooling strategy, with specific energy requirements equal to 2.8 kWh/m$^2$a (*thermal zone 3, ground floor north-exposed*) and 12.1 kWh/m$^2$a (*thermal zone 4, ground floor south exposed*).

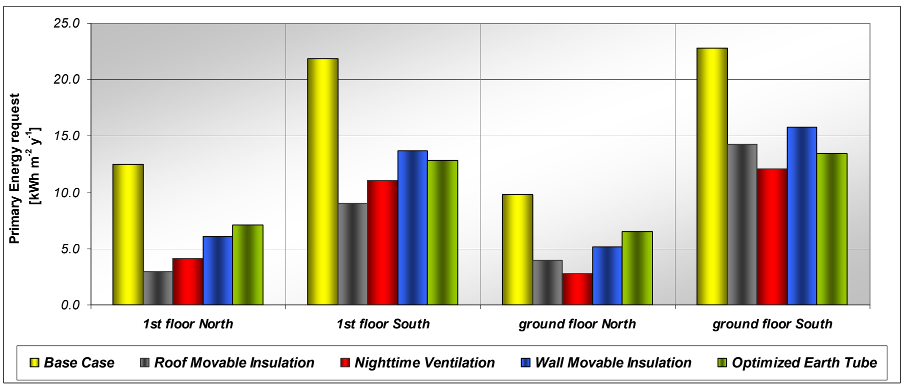



*Figure 4.6.22 – Primary energy requested by the different thermal zones on varying the adopted passive cooling solution (Oslo)*

Summarizing, the best solutions in terms of primary energy are, for each thermal zone:

- thermal zone 1 (1st *floor north-exposed):* the <u>roof movable insulation</u> induces a primary energy saving around 9.5 kWh/m$^2$a (*i.e. – 76% compared to the base case*);
- thermal zone 2 (1st *floor south-exposed):* the <u>roof movable insulation</u> induces a primary energy saving around 12.8 kWh/m$^2$a (*i.e. – 58% compared to the base case*);
- thermal zone 3 (*ground floor north-exposed):* the <u>nighttime ventilation</u> induces a primary energy saving around 7.0 kWh/m$^2$a (*i.e. – 71 % compared to the base case*);
- thermal zone 4 (*ground floor south-exposed):* the <u>nighttime ventilation</u> induces a primary energy saving around 10.8 kWh/m$^2$a (*i.e. – 47 % compared to the base case*).

The next analysis evaluates the thermal comfort conditions achievable without an air-conditioning system. The indoor air temperatures have been evaluated, adopting the investigated passive cooling strategies and leaving the indoor thermal level free running. All the temperature trends are reported in figure 4.6.23. Also in this case, the analyses are referred to the summer hottest period (*10th ÷ 20th July*), investigating what happens in the thermal zone 2 and 3.

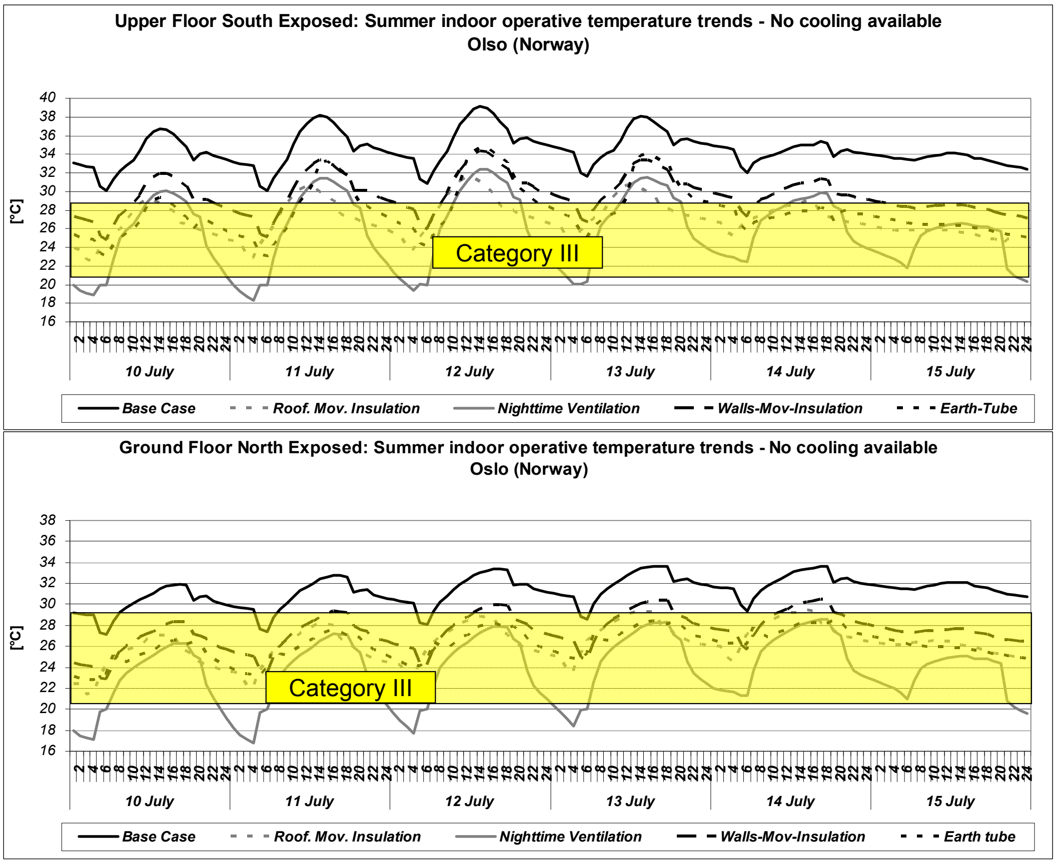



*Figure 4.6.23 – Office building simulated in Oslo indoor temperature trends in July and comfort conditions according to EN 15251 (up: thermal zone 2; down: thermal zone 3)*

With reference to the thermal zone 2 (*upper floor south-exposed*), the figure 4.6.23 (*up graph*) shows that:

- adopting the nighttime ventilation, comfort conditions calculated by means of the European Standard EN 15251 (Category III, 65 % acceptation, i.e. indoor air temperature < 27.5 °C) are possible for almost the 28% of the working time in the hottest days of the year (*$10^{th}$ → $13^{th}$ July*), while for about the 80% of the time in the following days (*$14^{th}$ – $15^{th}$ July*);
- adopting the roof movable insulation, comfort conditions calculated by means of the European Standard EN 15251 (Category III also in this case) are possible for about 15% of the working time in the hottest days of the year (*$10^{th}$ → $13^{th}$ July*), and for the whole diurnal time in the following days (*$14^{th}$ – $15^{th}$ July*).
- earth-to-air heat exchanger and movable insulations of the opaque vertical walls guarantee poor comfort conditions in these critical days.

The described results are referred to a thermal zone quite critical and to the hottest days of the year. Considering the whole summer season, actually, the earth tube (*very effective in June*), the movable insulation of the roof and the nighttime ventilation guarantee a quite complete thermal comfort within the building indoor environment, and this can be easy explained seeing figure 4.6.23 (*down graph*), where the thermal zone 3 (*ground floor north-exposed*) was analysed.

With reference to the thermal zone 3, is quite clear that, also in the most critical summer period, roof movable insulation, earth tube mechanical ventilation and, above all, the use of the nighttime ventilation induce comfort conditions (*Category III – EN 15251*) for the great part of the summer season. These results can be easy understood seeing want happens in the 95% of the working time, when indoor thermal levels lower than 28 °C are achieved.

The best solution, as already previously noted, is obtained adopting the nighttime ventilation, because, during the nocturnal hours, the Norwegian external temperatures are always lower than the indoor ones. Therefore, the nigh ventilation can induce a very effective discharge of the building envelope (*convective heat exchange*), charged by the internal gains and by the solar radiation during the daytime. In particular, compared to the base case (*no passive cooling solution adopted*), there is meanly a temperature difference around - 6 °C during the daytime, around – 9°C in the night.

Although globally the nighttime ventilation guarantees the best performances, this passive cooling strategy induces very high excursions of the indoor air temperature during the 24h: in particular the thermal level swing is, meanly, around 7 °C (24h), while, adopting the movable insulation of the roof or the earth tube diurnal ventilation, the variation day-night is of about 4 ÷ 5 °C. Considering that the office buildings are occupied only during the daytime, the great temperature excursions derived by the adoption of the nighttime ventilation are not a significant problem. Lower performances, but anyway not so bad considering that this is the hottest period of the year, are induced recurring to the movable insulation of the opaque wall.

Also with reference to the climatic conditions of Oslo, the last analysis is referred to the energy efficiency ratios obtainable with a good design of the earth-to-air heat exchanger. In particular the two EERs have been again evaluated:

1) $EER_{DESIGN}$: this considers the external conditions during the central hours of a July day (*table IV.4, outdoor air at 27 °C*) and the air temperature after the thermal exchange in the earth-to-air heat exchanger. The achievable heat losses are calculated (*considering the mass flow rate and the specific heat*) and then compared with respect to the electric power absorbed by the fan. The adopted method was explained in the equation 3;
2) $SEER_{SEASONAL}$: this is referred to the whole summer season, and so considering the seasonal savings of the thermal energy required, compared to the seasonal fan electric energy consumptions; the method was already shown in the equation 4.

With the same criteria adopted for the other investigated cities, the $EER_{DESIGN}$ has been calculated considering an external temperature of 27 °C (table IV.4) and evaluating the air temperature after the thermal exchange in the earth tube (9 °C, figure 4.4.7):

- $EER_{DESIGN}$ = 0.80 kg/s * 1.01 kJ/kg K * (27 °C – 9 °C) / 1.25 kW = 11.7 $kW_{thermal}/kW_{electric}$.

The nominal EER is very high (*the same value assumed for Berlin*), showing that where the soil conditions are particularly favourable (*winter cold climates, and so cold conditions also in summer, because of the elevated time lag of the soil*) a well designed earth-to-air heat exchanger results a very well-adapted solution. Actually, the coefficient of performance is meanly 3-4 times higher than a traditional cooling system.

About the seasonal energy efficiency ratio ($SEER_{SEASONAL}$), considering the seasonal ground cooling effect compared to the primary energy required by the extraction fan of the earth tube, results:

- $SEER_{SEASONAL}$ = 6383 $kWh_{thermal}$ / 1278 $kWh_{electric}$ = 5.0 $kWh_{thermal}/kWh_{electric}$.

With reference to the whole season, the earth tube efficiency results a little bit lower than the maximum obtainable: it suggests a reduction of the working period of the earth-to-air heat exchanger, being, perhaps in September, not very effective. Therefore, where the enthalpy loss, across the buried pipes, is not so high (*due to the low outdoor air temperature*), the adoption of simple natural diurnal ventilation is more useful.

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The proposed passive cooling solutions, singularly simulated, induce quite good results as regards the 4 considered climatic conditions. According to the targets of this study, the final objective consists into the research of the best solutions in order to minimize the thermal gains inside the office building. The final target is, therefore, the obtainment of the lowest possible thermal load in the very warm climate of the south-Italy (*reducing the air-conditioning energy needs*) and the nullification of the active energy cooling in the moderate summer climates of German cities (*reaching, in this way, the EnOB targets)* and with reference to the north-Europe climates.

These purposes are identified in order to demonstrate that, even considering elevated thermal comfort conditions, best practices in the use of the climate peculiarities (*temperature of the sky, nighttime outdoor air temperature, and favorable conditions of the soil*) induce the design of energy sustainable buildings, without too expensive technological solutions.

About this last point, in order to contain the building costs, in the next paragraph only the two most effective passive cooling solutions have been coupled, with reference to each one of the four investigated thermal zones.

### 4.6.2 THE COUPLING OF THE MOST ADAPT PASSIVE COOLING SOLUTIONS

For each considered climatic region, and with reference to the best passive cooling solutions, such as evaluated for each thermal zone of the simulated office building, in table IV.11 the best coupling are identified.

In each of the 4 office spaces (*thermal zones 1-4, see figure 4.3.1*) only two passive cooling solutions have been coupled, choosing the most effective both in terms of obtainable cooling energy savings and in terms of primary energy required. In fact, even if the cooling effect is always free obtained free, one of the 4 investigated solutions requires the use of electrical fans (*earth tube mechanical ventilation*), in order to create the necessary depression conditions within the pipe to induce a correct air flowing inside the buried tube.

In this chapter, above all the building summer performances are investigated; in particular, the earth-to-air heat exchange is the only one investigated solution the provides also savings during the winter period too, when, by means of the thermal recovery from the ground, a pre-heating effect of the ventilation air is achieved.

About the earth tube design, in this study extraction fans have been simulated. This earth tube typology could be convenient in summer, because there is not the elevation of the air temperature due to the fan energy transfer. On the other hand, this design criterion of course results a little bit penalizing during the winter, when, instead, an enthalpy growth is achieved adopting intake fans.

Furthermore, in this section, also another passive cooling solution for the building envelope has been implemented into the simulated office building: the adoption of cool paint coatings, in order to reduce the solar energy absorbed by the building envelope. About this, various literature studies and applications regarding the external coatings useful to reduce the solar heat gains are summarized and reported in the Chapter 3 of this Thesis.

In particular, several research centers carry out studies, energy diagnoses and certifications of building envelope components, as regards the energy performances in terms of the structure aptitude to absorb and transfer inside the solar radiation or to reject it. In particular, the CRRC certifications define performance levels of a building component evaluating its solar reflectance and far-infrared emissivity. Moreover, the SRI index, introduced by the American Society for Testing and Materials (ASTM), suggests the selection of building envelope coatings useful to reduce the peak demand for electric energy in summertime, with high energy savings (of about 10% - 60% according to Parker *et al.* [36]) related to a reduced use of active cooling systems.

Table IV.11: The choice of the coupled passive cooling solutions: for each thermal zone, two strategies have been considered, starting by the previously described results

| **Naples**<br>**Stuttgart** | ***Zone 1:***<br>*1st floor*<br>*North exposed* | ***Zone 2:***<br>*1st floor*<br>*South exposed* | ***Zone 3:***<br>*Ground floor*<br>*North exposed* | ***Zone 4:***<br>*Ground floor*<br>*South exposed* |
|---|---|---|---|---|
| *Roof Movable Insulation* | ▲ | ▲ | | |
| *Nighttime ventilation* | ▲ | ▲ | ▲ | ▲ |
| *Wall Movable Insulation* | | | | |
| *Earth Tube* | | | ▲ | ▲ |
| ** the upper corridor was cooled by roof movable insulation and nighttime ventilation, while the corridor at the ground floor adopts nighttime ventilation and EAHX diurnal ventilation* | | | | |
| **Berlin** | ***Zone 1:***<br>*1st floor*<br>*North exposed* | ***Zone 2:***<br>*1st floor*<br>*South exposed* | ***Zone 3:***<br>*Ground floor*<br>*North exposed* | ***Zone 4:***<br>*Ground floor*<br>*South exposed* |
| *Roof Movable Insulation* | ▲ | ▲ | | |
| *Nighttime ventilation* | | | ▲ | ▲ |
| *Wall Movable Insulation* | | | | |
| *Earth Tube* | ▲ | ▲ | ▲ | ▲ |
| ** the upper corridor was cooled by roof movable insulation and nighttime ventilation, while the corridor at the ground floor adopts nighttime ventilation and EAHX diurnal ventilation* | | | | |
| **Oslo** | ***Zone 1:***<br>*1st floor*<br>*North exposed* | ***Zone 2:***<br>*1st floor*<br>*South exposed* | ***Zone 3:***<br>*Ground floor*<br>*North exposed* | ***Zone 4:***<br>*Ground floor*<br>*South exposed* |
| *Roof Movable Insulation* | ▲ | ▲ | | |
| *Nighttime ventilation* | | ▲ | ▲ | ▲ |
| *Wall Movable Insulation* | | | | |
| *Earth Tube* | ▲ | | ▲ | ▲ |
| ** the upper corridor was cooled by roof movable insulation and nighttime ventilation, while the corridor at the ground floor adopts nighttime ventilation and EAHX diurnal ventilation* | | | | |

Givoni [37] has carried out many other experiments also with reference to naturally ventilated small buildings, characterized by different external surface coatings: in summer, the internal average temperature for grey buildings was around 3 °C higher compared to white painted ones. Experimental analyses carried out in India by Bansal *et al.* [38] showed that a white building, without air-conditioning system, maintains a summer internal average temperatures around 4 ÷ 8 °C lower than the same building with dark external coating.

Other experimental and numerical studies in the early 90's showed that the action on the radiative characteristics of the outer surfaces is a very effective action, for both thermal comfort inside not air-conditioned buildings and energy request in conditioned architectures [39 - 42].

Finally, the Florida Solar Energy Center investigated the performance achievable using 37 different surface finishes [43]: Parker *et al.* demonstrated that, also compared to new technologies, clear colors of external surfaces induce the best performances.

In the following simulations, not only the coupling of the best passive cooling solutions already investigated and singularly analyzed has been considered, but, furthermore, also cool-paints for the sun and sky exposed external building surfaces have been adopted.

In particular, the previously modeled building, characterized by a typical concrete external coating, in the following studies has been simulated with the radiative characteristics of a white-painted surface (*i.e. white plaster*).

**Naples**

For the first floor, the nighttime ventilation and the roof movable insulation have been coupled, while, as regards the ground floor, the nocturnal ventilation and the artificial ventilation adopting the earth-to-air heat exchanger were combined; also the adoption of cool paints for the roof and the vertical wall has been considered.

The following results, such as represented in figure 4.6.25, are referred to a naturally ventilated building, so that the indoor temperature, in summertime, can free run; the analyses are referred to the whole warm season (*15$^{th}$ June – 15$^{th}$ September*).

Considering the thermal comfort conditions provided by the European Standard EN 15251, also in the hot summer climatic conditions of the south-Italy, an indoor thermal comfort is possible in not-conditioned building, if well-adapted passive cooling strategies were used.

In this case, both the most and less critical thermal zones have been analysed: respectively the thermal zone 2 (*south-exposed, first floor*) and the thermal zone 3 (*north-exposed, ground floor*).

As shown in figure 4.6.25, with reference to the thermal zone 2, for the 69% of the summer working time, the 65% of the people feels thermal comfort conditions (*Category III*), while the Category II and III (*respectively 80% and 90% acceptation*) are guaranteed for the 41% and 27% of the working period.

These results are not fully satisfactory, even if they show a very well-designed building envelope and system behaviours, considering the critical summer conditions of this climatic region. With reference to the thermal zone 3, has been calculated that:

- Category I thermal comfort conditions (*EN 15251 – naturally ventilated building*) guaranteed for the 62% of the summer working time;
- Category II thermal comfort conditions (*EN 15251 – naturally ventilated building*) guaranteed for the 81% of the summer working time;
- Category III thermal comfort conditions (*EN 15251 – naturally ventilated building*) guaranteed for the 86% of the summer working time.

It is quite clear that, even if these results do not guarantee a complete free cooling, the use of the air-conditioning system can be hardly reduced adopting the modelled passive cooling strategies.

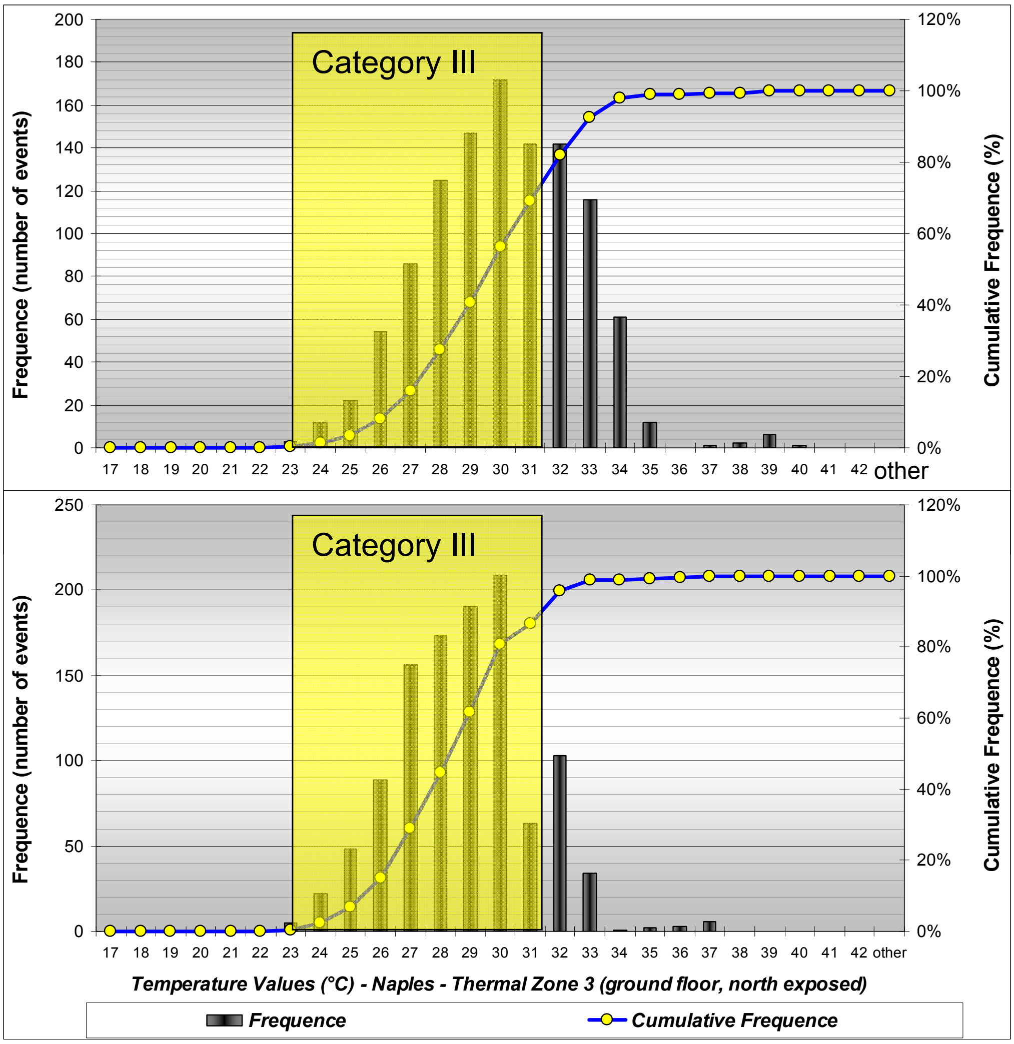


*Figure 4.6.25 – Office building simulated in Naples. Summer working time (only diurnal hours): possible comfort conditions according to the standard EN 15251*

In fact, considering a building characterized by the presence of an air-conditioning system, in order to maintain the indoor air temperature at a fixed value of 26 °C, the annual energy needs for summer cooling, both in terms of thermal and primary energy, results:

- zone 2 (*south-exposed, 1st floor*): the thermal energy request results equal to 47 kWh/m²a, while the base case requires 66 kWh/m²a; instead, the primary energy request is around 44 kWh/m²a while the base case requires 62 kWh/m²a. Thus, the obtained savings are the 29%;
- zone 3 (*north-exposed, ground floor*): the thermal energy request is equal to 19 kWh/m²a, while the base case requires 43 kWh/m²a; instead, the primary energy request is around 18 kWh/m²a while the base case requires 41 kWh/m²a. Thus, the obtained savings are the 56%;
- whole building: adopting the <u>coupled passive cooling solutions,</u> the summer thermal energy request is around 36 kWh/m²a, while the base case requires 59 kWh/m²a; the

primary energy request is 34 kWh/m$^2$a while the base case requires 55 kWh/m$^2$a. Thus, the obtained savings are the 40%.

*Of course, adopting also other simple strategies to reduce the summer solar gains (e.g. window shadings), the cooling energy needs can be further reduced.*

**Stuttgart**

With reference to the Baden-Württemberg main city, only a naturally ventilated building has been considered, because the target of this study, with reference to the German climatic conditions, was the achievement of the EnOB requirements (*i.e. no active cooling in summertime*).

Thus, coupling of best passive cooling strategies before presented, and modelling also the cool-painting of the external surface coatings, the results shown in figure 4.6.26 have been obtained. The analyses have been carried out with reference to the whole summer season, analyzing the indoor temperature trends and the achievable comfort conditions as suggested by the Standard EN 15251 for naturally ventilated buildings. The coupling of the passive cooling solution (table IV.11) consists in:

- first floor: *the nighttime ventilation and the roof movable insulation* have been considered in the same time, in order to discharge, as much as possible, the envelope structure heated by the diurnal solar radiation and by the elevated indoor heat gains. The cooling effect is guaranteed, in this way, both through external radiative phenomena (*roof movable insulation*) and internal convective heat exchanges (*nighttime ventilation*);
- ground floor: *the nocturnal ventilation and the artificial earth tube ventilation* have been coupled, in order to provide a comfortable thermal level of the external air supplied into the environment. During the night, the external natural ventilation discharges the envelope heated mass, while, during the day, the fresh air crossing the buried pipes determines indoor comfort conditions;
- about the corridors, the upper one is cooled by roof movable insulation and nighttime ventilation, while the corridor at the ground floor is cooled by nighttime ventilation and EAHX diurnal ventilation.

In figure 4.6.26, the indoor air temperature trends have been reported, with reference to the whole summer season and considering the thermal comfort conditions provided by the European Standard EN 15251. Also in this case, two representative thermal zones have been considered: the thermal zone 2 (*south-exposed, first floor*) and the thermal zone 3 (*north-exposed, ground floor*).

With reference to the thermal zone 2, characterized by the elevated heat gains due to the south-exposure and to the solar radiation on the roof, in figure 4.6.26-a, it is shown that:

- EN 15251 Category I (90% acceptation) is guaranteed for the 88% of summer working hours;

- EN 15251 Category II (80% acceptation) is guaranteed for the 94% of summer working hours;
- EN 15251 Category III (65% acceptation) is guaranteed for the 100% of summer working hours.

These results are very satisfactory, and even better performances are obtained considering the thermal zone 3 (figure 4.6.26-b), where the north-exposure and the absence of an sun-exposed roof determine the EN 15251 Category I (*and, of course, also II and III*) for the 100% of the summer working hours.

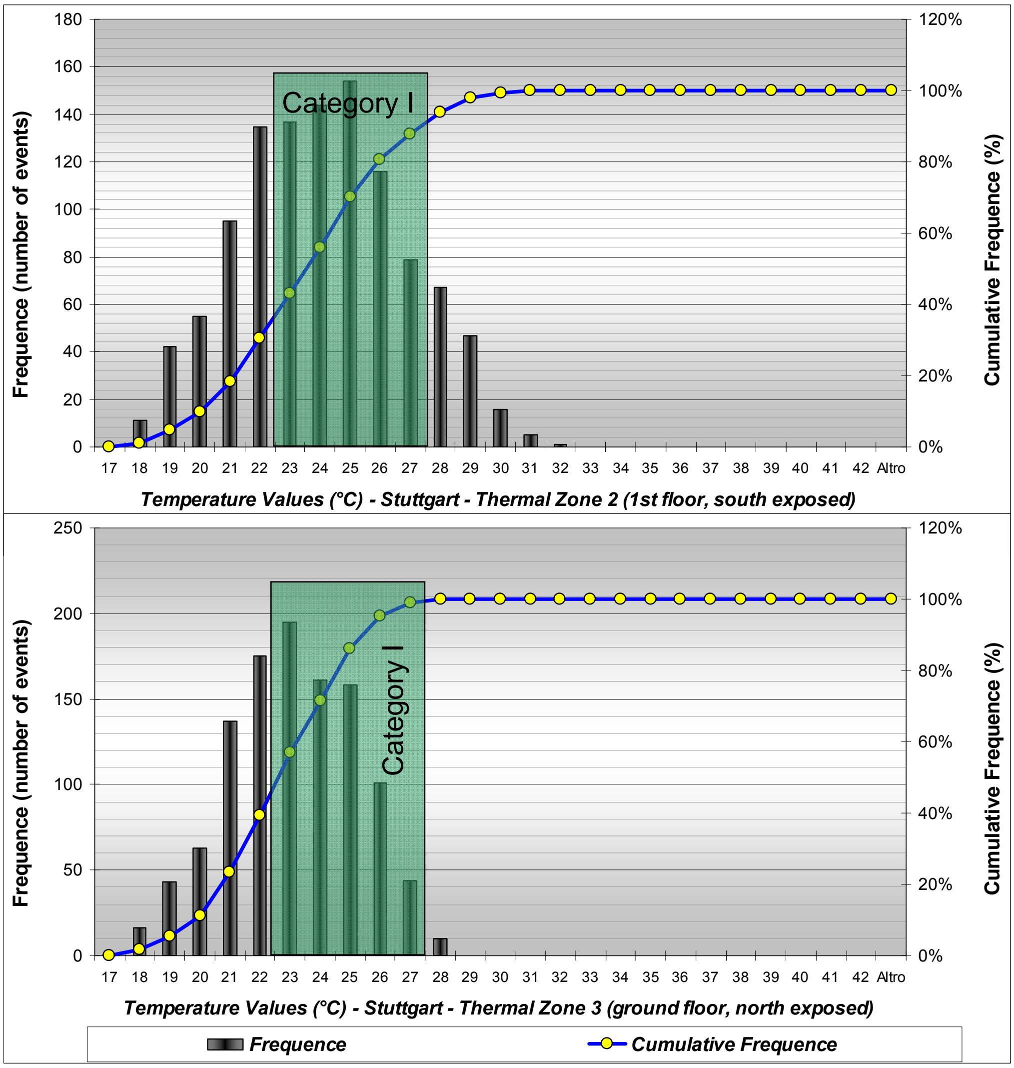


*Figure 4.6.26 – Office building modelled in Stuttgart. Summer working time (only diurnal hours): possible comfort conditions according to the standard EN 15251*

*Therefore, it is quite clear that the EnOB target, about the summer season (no active cooling need) results fully achieved.*

**Berlin**

Also in this case, only a naturally ventilated building has been considered, in order to verify the EnOB targets about the summer performances. Thus, the indoor temperatures during the summer season have been evaluated, in order to understand which comfort conditions are possible coupling the most adapt passive cooling solutions, as below described (*see also table IV.11*).

At the first floor, a different coupling compared to Stuttgart has been considered, providing, in the same time, movable insulation of the roof and diurnal ventilation with buried tubes. In this way, during the nighttime, the radiation between roof and sky cools the ceiling exposed mass, while, during the day, the external air supplied into the building is opportunely cooled inside the EAHX. This last passive cooling solution was adopted also for the ground floor, even if, in this situation, it was coupled with the nightime ventilation. The principle is the same: 2 different strategies have been adopted, 1 acting during the night (*discharging of the building mass*) and 1 acting during the day (*supplying fresh air into the building*). About the corridors, the same design criteria already seen for Stuttgart have been designed: the upper one is cooled recurring to the roof movable insulation and nighttime ventilation, while the ground floor corridor is simulated with nightime ventilation and EAHX diurnal ventilation.

The results, divided for the usual 2 different thermal zones (2 and 3), are reported in figure 4.6.27.

With reference to the thermal zone 2 (*upper floor, south-exposed*), the obtained results are very satisfactory, as shown in figure 4.6.27-a. In particular, considering the European Standard 15251, 3 classes of thermal comfort conditions have been indicated and, for this climatic condition, these are (see table IV.11):

- Category I: comfort range included in the limit values 23.1 – 27.1 °C;
- Category II: comfort range included in the limit values 22.1 – 28.1 °C;
- Category III: comfort range included in the limit values 21.1 – 29.1 °C.

Adopting this criterion, with reference to the thermal zone 2, the following results have been obtained:

- Category I (90% acceptation) is guaranteed for the 95% of summer working hours;
- Category II (80% acceptation) is guaranteed for the 98% of summer working hours;
- Category III (65% acceptation) is guaranteed for the 100% of summer working hours.

These results, also considering this critical thermal zone, demonstrate that in the central Europe climatic region also when the indoor gains are very elevated (*office buildings*), a correct design of the building envelope and an useful choice of the most adapt passive cooling solutions can guarantee comfort conditions in summertime, also without the use of an active air-conditioning system.

The same analysis has been carried out also for the thermal zone 3 (*ground floor, north-exposed),* that, lacking the 2 penalizing characteristics of the thermal zone 2 (*south-exposure and radiated roof*), of course is contradistinguished by lower indoor temperatures. Thus, the whole summer working period is characterized by the best one comfort condition established by the EN 15251, *i.e. Category I guaranteed for the whole summer working period (*figure 4.6.27-b).

The adopted passive cooling solutions are so effective that, above all in the first hours of the day, over-cooling problems can happen. Really, this is not a problem, being enough, in order to raise the indoor temperature, acting on the control strategy of the passive cooling solutions, or, even more easily, opening the building windows.

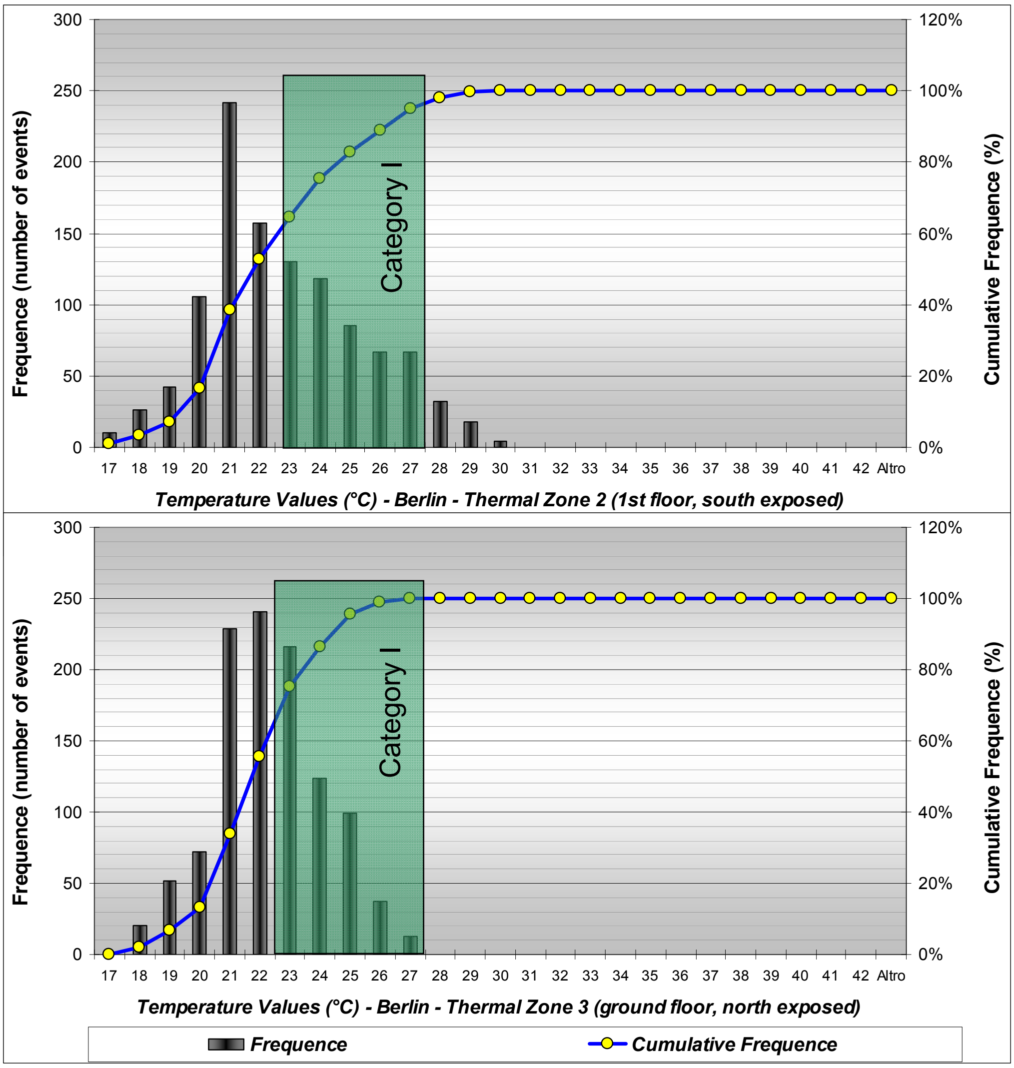


*Figure 4.6.27 – Office building modelled in Berlin. Summer working time (only diurnal hours): possible comfort conditions according to EN 1525.*

Therefore, also for Berlin, not only the EnEV 2007 targets have been achieved, but, above all, the EnOB requirement about the summer season has been fully satisfied.

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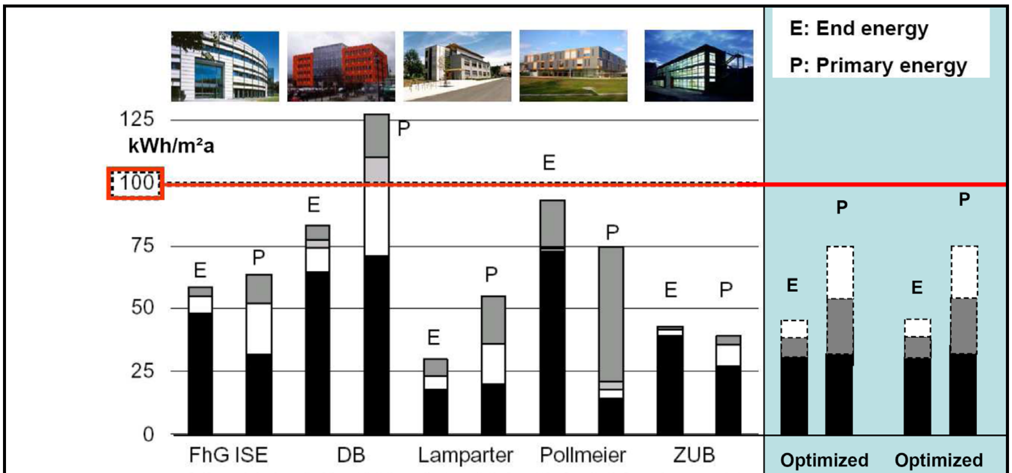
In figure 4.6.28, with reference to the EnOB demonstration program, the same analyses carried out for other office buildings funded by the German Government have been presented.

In particular, the simulated buildings for Stuttgart and Berlin, after the passive cooling optimization, have been located in the graph reported in the paper written by Günter et al. [44], referred to the descriptions of the energy performances achieved in several commercial buildings funded by the EnOB German program.

In both Stuttgart and Berlin, the energy optimized office building guarantees performances fully respectful of the EnOB targets. In particular, even if the *end* and *primary energy* requirements, to provide the winter indoor heating, are a little bit higher than the values calculated in the paragraph 4.6, also in this case these are lower than the limit of 40 kWh/m$^2$a.




| | FhG ISE | | DB | | Lamparter | | Pollmeier | | ZUB | | Optimized In Stuttgart | | Optimized In Berlin | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| lighting | 3,7 | 11,1 | 5,7 | 17,1 | 6,2 | 18,6 | 18,0 | 54,0 | 1,3 | 3,9 | | | | |
| cooling | 0,0 | 0,0 | 3,5 | 10,5 | 0,0 | 0,0 | 1,1 | 3,2 | 0,0 | 0,0 | 0.0 | 0.0 | 0.0 | 0.0 |
| ventilation | 6,8 | 20,4 | 9,6 | 28,8 | 5,5 | 16,5 | 1,0 | 3,0 | 2,7 | 8,1 | | | | |
| heating | 48,1 | 31,6 | 64,5 | 71,0 | 18,0 | 19,8 | 72,9 | 14,6 | 39,0 | 27,3 | 30.2 | 33.2 | 33.8 | 37.2 |
| **total** | **59** | **63** | **83** | **127** | **30** | **55** | **93** | **75** | **43** | **39** | | | | |

*Figure 4.6.28 – The performances of some office buildings monitored by the EnOB [44]*

Compared to the previously calculated results (*figures 4.6.4 and 4.6.6*), the winter heating thermal, end and primary energy requests are now higher because, in order to optimize the summer energy performances, cool paints have been provided for the external envelope surfaces (*roof and opaque wall*). Therefore, the high solar reflectance and the high infrared emissivity reduce the solar heat gains in wintertime too. Bellia *et al.* [45] reports the same results: in moderate climate conditions, the extra energy requests in wintertime, due to a cool painted building compared to a concrete exposed one, is around 2 - 3 kWh/m$^2$a.

With reference to figure 4.6.28, adding the mean values about the energy requirements for the building ventilation and artificial lighting (*calculated considering the 22 buildings of the EnOB program*), the simulated office building is, in both Stuttgart and Berlin, largely under the 100 kWh/m$^2$a. This limit is referred to the annual global primary energy demand such as identified by the EnOB program.

**Oslo**

As regards the main city of the Norway, at the same way of Stuttgart and Berlin, only a naturally ventilated building was simulated, being the Norwegian summer conditions well adapted to promote the passive cooling solutions. In this case too, the coupling of the most effective passive cooling strategies has been considered together to the cool-painting of the building envelope.

The analyses have been carried out, also in this case, with reference to the whole summer season, and the indoor temperature trends (figure 4.6.29) have been investigated to verify the achieved thermal comfort conditions (*EN 15251 technical Standard*).

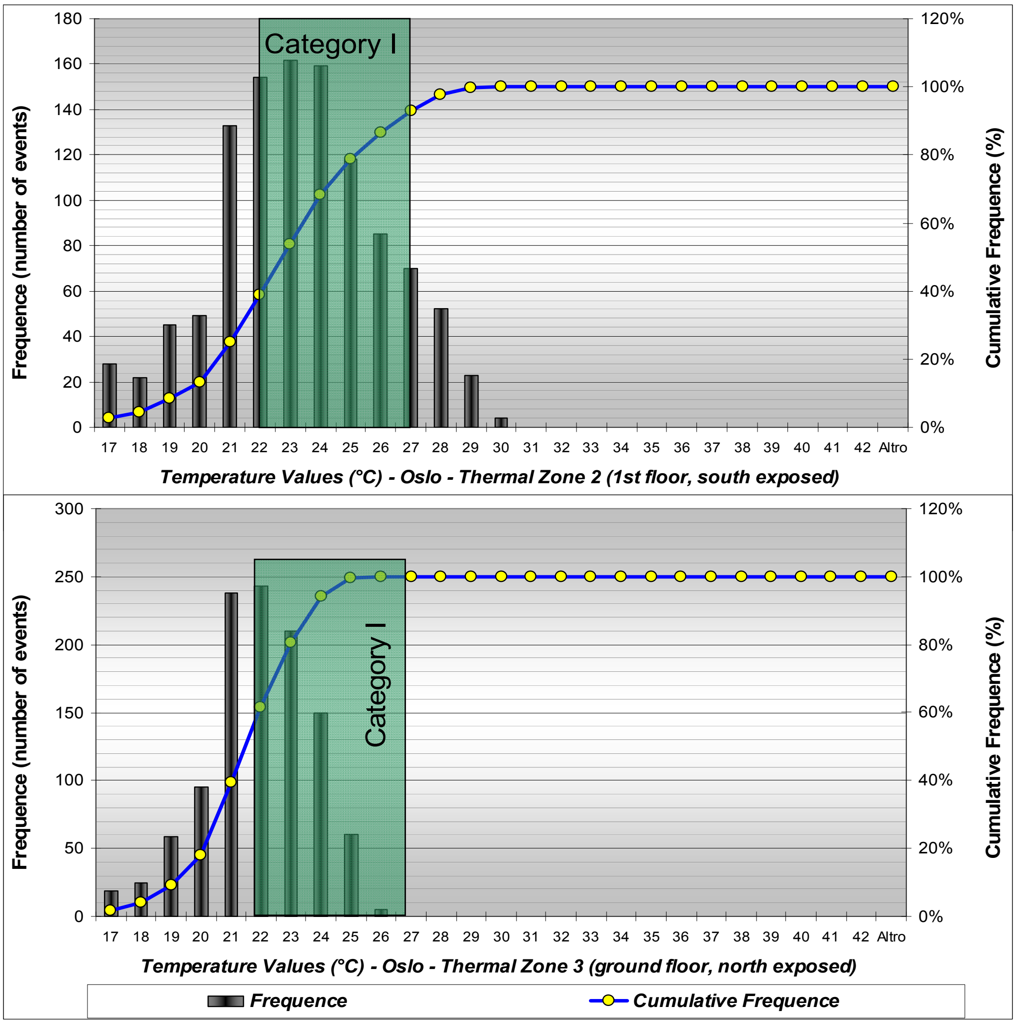



*Figure 4.6.29 – Office building modelled in Oslo. Summer working time (only diurnal hours): possible comfort conditions according to EN 15251.*

The passive cooling solution coupling is so defined (*table IV.11*):

- the thermal zone 1 (*first floor, north-exposed*) is interested by the coupling of roof movable insulation and earth tube ventilation during the diurnal time; in fact, as previously demonstrated, the cooling potential of the buried pipes, for this thermal zone, is higher than the nighttime ventilation;
- the thermal zone 2 (*first floor, south-exposed*) has been modelled considering, in the same time, the movable insulation of the roof and the nighttime ventilation. In this zone, characterized by an high thermal energy amount stored in the building mass, in fact, the proposed strategies induce a full energy discharging during the nighttime;

- the thermal zones 3 and 4 (ground floor) have been modelled considering the coupling of the nighttime ventilation and the artificial ventilation through the diurnal use of the earth-to-air heat exchanger. These zones are characterized by moderate heat gains, so that this coupling provides fresh air during the daytime and a well-adapted cooling of the building envelope (*by means of the nighttime ventilation*) during the nocturnal hours.
- at the same way of the building previously described, also in Oslo the corridors are simulated in different way; the upper one is cooled by roof movable insulation and nighttime ventilation, while the corridor at the ground floor is cooled by means of nighttime ventilation and EAHX diurnal ventilation.

With reference to the thermal comfort conditions, always according to the EN 15251 methods, for this climatic region the 3 classes are so identified:

- Category I: comfort temperature range included in the limit values 22.6 – 26.6 °C;
- Category II: comfort temperature range included in the limit values 21.6 – 26.6 °C;
- Category III: comfort range included in the limit values 20.6 – 28.6 °C.

In figure 4.6.29-a, the indoor air temperature trends are reported with reference to the thermal zone 2, also in this case more critical compared to the zone 3. Analyzing the indoor thermal levels, numerically calculated, the following results have been obtained:

- Category I (90% acceptation, ) is guaranteed for the 88% of summer working hours;
- Category II (80% acceptation) is guaranteed for the 95% of summer working hours;
- Category III (65% acceptation) is guaranteed for the 99% of summer working hours.

Therefore, in this case too, the results show a high potential of the passive cooling strategies, which provide indoor thermal conditions comfortable, without using any active air-conditioner.

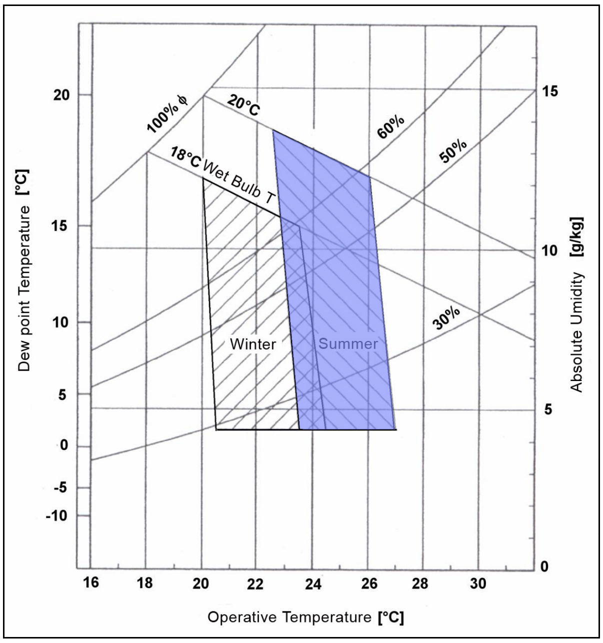



*Figure 4.6.30 – ASHRAE 2001: summer and winter thermal-hygrometric comfort conditions*

Even better performances are obtained considering the thermal zone 3 (figure 4.6.29-b), where, of course, there are less critical indoor conditions, because of the north-exposure and the direct contact between the building and the soil. In figure 4.6.29-b it is quite clear that 100% of summer working time is classified 100% comfort condition Category I: this result means that there is absolutely no need of an active cooling system.

Also considering an older thermal-hygrometric comfort standard (*the ASHRAE Standard 2001, figure 4.6.30*), the upper limit for the summer thermal comfort of 26.5 °C never is passed.

About possible over-cooling problems, during the first hours of the working day often indoor temperature levels lower than 22 °C have been calculated. Actually, this represents an event that can be easy solved, easily acting on the passive cooling regulation systems (*for example turning off the earth tube ventilation*) or, more simply, opening the window and so providing space natural ventilation.

## 4.7 DEEPENING: POTENTIAL OF THE GROUND COOLING FOR THE ITALIAN CLIMATES

In this paragraph, the performances achievable optimizing an earth-to-air heat exchanger are evaluated for winter and summer times, both with reference to Italian air-conditioned buildings and naturally ventilated ones. Starting from the generic configuration already studied, the target of this further deepening is the evaluation of the cooling and heating potential, of a ventilation system equipped with buried pipes, in moderate climates. In particular, this passive cooling solution, quite diffused in the central-Europe climates, could be usefully applied also in the Mediterranean countries, and, therefore, an investigation on the main boundary design conditions (*on varying the climates*) is necessary.

The varied boundary conditions are those related to the environmental context, the soil, the tube properties and connected behaviours of the airflow crossing it. Several control strategies have been simulated too, in order to propose the most suitable design criteria for each Italian climatic zone.

In particular, as already shown in the previous paragraphs, the electrical energy required by the fans represents a design critical aspect; it requires a very accurate evaluation, in order to achieve the maximum thermal exchange, limiting the pressure drops inside the buried pipes (and so the fan pressure head). Otherwise, the electric request can reduce, nullify or also make penalizing the use of EAHX.

Starting from an accepted model to predict the physical phenomena and thermal parameters occurring in this application, this paragraph presents a parametric analysis on varying the coefficients reported in the mathematical models, in particular acting on the boundary conditions that influence the effectiveness of the ground thermal recovery. Three different climate conditions were considered - Naples, Rome and Milan – completely expressive of the Italian climate.

The base case modelled (figure 4.7.1) building, is the same already proposed for the study referred to the European climates, being this fully respectful also of the present Italian energy laws. The main peculiarities, both about the building envelope and the technical systems (description in table IV.12) satisfy the Italian energy prescriptions.

Vertical walls, roof and basement have a thermal mass of 240 kg/m$^2$, 380 kg/m$^2$ and 412 kg/m$^2$ respectively, fully satisfying the legal measures as regards the summer overheating. The two-floor building globally is divided in 6 thermal zones. The window area results of 146 m$^2$ (around 20% of the whole vertical exposed surfaces = 722 m$^2$).

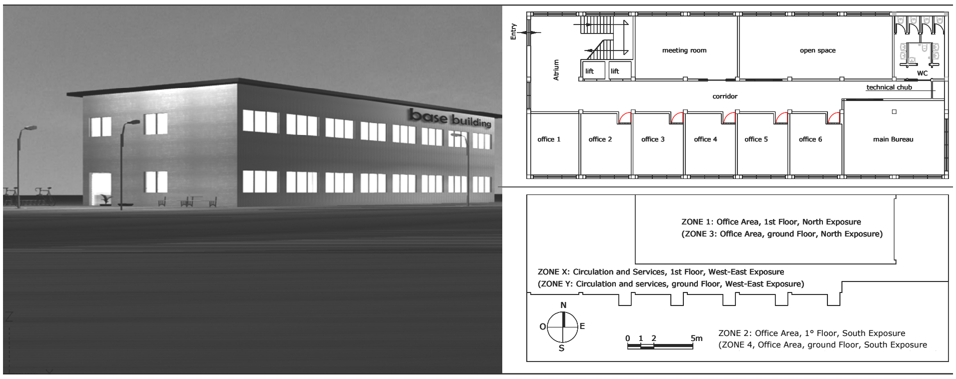



*Figure 4.7.1 - The modelled building; plan, thermal zones and volumetric scheme*

Table IV.12: Main boundary conditions of the office building modelled

| DIMENSIONS OF THE OFFICE BUILDING AND BOUNDARY DESIGN CONDITIONS | | | |
|---|---|---|---|
| Length (N-S direction) | 12.8 m | Width | 32.30 m |
| Height | 8.0 m (two floors) | Plan area and volume | 413 m$^2$ – 3304 m$^3$ |
| Surface to volume ratio | 0.47 m$^{-1}$ | Ventilation | 21.6 m$^3$/h person |
| $T_{SUMMER\text{-}SET\text{-}POINT}$ *(no cooling if no people)* | 26 °C | $T_{WINTER\text{-}SET\text{-}POINT}$ *(16 °C during no occupancy)* | 20 °C |
| $U_{WINDOW}$ | 1.1 W / m$^2$ K | $U_{VERTICAL\ OPAQUE\ STRUCTURES}$ | 0.29 W / m$^2$ K |
| $U_{ROOF}$ | 0.17 W / m$^2$ K | $U_{BASEMENT\ FLOOR}$ | 0.29 W / m$^2$ K |
| Cooling (fan coils + water chiller) | $\eta_{el}$ * SEER = 0.36 * 3.00 = 1.08 | Heating (fan coils + gas condensing heater) | $\eta_{OVERALL}$ = 0.76 |
| Electric energy cost | 0.20 € / kWh | Natural gas cost | 0.65 € / Nm$^3$ |
| ** A hourly scheduling is fixed with reference to occupancy, lighting, and other electric equipments installed* | | | |

## 4.7.1 THE PHYSICAL MODEL: DESCRIPTION AND INFLUENCING PARAMETERS

In the last years, several authors and scientists studied and interpreted the physical phenomena governing the ground heating/cooling applications. In particular, as regards the ground properties and thermal gradient under the soil external level, in this research, the Krarti's model has been adopted [34], where the author evaluates $T_{MEAN\ SURF}$ (*the mean soil surface temperature*) as reported in the equation 5:

$$T_{MEAN\,SURF} = \left(1/h_e\right)\cdot\left[h_r T_{MEAN\,AIR} - \varepsilon\Delta R + \beta S_m - 0.0168 h_s f b\left(1-RH\right)\right] \qquad (5)$$

As regards $h_e$ and $h_r$, both are related to the convective heat transfer coefficient of the soil surface, $h_s$, as described in the equations 6 and 7, with a = 103 Pa/°C.

$$h_e = h_s \cdot \left(1 + 0.0168af\right) \quad (6) \qquad\qquad h_r = h_s \cdot \left(1 + 0.0168\, a \cdot RH \cdot f\right) \quad (7)$$

The phase angle difference between the air and the soil surface temperature, the amplitude of the soil surface ($A_s$), and the related phase constant ($t_0$) are then determined, while, considering a soil characterized by a uniform thermal diffusivity, the equation (8) describes the ground temperature at any depth and on the time dependence.

$$T_{GROUND}(z,t) = T_{MEAN\,SURF} - A_s \exp\left[-z(\pi/365\alpha_s)^{1/2}\right] \cdot \cos\left\{(2\pi/365) \cdot \left[t - t_0 - (z/2)(365/\pi\alpha_s)^{1/2}\right]\right\} \quad (8)$$

As regards the heat transfer among the soil, the buried pipes and the air crossing these, the main descriptive equations are:

$$R_{convection} = 1/\left(2\pi r_1 L h_c\right) \quad (9)$$

$$R_{TB\,conduction} = \left[1/\left(2\pi L k_p\right)\right] \cdot \ln\left[\left(r_1 + r_2\right)/r_1\right] \quad (10)$$

$$R_{T\&S\,conduction} = \left[1/\left(2\pi L k_s\right)\right] \cdot \ln\left[\left(r_1 + r_2 + r_3\right)/\left(r_1 + r_2\right)\right] \quad (11)$$

$$h_c = Nu \cdot k_{air} / 2r_1 \quad (12) \qquad\qquad U_{tot} = 1/R_{tot} \quad (13)$$

Table IV.13: General nomenclature of the used symbols and units

| | | |
|---|---|---|
| T | temperature: MEAN SURF = mean soil surface, AIR = mean air | (°C) |
| $T_{GROUND}$ (z, t) | ground temperature at time t and depth z | (°C) |
| $h_s$ | convective heat transfer coefficient at the soil surface | (W/m$^2$ K) |
| ε | hemispherical emittance of the ground surface | - |
| ΔR | radiation constant (63 W/m$^2$) | (W/m$^2$) |
| $\alpha_s$ | soil thermal diffusivity | (m$^2$/s) |
| $\beta_s$ | soil absorption coefficient (= *1– soil albedo*) | - |
| $S_m$ | average solar radiation | (W/m$^2$) |
| *B* | constant (609 Pa) | (Pa) |
| *f* and Nu | fraction of evaporation rate and number of Nusselt | - |
| RH | air relative humidity | (%) |
| $A_s$ | amplitude of the soil surface temperature variation | (°C) |
| K | thermal conductivity (s = soil, air = outdoor air, p = tube) | (W/m K) |
| *t* and $t_0$ | time passed from the begin of the year and phase constant of the soil | (s, days) |
| Z | depth of the tube section center with respect to the soil surface | (m) |
| $h_c$ | convective heat transfer coefficient at the inner pipe surface | (W/m$^2$ K) |
| L | length of the pipe | (m) |
| $r_1$ and $r_2$ | Inner radius of the pipe and thickness of the pipe | (m) |
| $r_3$ | distance between the pipe center and the undisturbed soil | (m) |
| $U_{tot}$ | overall heat transfer coefficient | (W/m$^2$K) |
| $R_{tot}$ | total thermal resistance between the tube crossing air and the soil | (m$^2$K/W) |

A general nomenclature, with reference to all the symbols and units used in this section, is reported in table IV.13.

Lee and Strand [46] report a full description of the model. The correct evaluation of the ground temperature represents a design key-point. Figure 4.4.7 shows a satisfactory accordance between the ground temperature reported by Pfafferot *et al.* [30] for central Europe climates (graph A) and the EAXH outlet air temperature here evaluated adopting the physical model above described (graph B). *The cited figure is in the section 4.4.4 of this chapter.*

The good accordance of the central lines is evident, above all considering perfectly reasonable a limited difference, around 1.5 – 2°C, in the calculated parameters. As regards the earth-to-air heat exchanger, table IV.14 describes the starting design model.

Table IV.14: Base earth tube model: design characteristics

| | Whole Office Building | | |
|---|---|---|---|
| | Zones 1 & 3 | Zones 2 & 4 | Zones Y & X |
| Design volume airflow rate (each zone) | 2 x 0.096 $m^3/s$ | 2 x 0.144 $m^3/s$ | 2 x 0.088 $m^3/s$ |
| Design airflow (building) and EAHX type | 2361 $m^3/h$ (e.g. 0.66 $m^3/s$) - Fan on exhaust position | | |
| Tube depth and tube length | Depth =3.00 m; length = 50 m (horiz.) + 5 m (vert.) | | |
| Tube material and thickness | PVC: k = 0.16 W/(mK); thickness = 5mm | | |
| Pipe radius and Soil condition | 165 mm – Heavy and damp soil | | |
| Buried pipe: pressure drop and air speed | 2 Pa/m - 7.7 m/s | | |
| Building ducts: pressure drop and air speed | 2 Pa/m – 4 ÷ 6 m/s | | |
| Fan electrical absorbed power | 1250 W | | |

In the followings, with reference to the Krarti's physical model briefly above described, the incidence of the main parameters influencing the EAHX performances is singularly evaluated and then numerically quantified.

### 4.7.2 Earth tube cooling potential: parametric analysis regarding the design options

#### *a) Climate and Soil compostion influence*

The earth tube achievable performances are strongly influenced by the weather data, so that each singular application requires attention to the specific climatic conditions. The depth of the buried pipes is to be selected depending on the purpose (*ventilation air pre-heating or cooling*) and with reference to the specific climate.

The maximum cooling potential of earth tubes is not achieved in very hot/humid climates, being the ground, under reasonable depth, not enough cool during the summer months, so that the cooling potential results quite limited.

The soil typologies numbered (1 – 4) in table IV.15 have been considered in a first group of simulations; the results are reported in figure 4.7.2.

With respect to the base case (*without EAHX*), even the less apt kind of ground (dry and heavy), anyway determines savings (figure 4.7.2-A) around 25% (*Naples*), 31% (*Rome*), 38%

(*Milan*). In this last city, the highest cooling potential has been obtained; this because the ground free cooling effect is strongly related to the coolness of the winter season: *in cool regions, the time constant of the ground, at the design depth, makes the soil particularly apt as cool sink in summertime.*

Generally, high water content in the soil improves the EAHX performances (Guither *et al.* [47]), being the wet ground more conductive compared to the dry one (table IV.15). Even if the ground composition is an aspect related to the location of the building, during the installation of the earth tube, after the ground excavation and the pipe deposition, the backfilling could be executed adopting a material even different with respect to the original ground before removed. Peat and dry soil should be avoided.

Table IV.15: Thermal properties and physical behaviours of the soil

| *Albedo corresponds to: 0.1 wet soil, 0.2 moderate soil, 0.3 dry soil.* | Dry density *kg / m³* | Conductivity *W / (m K)* | Diffusivity *m² / day* |
|---|---|---|---|
| **Soil** | | | |
| 1. Heavy clay (15% water) | 1925 | 1.4 ÷ 1.9 | 0.042 ÷ 0.061 |
| 2. Heavy clay (5% water) | 1925 | 1.0 ÷ 1.4 | 0.047 ÷ 0.061 |
| Light clay (15% water) | 1285 | 0.7 ÷ 1.0 | 0.047 ÷ 0.055 |
| Light clay (5% water) | 1285 | 0.5 ÷ 0.9 | 0.050 ÷ 0.056 |
| Heavy sand (15% water) | 1925 | 2.8 ÷ 3.8 | 0.084 ÷ 0.110 |
| Heavy sand (5% water) | 1925 | 2.1 ÷ 2.3 | 0.093 ÷ 0.140 |
| 3. Light sand (15% water) | 1285 | 1.0 ÷ 2.1 | 0.047 ÷ 0.093 |
| 4. Light sand (5% water) | 1285 | 0.9 ÷ 1.9 | 0.055 ÷ 0.120 |

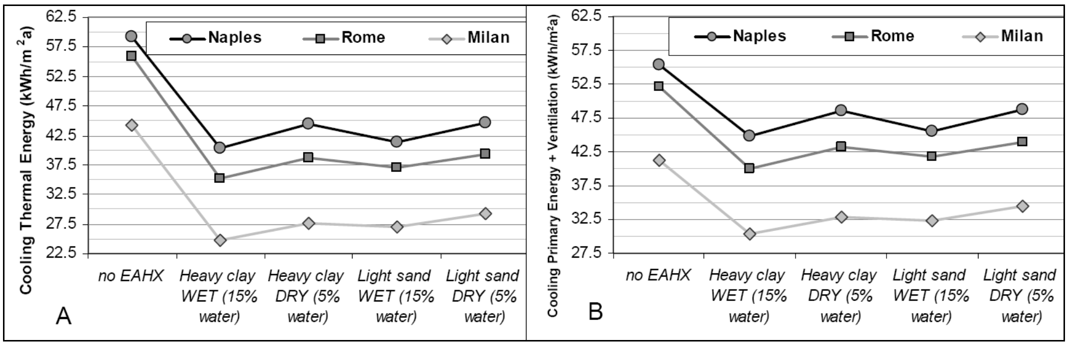



*Figure 4.7.2 – Influence of the ground typology on the summer cooling energy request*

As regards the material surrounding the tube, a good contact between soil and pipes has to be ensured, by means of compacted clay or sand. As reported in several literature sources, the wet light sand is strongly apt, not only in order to improve the thermal exchange, but also for a correct tube installation, permitting a well modelable plan for the pipe positioning. This ground type shows the best performances.

In terms of primary energy (figure 4.7.2-B), the results are less satisfactory because of the fan demanded electric energy. The obtained results confirm that the soil material affects less the cooling potential compared to the ground wetness; in fact, the water content growth (*from 5% to 15%*) induces meanly an increase around 30% in the material thermal conductivity.

From the equations above reported, the relevant role of climate and ground composition on the earth tube performances can be inferred.

Radiation absorption coefficient, amplitude of the soil surface temperature variations, soil diffusivity, conductivity and phase constant act on the underground temperature profile (*equation 8*) and on the tube thermal level (*equation 11*).

*b)* INFLUENCE OF THE TUBE MATERIAL

The pipe material appears in the equations 10, 11, 13 and acts on the energy heat transfer between the ground and the air crossing the tube. In particular, neglecting the transient phenomena interesting the tube (*lightweight and, therefore, marginal thermal capacity*), the material conductivity and thickness are the main responsible of the transferred energy amount.

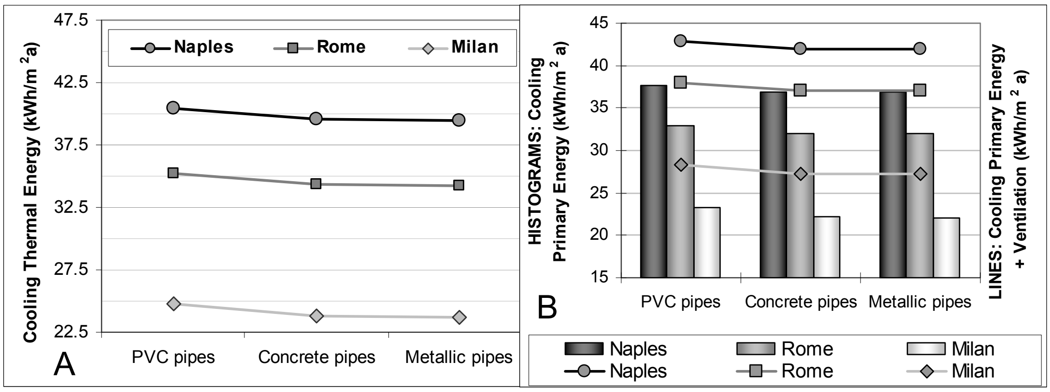



*Figure 4.7.3 – Influence of the buried pipes material on the summer cooling energy request*

Several literature sources show that concrete, plastic or metallic pipes induce, globally, thermal performances not so different (*figure 4.7.3*); thus, the selection of the tube material becomes connected to other necessities, among which costs (*e.g. the iron tubes are much more expensive*), durability, maintenance and design complexity.

Considering the small thicknesses of the tubes (*6 mm PVC, 7 cm concrete, 7 mm for the metallic one*), despite the very different thermal conductivity values, the tube material does not influence, at the right depth and for usual length, significantly the heat exchange. Thus, even PVC tubes ($\lambda = 0.16$ *W/mK*) guarantee substantially the same results of metallic pipes ($\lambda = 17$ *W/mK*). All the results are reported in figure 4.7.3.

The concrete tubes require a further internal coating, in order to avoid possible Radon infiltrations; other critical aspects related to the use of a concrete tube are the joints of the various segments. Even if a correct and frequent cleaning of the tubes often guarantees good hygienic conditions (also after many years), usually pipes with an antimicrobial inner layer are recommended, to avoid the growth of moulds and bacteria.

Condensation discharge and easy access in critical points are other design key aspects.

*c)* INFLUENCE OF THE BURIED PIPE LENGTH

The thermal exchange among the ground, the tube and the air mass crossing it increases when the length of the buried pipes is maximized. In figure 4.7.4, the effects of various lengths on the outlet air temperature are represented, together with the trend of the ambient air thermal level.

As shown in the equations 9, 10 and 11, the tube length influences the overall thermal exchange between the ground and the airflow crossing the pipes.

From diagrams a), b) and c), it is quite clear that lengths around 10 meters are completely unsatisfactory while, for all the considered climates, the difference in the temperature of the air leaving the tube is not so significant over 50 meters; the same results have been found by Lee and Strand [46].

If passing from 10 meters to 50 meters the outlet air temperature difference is around 4 °C (Naples), 5 °C (Rome), 6 °C (Milan), instead, raising of further 40 meters the tube length (90 meters) the achievable temperature reduction is very contained, meanly 1.5 °C for the 3 considered cities. Even if the airflow within the pipes is very correctly designed (→ *the pressure drops are minimized*), anyway a temperature reduction less than 2 °C cannot justify the higher fan absorbed energy, necessary to compensate the higher tube length and pressure drops.

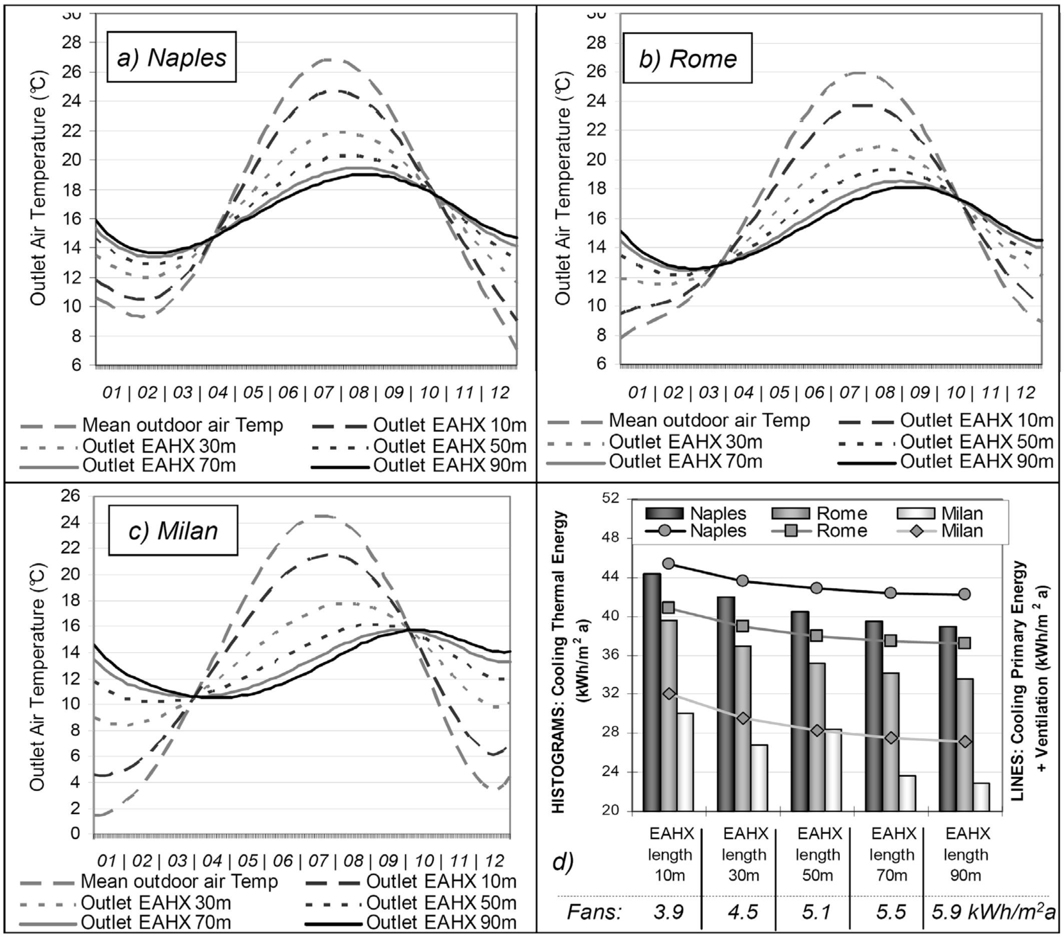



*Figure 4.7.4 – Influence of the tube length on the outlet air temperature (a,b,c) and on the summer cooling energy request (d)*

In other words, the temperature decrease, after a certain length connected to the soil conditions, has an asymptotic trend, while the pressure drops (*and so the required fan pressure head*) maintains a linear increase. As shown in the graphs a), b) and c), for the climatic conditions here considered, lengths around 50 meters are preferable.

Even considering the electric energy absorbed by the EAHX fans, an earth tube of 50 meters provides savings, compared to the building without geothermal exchange, around 12.5 kWh/m$^2$a (*Naples, base case → 55.3 kWh/m$^2$a),* 14.2 kWh/m$^2$a (*Rome, b.c. → 52.2 kWh/m$^2$a*), 13.0 kWh/m$^2$a (*Milan, b.c. → 41.3 kWh/m$^2$a*), in terms of active cooling primary energy requests.

### *d) INFLUENCE OF THE TUBE DEPTH*

In figure 4.4.7 (*in the section 4.4.4 of this chapter*), reporting the study of Pfafferot *et al.* [30], it can be seen that the thermal level trend induces the optimal use of an earth-to-air heat exchanger at around -8 m. In fact, a depth ensuring a time lag effect of around 6 months represents the best solution, so that (*figure 4.4.7, - 8 m curve*) the ground temperature, in summer at the pipe depth, is lower than in winter. In this way, the thermal exchange is more effective, in both the seasons, with respect to the depth characterized by a ground constant temperature throughout the year.

In typical applications, the ground moving costs impose a tube placement at -2 ÷ -5 meters. On varying the tube depth, the earth moving costs increase, so that, even if raising the depth induces better thermal performances, the excavation extra-costs should be correctly evaluated.

In figure 4.7.5 it is shown that, while a much better thermal exchange characterizes the depth of -3 m with respect to the cooling effect obtainable at -1 m, a further deepness (-4 m) causes only a low increase of the thermal exchange.

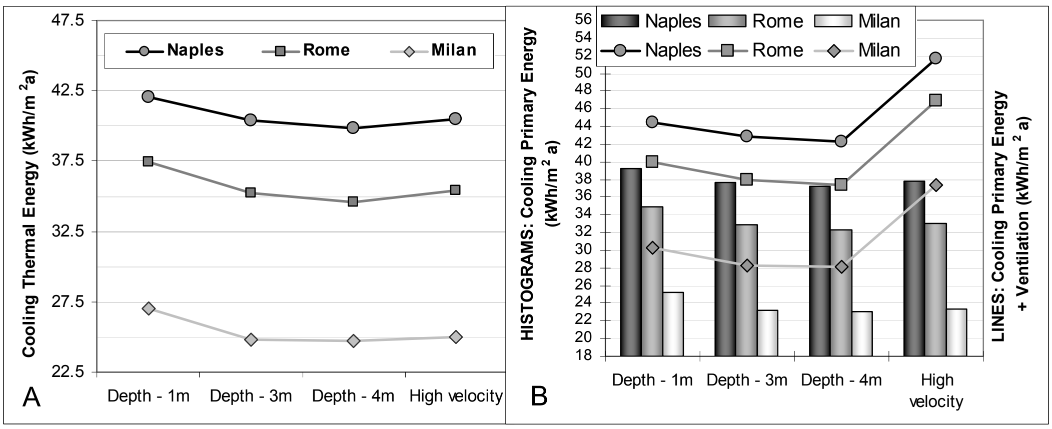



*Figure 4.7.5 – Influence of the depth and air motion inside the pipes*

Thus, if the excavation costs are low (*unleashed soils, i.e. around 2.4 €/m$^3$*), a deeper tube placement can be convenient, while, in presence of hard rock or tile (*earth moving costs of* *around 32 €/m³*), a depth of 2.5 ÷ 3 meters determines the best compromise between investment costs and achievable energy performances. The influence of the tube depth appears in the equation 8.

In the same figure 4.4.5, also a different air motion inside the pipes has been considered (high velocity). The considered reference air velocity inside the buried pipes is around 7.7 m/s (*base boundary conditions reported in table IV.14*): this determines a constant pressure drop of 2 Pa/m. Raising the air velocity to 20 m/s (*so providing littler tube radius*), a reduction of the pipe costs is achieved, but two penalizing effects occur:

- the specific pressure drop rises, in the earth tube, at 19 Pa/m and, globally, the fans require 2600 W (*base case → 1250 W*);
- the heat exchange is interested by a significant reduction due to the minor thermal exchange surface (*higher velocity and unvaried flow rate → lower pipe radius*).

As already expressed in the introduction, the ground heating/cooling induces a thermal recovery from the soil temperature (*thermal energy recovery, i.e. low exergetic value*), spending a certain amount of mechanical energy (*electric → high exergetic value*). Considering the different energy quality (*and so the conversion in primary energy*), the adoption of an earth tube is convenient only if high differences between the ventilation energy required and the thermal savings are obtained. Thus, high air velocity (*that implies higher fan*) is absolutely not convenient.

About the thermal energy recovery penalization, for the 3 cities considered, the reduction achieved rising the air speed (*lower tube section → lower thermal exchange area, even if the convection heat transfer rises*) is not relevant (*meanly around 2.1 kWh/m²a*). Contrariwise, in terms of primary energy required by the fans, the penalizing effect is significant, passing from 5.1 kWh/m²a to 11.5 kWh/m²a, considering a summer working period (*5 days/week*) of 67 days and 15 hours/day.

### *e) INFLUENCE OF THE FAN POSITION AND AIRFLOW RATE*

An earth tube heat exchanger, depending on the complexity of the air ducts (*with reference to both the buried pipes and the air channels inside the building*) can adopt intake fans, exhaust ones or both. Inlet fans are normally useful to guarantee indoor air overpressure in winter, in order to limit/avoid ambient air infiltrations. In summer, indoor overpressure is not always necessary, so that inlet or outlet fan can be used. The exclusively adoption of outlet fans requires a careful sizing of the ventilation system, so that the room extraction valves guarantee the correct airflow rates in all the building zones.

In this paragraph, being a deepening regarding the ground cooling for Italian climates, two different kinds of air ventilation solutions have been considered: intake ventilation and exhaust ventilation.

The air temperature growth, due to the fan crossing, depends on shape and rotational speed of the fan blades; in typical air-conditioning applications, the air $\Delta T$ due to the fan crossing is in the range 1 ÷ 2 °C. In figure 4.7.6, the influence of the fan position is reported.

Leaving the same ventilation airflow rate (*i.e. 1 ACH*), the building cooling thermal requests result around 0.4 kWh/m$^2$a higher when intake fan is used.

Considering a building provided with an active cooling system, this extra-cost is very contained at the typical costs of the electric energy (table IV.12).

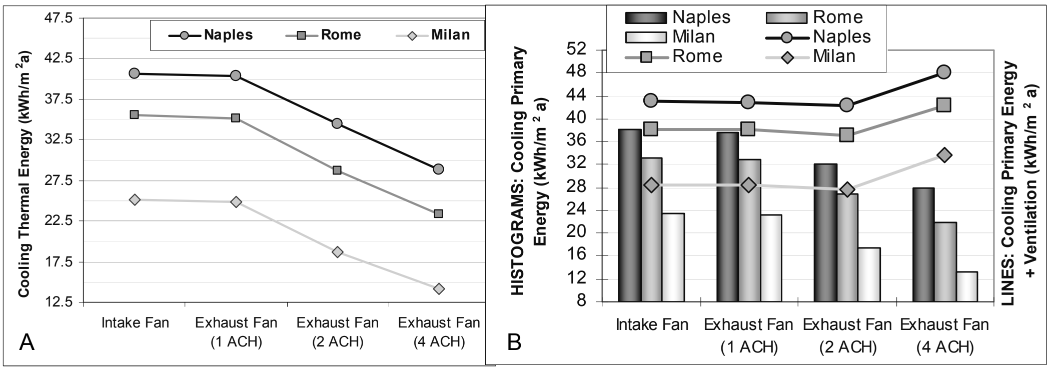



*Figure 4.7.6 – Influence of the fan position and airflow rate*

In addition, different amounts of ventilation air supplied into the building have been considered (*figure 4.7.6*); in particular, further 2 different sizes of the EAHX have been simulated, providing 2 (*44 m$^3$/h per person*) and 4 ACH (*88 m$^3$/h per person*) respectively. Of course, in the 3 climates considered, raising the EAHX supplied air amount, the achievable energy savings become very significant. In fact, in summer, independently on climate, ground composition, tube length, depth or material, the underground soil temperature is lower than the indoor comfort temperature (*in the range 26°C ÷ 30 °C according to the various thermal comfort criteria*). Thus, using an earth tube, the growth of the ventilation air amount always determines a reduction of the active cooling requests.

In terms of primary energy, the results are of course very different. In fact, although a very correct design of the system induces no higher specific pressure drops (*if the air velocity, despite the higher airflow rate, is maintained constant acting on the tube section*), the fan electric power grows because of the airflow increase.

$$Fan\ Power = \left(Volumetric\ flow rate \cdot Pressure head\right) / \eta_{FAN} \qquad (14)$$

In terms of primary energy, the electricity plays a great role (*conversion factor = 2.8)* as regards the overall balance. Thus, even if the thermal energy savings are noticeable, globally, for the three considered climates, the same performances have been obtained adopting 1 or 2 ACH. A further growth of the airflow amount (*i.e. 4 ACH*) determines a further reduction of the active thermal energy required (*figure 4.7.6-A*), but also a significant growth of the overall primary energy use (*figure 4.7.6-B*).

Considering equivalent the performances of the ventilation characterized by 1 or 2 ACH is wrong. This occurs because higher airflow rates are strongly penalizing if also the wintertime is considered. In fact, in winter the EAHX ventilation can be used as pre-heating strategy, because the heat exchange between the soil and the outdoor air makes the ventilation less penalizing (*guarantying a pre-heating effect*): *less penalizing but anyway thermodynamically penalizing*! So, even with the best design, the air coming from the buried tube is always at a temperature lower than the indoor set point (≈ 20°C). Therefore, contrariwise to the summer, in winter, any growth of the supplied air over the necessary air-change induces an increase of the ventilation thermal load. Moreover, other penalizations derive from higher fan needs.

### *f) Influence of the Earth tube control strategy*

Five different control strategies have been considered, always starting from the base case described in table IV.14. The daily working period of the earth to air heat exchanger has been varied, such as described in table IV.16 and all the results are reported in figure 4.7.7, in terms of thermal energy requirements (*4.7.7-A*), and primary energy with and without the fan energy demands (*4.7.7-B*).

Table IV.16: Analysed control strategies for the EAHX working

| | *Control 1* | *Control 2* | *Control 3* | *Control 4* | *Control 5* |
|---|---|---|---|---|---|
| *Working period 1*<br>*Working period 2*<br>*Working period 3* | *16/06÷15/09* | *16/06 ÷15/09* | *16/06÷15/09* | *16/06÷15/09* | *16/06÷30/06*<br>*01.07÷31/08*<br>*01/09÷15/09* |
| | *5 days/week* | | | | |
| *Start-up & Power-off 1* | *5.00 – 20.00 (15 hours/24)* | *6.00 –19.00 (13 hours/24)* | *8.00 – 19.00 (11 hours/24)* | *9.30 – 18.30 (9 hours/24)* | *5.00 – 20.00 (15 hours/24)* |
| *Start-up & Power-off 2* | | | | | *8.00 – 19.00 (11 hours/24)* |
| *Start-up & Power-off 3* | | | | | *5.00 – 20.00 (15 hours/24)* |

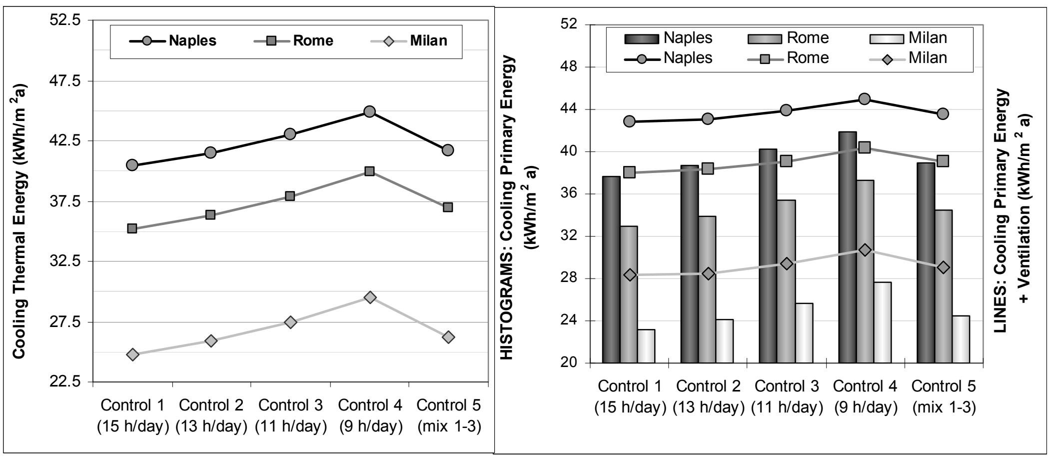



*Figure 4.7.7 – Influence of the earth tube control strategy*

It is quite clear that, despite the fan energy requirements, the most convenient solution is the use of the earth tube ventilation during all the diurnal hours, and it is verified for all the considered climates. Thus, the first strategy represents the best control solution (*control strategy 1, e.g. 15 hours/day*), with a cooling primary energy request (*lines in figure 4.7.7-B*) around:

- Naples: 42.8 kWh/$m^2$a (*55.3 kWh/$m^2$a without the earth tube*);
- Rome: 38.0 kWh/$m^2$a (*52.2 kWh/$m^2$a without the earth tube*);
- Milan: 28.3 kWh/$m^2$a (*41.3 kWh/$m^2$a without the earth tube*).

This occurs despite higher electric energy requirements (*converted in primary energy: control strategy 1 → 5.1 kWh/$m^2$a, 2 → 4.4 kWh/$m^2$a, 3 → 3.7 kWh/$m^2$a, 4 → 3.1 kWh/$m^2$a, 5 → 4.6 kWh/$m^2$a*)

### 4.7.3 EARTH TUBE OPTIMIZATION AND COUPLING TO OTHER PASSIVE COOLING SOLUTION

The previous parametric studies are the basis for an optimization of the earth tube, coupling, as regards the summertime, this passive cooling technique with another passive strategy - the nighttime ventilation - in order to cool the building shell during the nocturnal hours. The effectiveness of this coupled adoption of different passive cooling strategies has been already shown in the previous pages of this chapter as regards several European climates.

The base idea consists in the adoption of two different strategies, one acting during the night (*in order to cool the building shell and "activate" its mass*) and one during the day (*supplying fresh air into the building*).

With reference to the earth-to-air heat exchanger, the final system is characterized by depth = -3 m, length = 50 m, material = PVC, airflow = 3300 $m^3$/h (*1 ACH*), air speed = 7.7 m/s, exhaust fan adoption, control strategy 1 (*summer → 15 hours/day*).

#### *a) SUMMERTIME*

Until now, the building simulated has not been provided with window shadings, because the aim of the analyses was the investigation of the EAHX potential in reducing the thermal load in summertime. In the next simulations, also a window shading system (*outdoor blinds, horizontal slats*) has been considered.

In figure 4.7.8 the energy requests for summer cooling are represented, in terms of thermal energy needs (fig. 4.7.8-A) and primary energy demands, with and without the fan electric requests (figure 4.7.8-B).

Reading the curve slopes (*figure 4.7.8*), the use of the EAXH, alone, seems more effective than the adoption of window shadings and nighttime free cooling in reducing the summer thermal loads.

Adopting for the base case building all the 3 passive strategies, the reduction of the active cooling needs becomes quite significant:

- Naples: thermal request = 33 kWh/$m^2$a (*base case = 59 kWh/$m^2$a → - 44%*);
- Rome: thermal request = 28 kWh/$m^2$a; (*base case = 56 kWh/$m^2$a → - 50%*);
- Milan: thermal request = 17 kWh/$m^2$a; (*base case = 44 kWh/$m^2$a → - 61%*).

The new Italian building energy regulation (*Legislative Decree 192/2005, Presidential Decree 59/2009*) imposes limits to the building envelope thermal energy needs in summertime:

- climatic zones A and B → maximum value = 40 kWh/m$^2$a;
- climatic zones C, D, E and F → maximum value = 30 kWh/m$^2$a.

After the adoption of the 3 passive cooling solution, the building respects the legal value in Rome (*28 kWh/m$^2$a < 30 kWh/m$^2$a*) and Milan (*17 kWh/m$^2$a < 30 kWh/m$^2$a*), while, for Naples, the considered overheating reduction strategies are not yet enough (*33 kWh/m$^2$a > 30 kWh/m$^2$a*).

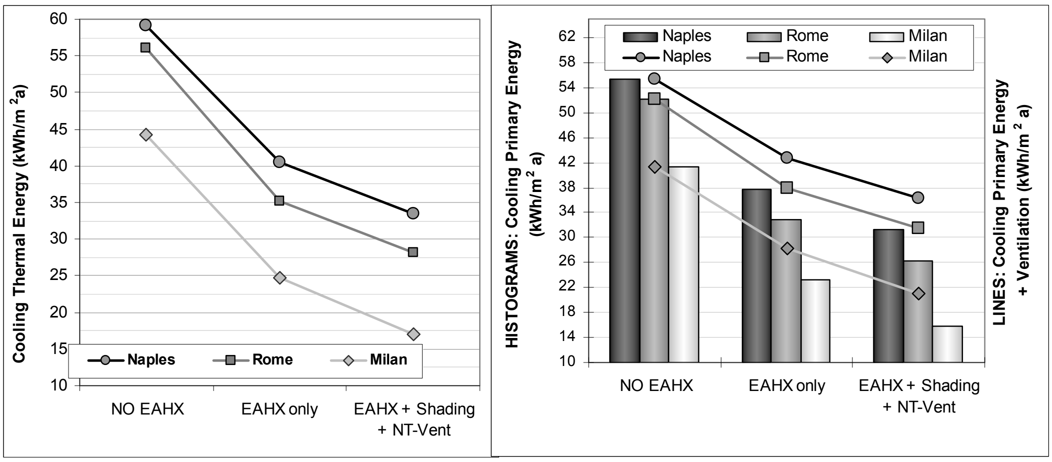



*Figure 4.7.8 – Summer energy performances obtained coupling EAHX ventilation, window shadings and nighttime ventilation*

Anyway, also in hot/warm climates the earth cooling contribute is satisfactory, even if the use of air-conditioners cannot be nullified. These results are confirmed also by Al-Ajmi *et al.* [48].

### b) VENTILATION SYSTEM AND EARTH TUBE: ENERGY EFFICIENCY RATIOS

With reference to each climate, the EAHX energy efficiency ratios (*EER*) have been evaluated. The EERs have been calculated both in nominal conditions (*$EER_{DESIGN}$*) and with reference to the whole summer period (*SEER, seasonal*):

- $EER_{DESIGN}$ (*cooling design day*) → calculated considering the instantaneous heat recovered from the ground (loss) with respect to the fan power (*equation 3*);
- SEER (*whole summer season*) → calculated comparing the seasonal energy recovered from the ground and the EAHX fan energy requests (*equation 4*).

These two different energy efficiency ratios have been calculated both considering the fan energy required for the whole ventilation system, and with reference to the only buried pipe (*pressure drops ≈ 1/3 compared to the whole ventilation plant*).

The ambient summer temperatures in design conditions have been selected from the climatic data ASHRAE 0.4% DB-MCWB: Naples 33.2 °C, Rome 30.8 °C, Milan 31.6 °C. Milan presents summer design conditions more critical than Rome (*according also to UNI*

*10339*). The results are reported in table IV.17. The cited equations 3 and 4, even if already reported previously, are here again proposed.

$$EER_{DESIGN} = \dot{m} \cdot c \cdot \left(T_{external-air} - T_{earth-tube-air}\right) / \, Fan_{\ electric\ request} = kW_{thermal} / \, kW_{electric} \qquad (3)$$

$$SEER = \left(Q_{ground\ recovered}\right) / \, seasonal\ Fan_{\ electric\ request} = kWh_{thermal} / \, kWh_{electric} \qquad (4)$$

Table IV.17: Ventilation system and EAHX coefficients of performance

| | | NAPLES | ROME | MILAN |
|---|---|---|---|---|
| $EER_{TOTAL}$ | ($Wh_{THERMAL}$ / $Wh_{ELECTRIC}$) | 10.4 | 10 | 12.9 |
| $EER_{EAHX\text{-}ONLY}$ | ($W_{THERMAL}$ / $W_{ELECTRIC}$) | 25.3 | 24.3 | 31.4 |
| $SEER_{TOTAL}$ | ($Wh_{THERMAL}$ / $Wh_{ELECTRIC}$) | 7.5 | 8.9 | 12.4 |
| $SEER_{EAHX\text{-}ONLY}$ | ($W_{THERMAL}$ / $W_{ELECTRIC}$) | 18.3 | 21.8 | 30.2 |

The highest energy efficiency ratios are obtained where the winter climatic conditions are colder (*so that, in summertime, the ground is cooler because of the soil phase constant effect*). The values are coherent with the experimental measurements reported in [30].

Also considering the whole ventilation system seasonal SEER, the performances are 2.5 – 4.0 times higher than a quite efficient cooling system (*typical SEER around 3.0 $kWh_{THERMAL}$ / $kWh_{ELECTRIC}$* ).

### *c) WINTERTIME*

In figure 4.7.9 the EAHX outdoor air preheating potential is represented; the graph shows that, in moderate climates (*Naples and Rome*) the external air can be heated around 4 °C, while in cold climates (*Milan*), the temperature growth is higher (≈ 10 °C).

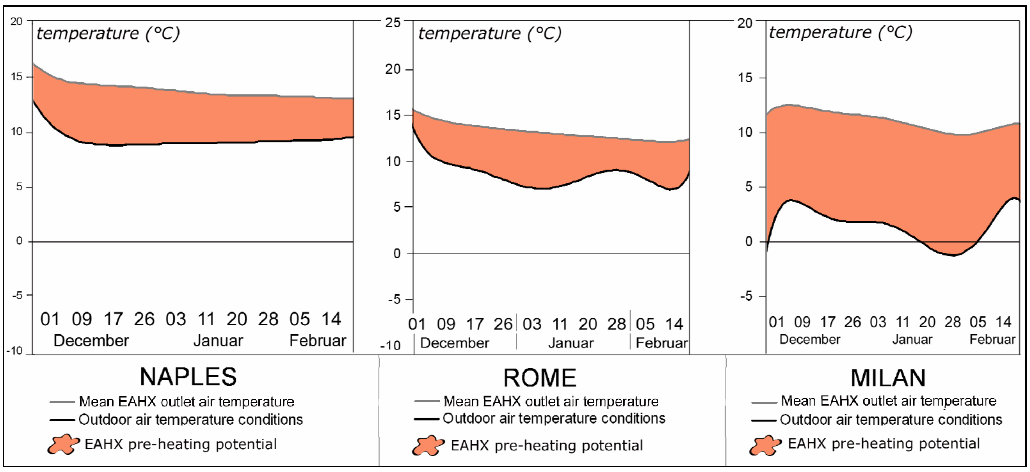



*Figure 4.7.9– Winter (December, January and ½ February) outdoor air and EAHX outlet air temperature*

The base building, without earth tube, has a thermal energy need, in wintertime, around 6.4 $kWh/m^2a$ (*Naples*), 7.5 $kWh/m^2a$ (*Rome*), 32.3 $kWh/m^2a$ (*Milan*); these values are very low because of the high thermal resistance of the building shell and the high endogenous heat gain of this case-study.

About the EAHX energy benefits, considering a working period of 9 hours/day (*8.00 ÷ 13.00 and 15.00 ÷ 19.00*) for 108 days (5 days/week), in the period 1 November ÷ 31 March, through dynamic energy simulations it has been calculated that:

- Naples: thermal potential reduction around 1.9 $kWh/m^2a$ → *2.5 $kWh/m^2a$ in terms of primary energy also computing the heating system efficiency.* Evaluating a fan consumption of 4.9 $kWh/m^2a_{PRIMARY}$, then the energy balance is negative (*-2.4 $kWh/m^2a$*), so the use of the EAHX is not convenient;
- Rome: thermal potential reduction of about 2.1 $kWh/m^2a$ → *2.8 $kWh/m^2a$ in terms of primary energy also computing the heating system efficiency*; the primary energy balance is negative also in this case (*-2.1 $kWh/m^2a$*);
- Milan: thermal potential reduction of about 5.2 $kWh/m^2a$ → *6.9 $kWh/m^2a_{PRIMARY}$*. Considering a fan consumption of 4.9 $kWh/m^2a_{PRIMARY}$, the energy balance is positive (+ *2.0 $kWh/m^2a$*) → the EAHX results apt also in wintertime.

*Thus, in winter too, the earth tube shows greater efficiency in cold climates (Milan).*

### 4.7.4 SUMMER CONDITION IN A NATURALLY VENTILATED BUILDING

Until now, all the energy evaluations have been carried out considering a full-conditioned building, and evaluating the active cooling savings achievable recurring to an earth tube. According to another approach, typical for the middle Europe climates, in this section the EAHX benefits have been estimated considering a naturally ventilated building: the indoor temperature free runs and the thermal conditions have been evaluated adopting the methods reported in the EN Standard 15251 as regards the adaptive thermal comfort criteria (*figure 4.7.10, table IV.18, equations 15 and 16*). *The calculations, simplified and not exhaustive (i.e. the mean outdoor temperature of July has been considered for the whole summer season), should be intended only as suggestion.*

In this analysis, the building performances have been evaluated analyzing each different thermal zone (*figure 4.7.1*), because, in the temperature evaluation inside a naturally ventilated building (*i.e no use of air-conditioning systems*), the room exposure plays a great role. For this reason, two different thermal zones have been considered:

- thermal zone 2 → 1st floor, south-exposed;
- thermal zone 3 → ground floor, north-exposed.

These different indoor spaces have been selected because of representative of the whole building variability, being, respectively, the most and less critical one. The indoor temperature conditions have been evaluated diagramming the temperature cumulative frequencies (*considering only the diurnal time and the summer working days*).

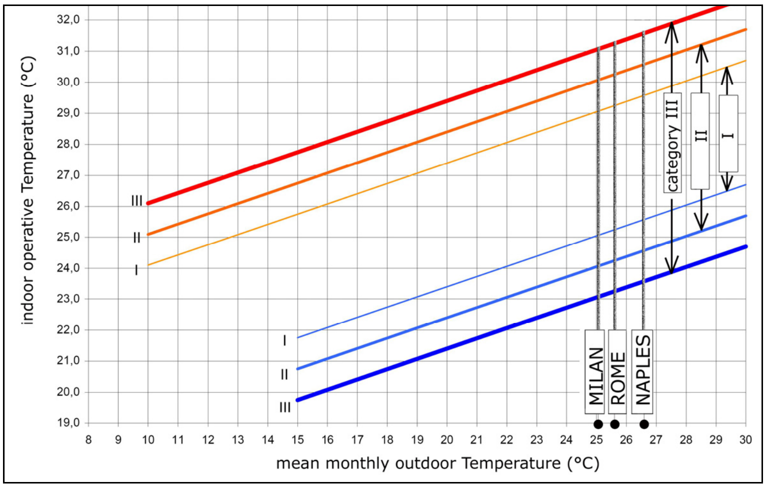



*Figure 4.7.10 – EN 15251: adaptive temperature limits in buildings without active cooling system*

$$\text{upper limit} \rightarrow T_{\text{INDOOR MAX}} = 0.33 \cdot T_{\text{OUTDOOR MEAN MONTHLY}} + 18.8 + X \quad (15)$$

$$\text{lower limit} \rightarrow T_{\text{INDOOR MIN}} = 0.33 \cdot T_{\text{OUTDOOR MEAN MONTHLY}} + 18.8 - X \quad (16)$$

where:

- Category 1 (90% acceptation, 10% dissatisfied) → X = 2;
- Category 2 (80% acceptation, 20% dissatisfied) → X = 3;
- Category 3 (65% acceptation, 35% dissatisfied) → X = 4.

Table IV.18: Definition of the comfort class temperature limits

| Comfort Conditions EN 15251 | Category I (90% acceptation) | Category II (80% acceptation) | Category III (65% acceptation) |
|---|---|---|---|
| Naples (*mean July T = ca. 26.7 °C*) | 25.6 – 29.6 °C | 24.6 – 30.6 °C | 23.6 – 31.6 °C |
| Rome (*mean July T = ca. 25.7 °C*) | 25.3 – 29.3 °C | 24.3 – 30.3 °C | 23.3 – 31.3 °C |
| Milan (*mean July T = ca. 25.1 °C*) | 25.1 – 29.1 °C | 24.1 – 30.1 °C | 23.1 – 31.1 °C |

The results, exhaustively reported in table IV.19 (*the values represent the time fraction - % - guarantying thermal comfort conditions*), show that:

- THERMAL ZONE 2: despite the adoption of the passive cooling solutions, no comfort conditions are achievable; in fact, also in the less critical thermal context – Milan –, where both the nighttime ventilation and the ground cooling potentials are higher, only a 43% of the summer working time results partially comfortable (*comfort condition category III*). With reference to Naples and Rome, even if the admitted indoor temperatures are higher than those referred to Milan, the indoor comfort conditions are worse.
- THERMAL ZONE 3: the comfort conditions category I also in this case are not satisfactorily achieved in Naples (36%) and Rome (50%), while useful results are obtained for Milan (80% time). Enlarging the admitted temperature range, the building

modelled in Milan shows much better performances, in particular with 89% of the summer working time category II and the 90% category III. This last one result is represented in figure 4.7.11. Considering the comfort conditions category III, quite poor results are achieved in Rome and Naples (respectively 74% and 50% summer working time).

Table IV.19: Achievable thermal comfort conditions

| | *Zone 2 (1st floor South)* | | | | *Zone 3 (ground floor North)* | | |
|---|---|---|---|---|---|---|---|
| | **Category I** | **Category II** | **Category III** | | **Category I** | **Category II** | **Category III** |
| Naples | 13.0 % | 10.0 % | 23.0 % | | 35.6 % | 43.3 % | 49.6 % |
| Rome | 20.0 % | 26.1 % | 29.9 % | | 50.1 % | 67.2 % | 74.4 % |
| Milan | 27.4 % | 36.5 % | 42.7 % | | 80.3 % | 88.8 % | 90.0 % |

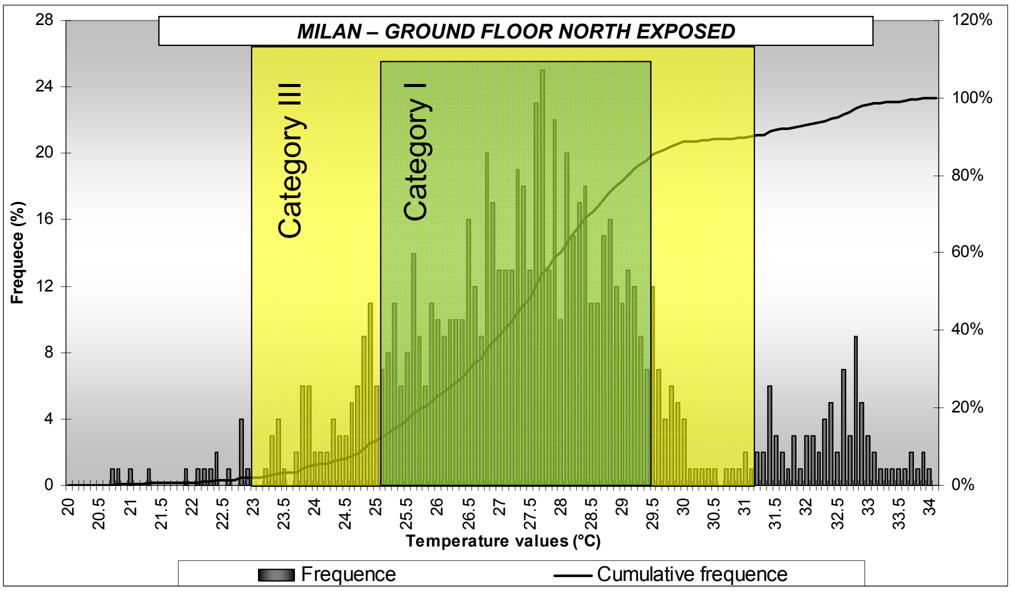



*Figure 4.7.11 – Office building modelled in Milan. Summer working time (only diurnal hours): possible thermal comfort conditions according to EN 15251 with reference to the thermal zone 3*

Finally, in Milan, the achievable results are good (*90% of the summer diurnal time characterized by indoor temperature lower than 30 °C*); with reference to Naples and Rome, even if the summer thermal levels in a naturally ventilated building aren't fully satisfactory, anyway the use of the active cooling can be noticeably reduced.

### 4.7.5 COST-BENEFIT ANALYSIS

The energy analyses showed a good potential achievable recurring to the ground cooling with reference to all the considered climatic regions, in summer.

As regards the winter, instead, only in cold climatic conditions (*e.g. Milan*) the thermal energy recoverable from the ground is useful.

In the followings, 5 technical economic samples have been proposed:

1) Ventilation system + PVC tube, unleashed soil: → excavation = 2.4 €/m$^3$, refilling = 2.0 €/m$^3$;
2) PVC tube, unleashed soil: → excavation = 2.4 €/m$^3$, refilling = 2.0 €/m$^3$;
3) PVC tube, tender rock: → excavation = 8.1 €/m$^3$, refilling = 2.0 €/m$^3$;
4) PVC tube, hard rock: → excavation = 32.5 €/m$^3$, manual refilling = 8.0 €/m$^3$;
5) Metallic tube, unleashed soil: → excavation = 2.4 €/m$^3$, refilling = 2.0 €/m$^3$.

Only for the case 1, also the cost of the ventilation system inside the building has been considered, while in the other samples the purpose was to underline the EAHX extra-cost compared to a traditional ventilation system. In table IV.20, common costs for a ventilation system equipped with an earth tube are reported.

Table IV.20: Earth tube ventilation systems costs

| EXCAVATION COSTS | | REFILLING COSTS | EARTH TUBE COSTS €/m | |
|---|---|---|---|---|
| *open section excavation* | | adopting mechanical devices and using the material previously moved off: 2.0 €/m$^3$ | plastic made (Φ = 160 mm) | 8.0 |
| Unleashed rocks: sand, Clay, gravel | 2.4 €/m$^3$ | | plastic made (Φ = 315 mm) | 28.0 |
| Tender rock | 8.1 €/m$^3$ | | plastic made (Φ = 400 mm) | 44.0 |
| Hard rock | 32.5 €/m$^3$ | | metallic made (Φ = 150 mm) | 52.0 |
| *force section excavation* | | manually executed refilling, using the material previously moved off: 8.0 €/m$^3$ | metallic made (Φ = 315 mm) | 170.0 |
| Unleashed rocks: sand, clay, gravel* | 2.9 €/m$^3$ | | metallic made (Φ = 400 mm) | 202.0 |
| Tender rock | 9.1 €/m$^3$ | | concrete made (Φ = 300 mm) | 34.0 |
| Hard rock | 52.8 €/m$^3$ | | concrete made (Φ = 400 mm) | 40.0 |
| ** over – 2 m, extra-cost around 2 €/m$^3$* | | | *Installation = + 20%* | |
| VENTILATION SYSTEM: *this cost includes the mechanical devices located inside the building (including ducts, diffusers, fans, installations): ≈ 8.0 €/m$^2$ of building plan surface* | | | | |

The considered excavation/backfilling section is represented in figure 4.7.12. About the other considered boundary conditions, the earth tube solution is the same defined in table IV.14. As regards the energy savings, evaluated in order to quantify the economical convenience, the results presented in figure 4.7.8 have been considered, comparing the "*NO EAHX*" case and the "*EAHX only*" one.

The heating/cooling system efficiencies and the energy costs are those represented in table IV.12, while the calorific power of the gas (*winter*) has been posed to 9.6 kWh/m$^3$gas.

Only with reference to Milan, the working period considered for earth tube includes the winter. The economical results are reported in table IV.21.

Excluding the ventilation system inside the building (*case 1*), that represents a fixed cost, the ground moving shows, almost always, a cost higher than the tube, sometimes also several times higher (Pfafferot *et al.* [30] and Thevenard [40]). When the ground typology determines an easy excavation work (*cases 2 and 3*), the earth tube represents a very convenient improvement of the ventilation system, with reduced payback values.

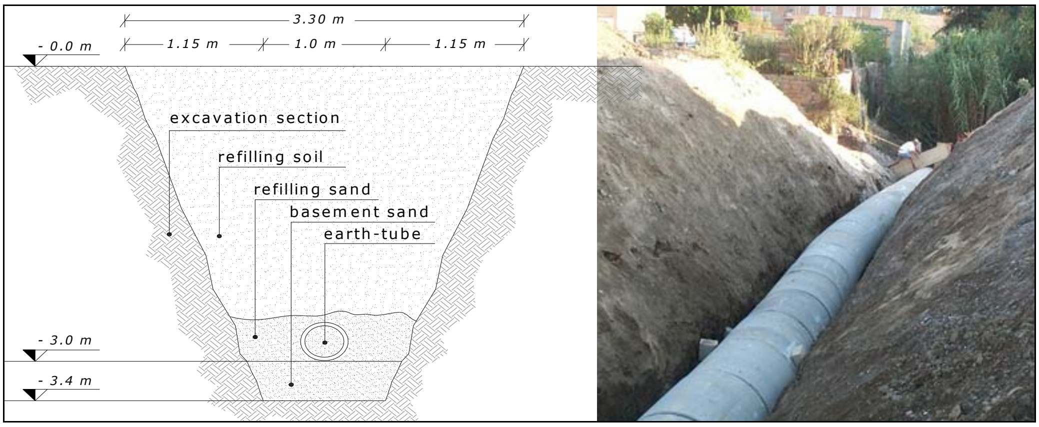



*Figure 4.7.12 – Earth tube installation: soil excavation and refilling*

Table IV.21 – technical economic evaluation

| | | Cooling savings (€) | Heating savings (€) | System cost (€) | Pay Back (years) | | Component costs | % |
|---|---|---|---|---|---|---|---|---|
| 1 | Naples | 633.9 | ---- | 11513 | 18.2 | | Ventilation | 70 % |
| | Rome | 720.1 | ---- | | 16.0 | | Ground moving | 15 % |
| | Milan | 659.3 | 120.1 | | 14.8 | | Earth tube | 15 % |
| 2 | Naples | 633.9 | ---- | 3513 | 5.5 | | Ventilation | Not considered |
| | Rome | 720.1 | ---- | | 4.9 | | Ground moving | 50 % |
| | Milan | 659.3 | 120.1 | | 4.5 | | Earth tube | 50 % |
| 3 | Naples | 633.9 | ---- | 5771 | 9.1 | | Ventilation | Not considered |
| | Rome | 720.1 | ---- | | 8.0 | | Ground moving | 69 % |
| | Milan | 659.3 | 120.1 | | 7.4 | | Earth tube | 31 % |
| 4 | Naples | 633.9 | ---- | 17809 | 28.1 | | Ventilation | Not considered |
| | Rome | 720.1 | ---- | | 24.7 | | Ground moving | 90 % |
| | Milan | 659.3 | 120.1 | | 22.8 | | Earth tube | 10 % |
| 5 | Naples | 642.8 | ---- | 12495 | 19.4 | | Ventilation | Not considered |
| | Rome | 724.3 | ---- | | 17.3 | | Ground moving | 14 |
| | Milan | 678.3 | 123.1 | | 15.6 | | Earth tube | 86 |

Instead, an onerous excavation (*hard rock, case 4*) and/or the use of expensive material (*metallic tube, case 5*) make not so convenient this strategy. In particular, the use of metallic material does not guarantee any benefits, with thermal performances only slightly better than the PVC ones…*and much higher installation costs.* Also this analysis shows that the highest benefits are obtained in cold climates.

## 4.8 CONCLUSIONS

The chapter has investigated the potential of several passive cooling strategies, with reference to an office building modelled according to the most recent German and Italian standards and energy regulations. The analyses showed that, while the present legal prescriptions result very well adapted in order to reduce the winter heating energy requests, the imposed verification are instead very low effective as regards the summer period energy performances.

In particular, a building full respectful of the present regulations about the summer energy performances (*low sun-exposed transparent surfaces, correct exposure of these, adoption of low solar transmittance glazing according to the German EnEV, high mass of the building envelope, elevated time lag effect and low attenuation factor according to the Italian laws*) doesn't achieve satisfactory performances. Despite all these measures, in fact, bad performances have been evaluated both in order to reduce the use of air-conditioners in air-conditioned buildings and in order to provide a satisfactory thermal comfort in naturally ventilated architectures.

About this last case, according to the EnOB program targets, only passive cooling solutions are admitted with reference to the German moderate climate.

A modelled base case has been simulated. Its characteristics, well designed according to the present prescriptions, actually determine only satisfactory performances in wintertime, with bad summer performances. Therefore, several passive cooling strategies have been defined, optimized and analyzed, singularly, in order to verify the achievable energy saving potential. The considered climate conditions (*Naples – Italy, Stuttgart and Berlin – Germany, Oslo – Norway*) were selected in order to give a framework well representative of the all possibilities presented by the European climates.

The analyzed passive cooling solutions are based on different heat transfer phenomena:

- movable insulation of the roof → *envelope radiative cooling acting from the external side of the building*;
- nightime natural ventilation → *envelope convective cooling, acting from the internal side of the building*;
- movable insulation of the vertical walls → *envelope radiative cooling acting from the external side of the building*;
- earth-to-air heat exchanger → *indoor space convective cooling during the diurnal hours*.

With reference to the ground cooling (*i.e. earth tube ventilation*), some preliminary analyses have been carried out, with reference to each city, in order to select the best control strategy. In fact, being possible a free cooling of the external air (*thermal energy saving*) but resulting necessary an electric energy amount (*high exergy*) for the fan work, an introductory optimization analysis has been considered necessary.

All the passive cooling solutions have been implemented with reference to several thermal zones of the building, being the position (*ground, last or intermediate floor*) and the exposure (*north or south*) strongly influent on the effectiveness of each specific solution.

The simulation post-processing has been carried out adopting two different evaluation methods: considering both a full conditioned building (*i.e. indoor temperature controlled during the working hours at 26 °C in summertime*) and also a naturally ventilated building (*so leaving the indoor air temperature free running*), according to the EnOB targets (*no active cooling*).

Then the cooling potential of each adopted passive solution has been investigated, with reference to each thermal zone of the building and for each considered city. Furthermore, on the basis of the achieved results, the most adapt coupling have been realized, in order to optimize the energy performance of the simulated office building. Choosing the most useful passive cooling solutions, only the best two for the single thermal zone have been selected and coupled, considering also necessary the limitation of the building construction costs.

In these last simulations, also another passive cooling strategy has been adopted: *the cool paint of the sun-exposed building envelope surfaces*, by means of external coatings that maximize the solar reflectance and the infrared emissivity, in order to reduce the temperature of the external surface during the day and to maximize the nighttime radiative thermal exchanges.

After the coupling of the best passive cooling solutions, another post processing evaluated the thermal and energy performances characterizing the office building.

In Naples, even if a not full satisfactory passive free cooling has been obtained, anyway a drastic reduction of the summer cooling loads has been achieved. Instead, for the central-Europe climates (Stuttgart and Berlin), a full passive cooling effect has been obtained, so that, for the big part of the summer working time, the indoor conditions can be evaluated Category I according to the technical Standard EN 15251, regarding the thermal comfort in naturally ventilated buildings. The same result has been obtained also in Oslo (north-Europe), where, sometimes, also summer free over-cooling phenomena (*above all in the morning first hours*) can happen; actually, this is not a problem being possible avoiding this effect acting on the natural ventilation or on the passive cooling solution regulation.

Finally, in this chapter, some suggestions are provided as regards both the reduction of the summer cooling active energy requests and the improvement of the indoor thermal conditions with reference to not conditioned buildings. The analysis methods, the considered climates, the selected passive cooling solutions and their optimization, even in applications characterized by hot external conditions and high endogenous heat gains, provide useful advices towards an environmental and energy sustainable design.

The studies show a very interesting cooling potential by means of the buried ventilation tubes, so that a specification regarding the ground cooling, with reference to the Italian climate, has been carried out. Also in this case, a quite efficient office building has been modelled, both air-conditioned and without active cooling systems, with reference to three climates expressive of the Italian conditions. Then the energy performances of an earth-to-air heat exchanger have been evaluated both in summer and winter times. In particular, starting from the description and validation of the adopted physical model, an exhaustive parametric analysis has been carried out varying the main characteristics of the earth tube.

The results show that wet/humid soil induces the best performances, becoming more influent the moisture content than the soil composition. Contrariwise, the pipe material does not represent a strongly incident parameter, since the pipe thermal resistance is always low, being the pipe thickness reduced, so that the thermal conductivity cannot influence significantly the overall thermal transmittance.

As regards the tube length, the improvement achievable adopting a tube longer than 50 m is not relevant. Thus, considering that the costs (ground moving and pipes) become higher, pipes too extended are not convenient. As regards the tube depth, a time temperature profile with a phase constant around six months is better than a quite constant value throughout the whole year; as regards moving earth costs and thermal exchange, a good compromise is achieved with a profoundness around 3 meters.

About the airflow characteristics inside the pipes, low speeds are preferable, above all in order to reduce pressure drops (and so fan energy request). The extra-cost due to the adoption of intake fan instead of exhaust one (being lower, in this second case, the supply air temperature) is not relevant.

As regards the air change number, 1 or 2 ACH in summer are preferable. A further increase of the airflow amount determines, also in summer, higher primary energy requirements, due to the relevant increase of fan energy requests. In winter, the best solution is to provide the minimum outdoor airflow necessary to guarantee a satisfactory indoor air quality.

About the control strategy, the best solution in Mediterranean climates consists in a long use of the ground cooling in summer (15 hours/day), in order to cool both the building shell/mass and the indoor air. In winter, a significant convenience has been obtained only in cold climates.

In Mediterranean climates, with reference to naturally ventilated buildings, no thermal comfort conditions are achievable, considering the whole summer season, in each thermal zone of the building. Therefore, despite important energy savings are obtained adopting the EAHX ventilation, it is anyway necessary the use of a traditional cooling system in office buildings located in central and south Italian regions. Better results have been obtained with reference to the north Italian climates.

Finally, as regards the costs, when the ground works are easy and cheap, the improvement of a ventilation system adopting the ground cooling is convenient (payback values of 4-9 years); otherwise, onerous excavation/refilling costs and selection of expensive tube material (metallic) can induce too long payback time values of the earth-to-air heat exchangers.

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# Chapter 5:

# Energy efficiency in the museum environment: energy saving strategies for the exhibition room air-conditioning, CFD evaluation of the air diffusion performances, the Museum Ritter experience

## 5.1 PRELIMINARY CONSIDERATIONS AND INTRODUCTION

The artwork conservation requires, in the Museums, a continuous control of the microclimatic thermal and hygrometric parameters. In particular, the necessary spatial and temporal stability of the assumed values is much more restrictive compared to other kind of air-conditioning applications.

The dual function of a museum - ensuring the persistence over time of a collective Good that could be not reproduced and, at the same time, providing that this cultural Heritage could be accessible to the community - imposes design, choice and control of microclimatic conditions, not derivable, uncritically, from other areas of the air-conditioning applications.

The temperature conditions of the air around the artefacts, stored in an exhibition room, and mainly the air thermal level sudden changes represent the greatest risks for a correct storage.

It is not sufficient ensuring thermodynamic conditions included in safety ranges. Contrariwise, the first requirement is the time stability of the microclimatic parameters, being their fluctuations and gradients, in the time or within the space, the most dangerous event for a correct preservation. In other words, even if the artworks are kept in places characterized by temperature and relative humidity values suitable for the conservation of each material, anyway, the temporal and spatial gradients of humidity and the thermal levels of the indoor air produce irreversible alteration and degradation processes.

Therefore, a strict control of the thermal and hygrometric transients is the main requirement that the air-conditioning system in a museum should guarantee, ensuring:

- high velocity in limiting and restoring the environmental thermal and hygrometric deviations of the controlled parameters with respect to the designed values;
- high reliability in order to minimize periods of no conservation conditions ("*time out of storage*");
- energy savings and low operating costs, being the air-conditioning operational time characterized by a continuous working, during all the year, 24 hours per day;
- security and architectural integration, because the big part of the Italian and, generally, European museums are hosted inside ancient buildings, that represent, themselves, cultural Heritage to preserve.

All-air air conditioning systems, characterized by constant airflow volume (CAV), with centralized functions of filtration, humidification/dehumidification, heating/cooling, control and maintenance, result usually the best system typology. In particular, this kind of air-conditioners are very fit in order to control the suitable stability of thermal-hygrometric parameters, ensuring, at the same time, an air flow amount that can quickly restore the design indoor conditions, reducing also the quantity of environmental pollutants characterizing the indoor air.

Usually the higher limit to the adoption of such systems is the large space that these require, that is difficult to find in ancient buildings (*above all when the building is, itself, characterized by architectonic and/or historical value*). This difficulty often conducts towards variable airflow systems (VAV), which require lower space and operating costs, but are also characterized by lower performances as regards the microclimate control, generally less effective compared to the constant airflow HVAC.

Moreover, in the museum air-conditioning, and particularly with reference to exhibition halls and warehouses, mixed air-water systems are often not preferred, in both the configurations with fan coils or radiant panels / cold ceiling; about this poor suitability, the main reasons are:

- these systems can be slow in responding to thermal load and humidity changes;
- often they are not suitable to guarantee an effective spatial uniformity of the thermal-hygrometric conditions;
- these could induce conservation risks, because of the possible broken of the pipes (*containing liquid water*), that could be very dangerous for the artwork preservation.

Similar limitations also make unsuitable the direct expansion systems, which, during the last years, have been widely diffused in the typology with refrigerant variable flow; in particular, these are quite inappropriate for this kind of application, because of the presence, within the halls, of pipes containing the pressured fluid necessary to add the refrigerant at the room heating/cooling units.

For the installation in the museum environment, the DOAS (*Dedicated Outdoor Air Systems*) are quite suitable; these systems, exclusively dedicated to the handling of the outdoor air, are coupled to air-conditioners working exclusively recycling the exhaust air. The outdoor air, thermally and hygrometrically handled, provides the requirements of purity and air-changes, balancing at the same time the latent heat load. The parallel system, instead, working recycling the indoor air, provides to the sensible heat load balances. The strict microclimate control that can be achieved, as well as the possibility of equipping the handling devices with devices designed to achieve energy savings (*for example, sensible or total heat recovery systems*), do this technology an effective solution in order to ensure the required rigorous needs as regards the museum environment air-conditioning.

The climate control of the museum results complex, with numerous critical aspects and requirements that the adopted HVAC system has to satisfy. Not only the most common solutions are often ineffective, but also the design method, derived from other fields of applications, does not ensure the development of appropriate systems for a well-adapted microclimate control within the exhibition halls. In particular, with reference to the exhibition spaces, the load impulsiveness and the necessary maximum stability require deeper analyses compared to the usual design approach of the air conditioning systems. In particular, it is absolutely not enough the simple sizing of the HVAC system under the design (nominal) conditions, that instead is often the target and the method carried out for residential or commercial applications.

In the following studies, the museum environment air-conditioning will be investigated under several points of view. After a necessary introduction relative to the main peculiarities of the cultural Heritage conservation and the museum specific requirements, various analyses have been carried out, by means of the BEPS – *Building Energy Performance Simulation* – and CFD – *Computational Fluid Dynamic* – studies. The analyses have been carried out in order to evaluate both the energy performance achievable on varying the kind, the equipments and the regulation strategies of air-conditioning systems and also in order to investigate the best design methods and solutions for the air diffusion into the exhibition room.

In particular, by means of the dynamic energy simulations, several kind of HVAC systems have been investigated in order to verify, in this critical application, first of all the energy required for a strict air-conditioning of the museum, and also the capability in controlling the microclimate, dynamically, inside the exhibition rooms.

Furthermore, using the computational fluid dynamic analysis, previsions about different air diffusion strategies have been carried out, evidencing the kinetic, thermal and hygrometric fields inside the conditioned-space, in particular evaluating the uniformity of the microclimatic conditions, such as the excursion of the temperature and relative humidity inside the exhibitions rooms. The fluid dynamic analyses, regarding several air-diffusion strategies, have been carried out in order to investigate the best solution for the air diffusion, in order to achieve, within the space, a strict control of the relative humidity and indoor temperatures uniformities. In particular, the hygrometric rate is the main important microclimatic parameter for a correct conservation, strictly linked to both the humidity content of the air and its thermal level.

Finally, the Museum Ritter in Waldenbuch - Germany, has been studied and analyzed, during a study period at *FBTA – Division of Building Physic & Building Services of the University of Karlsruhe*. The high effective energy solutions and technical systems adopted, the design activity full centred on the eco-compatibility, the innovative strategies and the accurate 2-years monitoring, do this building very expressive of the new low energy building culture.

As shown by an EEC survey, around the 75% of the almost 5 millions of monuments estimated in the European Community are located in Italy [1] and some buildings, losing the original functions, today are used as museums, archives and libraries.

The growing interest in the protection, restoration and promotion of such historical and artistic Heritage has been motivated by both a recent collective consciousness and new interest toward the European culture, promoted, economically, by public and private financial capitals. However, the adopted logical approach was often limited only to restoration actions of the artworks, neglecting the problem of a correct conservation of them (*i.e. storing the cultural Goods in confined areas suitable for a long-time preservation and thus preventing, controlling and limiting the deterioration processes*).

An effective policy consists in keeping the artworks under environmental conditions apt to avoid that the degradation begins or continues, and it is possible only managing all the factors that regard the conservation, starting by the knowledge of all the causes and mechanisms that induce the disruption events. The environment in which the artworks are located is the main culprit of the conservation state of the objects, so that a continuous monitoring of the microclimatic parameters is necessary.

If, furthermore, the museums are considered as not only places where the cultural Good are stored, but also where the fruition of these becomes possible (*and thus admitting the visitor presence*), the maintenance of strict values of temperature and humidity conditions becomes very problematic [2].

Therefore, generally it is essential the adoption of well-adapted air-conditioning systems, flexible and able to respond quickly to the deviations of microclimatic parameters with respect to the optimal values of conservation, especially with reference to the environmental relative humidity. The requirements of stability of these parameters are usually much more stringent compared to other kind of buildings.

In particular, the humidity control must ensure that:

*a) the materials are not interested in phenomenon of steam transfer or condensation; it would induce mechanical damage, as well as chemical and biological attacks;*

*b) drying mechanisms are avoided, because these would induce mechanical strains, often irreversible.*

Therefore, a suitable air conditioning system for museum environments should be able to balance quickly the deviations of the environmental controlled parameters, particularly in the exhibition halls and with reference to the humidity conditions. Usually, the most critical thermal loads are the ones connected to the visitor presence (*generally, impulsive and proportional to the overcrowding rate)* and the loads related to the ventilation air supplied into the environment.

In this study, first of all general considerations have been reported, particularly as regards the negative effects that an incorrect humidity control may induce; as it will show, it becomes necessary an appropriate air-conditioning in order to maintain the RH levels within the designed range. Then, two numerical case studies are presented, with reference to simulative analyses carried out to investigate the performances of several HVAC systems, both with reference to the dynamic control of the environmental conditions in the time (*BEPS – Building Energy Performance Simulations*) and within the space (*CFD – Computation Fluid dynamic analyses*).

Finally, a high efficient museum was presented. In particular, the Museum Ritter in Waldenbuch, investigated during a researching period at Fbta - Division of Building Physic & Building Services of the University of Karlsruhe (Germany), is shown because well represents a correct design method, under all the point of views interesting the museum air-conditioning and the energy efficiency concepts.

## 5.2 GENERAL PART: THE MUSEUM ENVIRONMENT – THERMAL-HYGROMETRIC CONTROL AND HIGH EFFICIENCY AIR CONDITIONING

### 5.2.1 THERMAL-HYGROMETRIC PARAMETER VALUES FOR THE CULTURAL GOODS CONSERVATION

The indoor microclimate, in absence of an environmental active control system, is determined by the interaction among objects, closed space and external environment, while, in presence of an air-conditioning system, the type of system installed, its size, operative conditions and operation/maintenance actions determine the indoor climate. In both the cases (*natural ventilated buildings or full-conditioned ones*), the optimal values of the indoor microclimatic parameters have to be identified through the synergy of various integrated multidisciplinary professionals (*conservator, restorer, architects, designer of the air-conditioning, technical engineers, consultants*). The first step starts by the investigation of the object conservation state, above all considering the artwork previous history and the values of the microclimatic parameters under which it has been stored.

The interaction between the museum environment and the interfering external factors may limit or, if not properly controlled, speeding up the process of deterioration, often irreversible, both with reference to the buildings and the artworks.

The problem of a perfect conservation is not easy to solve. This because, even if various indications about the most suitable conservation conditions and about the thermal-hygrometric values apt for the storage of different categories of cultural Goods are well known, the most critical aspect is the evaluation of quantitative information about the degradation, interesting the artworks, in relation to deviations from the microclimatic design conditions.

The main causative agents of degradation processes of the historical and artistic Heritage, preserved in the museums, are [3]:

- *electromagnetic radiation from sources of natural and artificial light;*
- *the thermal-hygrometric conditions of the air around the objects;*
- *the air quality in the conservation spaces;*
- *the air velocity in the exhibition room.*

Instead, about the possible degradation phenomena, the main risks are:

- *physical mechanisms (changes in size and shape of the objects);*
- *chemical mechanisms (chemical reactions);*
- *biological mechanisms (proliferation of micro-organisms, bacteriological attacks…)*

The choice of the microclimate for the conservation should take into account both the direct impact on the object materials and the indirect effects derived from a conservative habitat conducive to forms of biological degradation or unwanted chemical reactions, especially in presence of air pollutants.

The degradation or the optimal conservation of historic buildings (*and thus of the cultural artworks here stored*) depend primarily by temperature and humidity conditions characterizing the indoor environment, being these thermo-dynamic properties able to modify the material characteristics and behaviours.

Actually, as shown in many studies, even other parameters, such as the vertical and spatial distribution and gradient of the thermal-hygrometric parameters, the concentration of pollutants, lighting amount and quality, as well as the outdoor ventilation influence the degradation phenomena, above all under their synergistic effect with temperature and relative humidity.

The greatest risk for the conservation is represented by the thermal-hygrometric conditions of the air around the objects, and, especially, the sudden changes, in time and within the space, of their assumed values. In fact, even if the best values for a correct conservation are achieved with reference to any material, greater attention should be paid to the time and spatial stability [4] of the air conditions, limiting the temporal fluctuations and the spatial gradients. The stored Goods, in fact, can be also able to adapt themselves to microclimatic conditions not exactly ideal, while sudden changes of these conditions determine suddenly degenerative processes.

Until now, the studies related to the evaluation, as regards each material, of the correlation among incorrect thermal-hygrometric parameter values and consequent degradation, present results not always coherent and not yet fully agreed, being sometimes contradictory also the data emerging from experiments. Therefore, especially with reference to the environmental relative humidity, the absolute correct set-point values, the temporal and spatial admitted excursion ranges and their effect on the artwork conservations are, today, a working topic interesting the whole international community involved in the conservation of the world cultural Heritage.

In the last years, two new Italian technical standards have been released by the UNI - Italian Organization for Standardization:

- the UNI 10829/1999 "*Works of art of historical importance - Ambient conditions for conservation - Measurement and analysis*" [5];
- the UNI 10969/2002 "*Cultural Heritage - General principles for the choice and the control of the microclimate to preserve the cultural Heritage stored in indoor environments*" [6].

These documents defined a new approach as regards the cultural Goods conservation. Some authors [7] sustain that today this Nation has the most advanced methods and approach about the artwork preservation *("…the Italian standard….is probably the first and most modern standard in the world about microclimate for the optimal conservation of cultural Heritage Goods…"*), regulating all the aspects concerning the environmental conservation in museums.

The UNI 10829 suggests optimal values of thermal-hygrometric parameters for environmental conservation. In the design of new air-conditioning systems for indoor environments storing cultural Goods, when there are no specific indications, the UNI 10829 suggests values of microclimatic parameters for a correct conservation of 33 categories of materials, divided in three groups:

- materials / objects of organic nature;
- materials / objects of inorganic nature;
- mixed objects.

The suggested values regard:

- temperature and its maximum (*during the time*) excursion;
- relative humidity and its maximum (*during the time*) fluctuations.

The UNI 10829 also provides an accurate methodology for the measurement of micro-environmental parameters and the indoor space monitoring.

Each microclimatic monitoring should be carried out for a period not determined, but large enough in order to permit a full knowledge of the temporal trends in the values of physical quantities, measured in certain significant points of space, in order to have a detailed understanding of the thermal-hygrometric behaviour of the exhibition space.

In this technical standard, the thermodynamic behaviours during the time are distinct in variations in the short, medium and long terms. The measurements should be conducted keeping in mind the exhibition route/direction and, where possible, the exact spatial distribution of the artworks.

The analysis of the monitored data has to be accompanied by the consideration of other factors, such as the museum opening hours, lighting parameters, indices and modality of the overcrowding, operational working time of the HVAC system. Then, through the comparative study of all the collected measures, it can be possible a complete knowledge of the environment and its critical aspects (*see the paragraph 5.5 of this chapter regarding the Museum Ritter experience*).

With reference to each parameter, measured in a spatial point, the cumulative frequency during the considered time should be elaborated. Through the reading of the cumulative frequency diagrams, the "*indicators of environmental risks"* can be then determined. For each microclimate parameter, the "*deviation factor*" should be then calculated, and it is defined as the percentage of time in which the considered parameter is outside of the range considered suitable for a correct conservation. Through the methodology suggested by the technical standard UNI 10829, it is possible to obtain an overall and exhaustive knowledge of the microclimatic environment in which the collections are located.

During the February 2002, in Italy came into force the new technical standard as regards the air-conditioning for museums: the UNI 10969/2002 represents a technical authoritative reference enacted to orient the design and the modernization of air-conditioning systems dedicated to applications such as museum, libraries, archives and any other building containing cultural Goods. While the UNI 10829 provides a methodology, through which it is possible to carry out a correct monitoring and the analysis of the environmental parameters affecting the conservation, the UNI 10969 provides guidelines for the selection and control of the microclimate in the places housing artworks. This technical standard underlines the importance of a full knowledge of the history characterizing the artwork conservation. In particular, it is a key point the knowledge of the previous microclimates in which the Goods were stored, in order to understand and identify the deterioration processes, the present risk factors and in order to evaluate new appropriate storage conditions. Some indications, contained in the standard, are:

- *"if an object is already in a favourable microclimate, and there are no degradation processes in phase ..., the object should be maintained in the environmental conditions in which it is presently stored, and from which now it was conditioned;*
- *"the original microclimate can be improved by removing or mitigating one or more disturbing causes (diurnal cycles, time fluctuations, abrupt transitions, spatial gradients, etc.)."*
- *"if it is absolutely necessary the variation of the condition of an object remained for long time in any given microclimate, these conditions should be varied on the basis of specific studies ...";*
- *"in case of recently built objects or when their history results unknown….. the new microclimate has to be studied on the basis of their chemical and physical characteristics";*
- *"if it is necessary to alter the microclimate in which an object is stored, the transition to the new microclimate should be carried out in a very long time...."*

In figure 5.2.1, according to the technical indications above mentioned, a simplified diagram of the logic of approach is presented for this kind of application.

With reference to the international standards, the ASHRAE recent studies, included in the Application Handbook 2007 [8], focus the attention no longer on the single artwork, but instead on the entire collections, placing them, according to specific thresholds of sensitivity, in 5 classes of categories. When the optimal values of the thermal-hygrometric parameters have been evaluated, in order to provide the fit conservation of the collection, the object is placed inside a specific class of sensitivity (*AA-A-B-C-D*), according to the seasonal and short-term fluctuations allowed for the microclimatic parameters. For example, as regards the class AA (*i.e. the most sensitive collections*), the following values are suggested:

- air temperature between 15 °C and 25 °C, with short-term variations no higher than ± 2°C and seasonal variation non higher than ± 5°C;
- air relative humidity set-point equal to 50%, with maximum permitted fluctuation in the short term no higher than ± 3%.

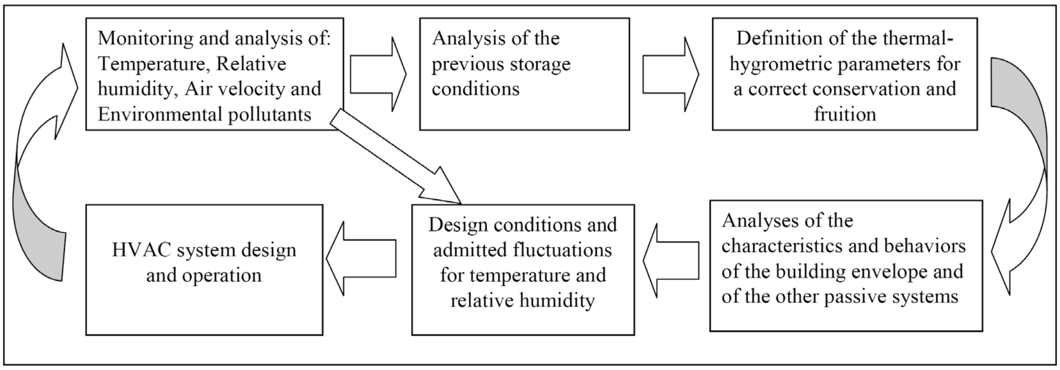


*Figure 5.2.1 – Logical scheme for the design process of an air-conditioning system for museums*

The ASHRAE standard underlines the great importance of passive solutions, in order to improve the building envelope performances, above all with the aim to prevent the sudden changes in the thermal and hygrometric loads deriving from the interactions with the exterior environment. In particular, a great thermal inertia of the building shell reduces and shifts the heat transfer from the external environment, reducing the peak and delaying the maximum thermal load in the indoor environment during the evening hours, when the endogenous heat gains are usually reduced (*no people presence*).

Also the moisture transfer through the building envelope has to be carefully estimated, in order to realize apt solutions in order to avoid water condensation phenomena, inside the walls or on their internal surface. Even with reference to passive solutions, the use of windows shading is, furthermore, necessary when the solar radiation enters directly in the exhibition areas, causing risks for the conservation of the artworks.

Often buildings designed and constructed for a different function are used as museums. Conrad [9] has divided the buildings, according to their performances, in 7 categories, each of these corresponding to a class of possible thermal-hygrometric fluctuations. The problem becomes much more complicated when the building is, itself, a cultural-historical Good. In this case, additional and controversial issues arise, being the construction envelope an important and integral part of the museum.

A good integration of a modern air-conditioning system becomes, in this case, one of the most complex aspects in the rehabilitation program of a historic building, representing a challenge that involves many professional competences.

### 5.2.2 HUMIDITY AND CONSERVATION

Garry Thomson, in the authoritative handbook "*The Museum Environment*" [10], says: "*…it is important to clarify, immediately, that the control of humidity and moisture transfers are much more important compared to the air temperature management*".

Considering organic materials such as wood, ivory, paper, parchment, bone, leather, these are characterized by specific balanced water content, fixing the indoor ambient air temperature and relative humidity. As regards the wood, for example, considering common indoor temperature (20 – 26 °C) its moisture mass content is around 10% of the mass, considering an indoor air relative humidity of 55%. When the RH rises up, the wood grows, and it becomes smaller when the relative humidity goes down. Of course, a lot of artworks are constituted by several and multiple materials, and, in this case, in order to avoid mechanical stresses, the best strategy is avoiding significant time variations of the hygrometric grad: in this way, an indirect but effective control of the object moisture content (*EMC – equilibrium moisture content*) can be obtained.

It is well-known that the time variations of ambient air temperature determine dimensional variations in the size of the materials. Comparing this thermal dilatations with the changes produced by the relative humidity excursions, these second ones result much more high: variation of some (*few*) percentage points in the RH correspond, as regards the dimensional changes, to about 10 °C with reference to the temperature fluctuations. Therefore, it becomes quite evident that the selection, design, working and maintenance of air-conditioning systems for a museum environment, as regards the relative humidity control, become very critical engineering challenges.

In addition, the ICCROM (*International Centre for the Study of the Preservation and the Restoration of Cultural Property, Unesco*) recommendations strongly insist on the RH control, because also the normal oscillations can cause irreversible damage to the materials constituting the artefacts. Adapted average values, with reference to the exhibition rooms, are generally identified within the range 35 - 55% throughout the year, with a monthly variation of ± 5% and a daily maximum excursion equal to ± 3%. For the conservation of particular artworks, more restrictive limits are suggested (*for example, 50% with a maximum daily variation of* ± *2%, or also particularly low values, ranging between 20% and 35%).*

On the other hand, at least in small museums, it is not sustainable an HVAC system that would contain within 3-5% the relative humidity excursion: installation and management costs make the necessary technologies out of the economical possibility of the big part of the museums. In this case, being not possible a so strict control, the best compromise should be achieved (*for example, recurring to microclimatic-controlled museum glasses*).

Thus, chosen the value of the relative humidity considering the kind and the chemical nature of the material that has to be stored, it is essential maintaining stable over the time this value. This because, also the normal hygrometric fluctuations, that usually do not affect the environmental comfort of the people, could be extremely dangerous for an artwork, above all when it is constituted by materials characterized by a low chemical stability.

It is important to underline [11] the closed link between the temperature control and relative humidity value. In fact, fixing the air absolute moisture content value, thermal variations cause relative humidity changes. This suggests that a good RH control can be obtained only when there is a perfect temperature management, in particular with reference to the quality and correct position of the environmental control sensors, precision and quality of the HVAC regulation devices, possibility in obtaining an adequate spatial uniformity of the thermal and hygrometric fields.

The humidity control must ensure that the materials are not affected by moisture adsorption or vapour condensation; in fact, the relative humidity influences size and shape of objects, because, as above mentioned, all the organic and/or hygroscopic materials adsorb and release water and moisture. These humidity transfers induce size and shape variations, and so the related deformations and mechanical cracks [12]. The interactions between the objects and the surrounding environment can be summarized in the following way:

- when the environmental relative humidity is low, the material gives moisture to the indoor air: so, air relative humidity values too reduced cause stiffness, contractions, and loss of flexibility, determining also the formation of lesions and cracks in the objects;
- when the environmental relative humidity is too high, instead, the objects adsorb water vapour, expanding their volume and it induces structural stress and mechanical damage.

Metallic artworks, when characterized by a high presence of water on their outer surface, are interested by an acceleration of the oxidation mechanism, while in the paper materials, the water induces colour alteration and exposure to bacteriological attack. Moulds, fungi and insects tend to proliferate in wet organic materials, while in the geological finds, in skin and bone tissues, the high humidity leads to changes caused by chemical reactions (*e.g. the crystallization*).

The physical changes due to the relative humidity fluctuations, in presence of very sensitive materials, cause destructive mechanical solicitations, above all when these occur in a very short timeframe. In figure 5.2.2, typical damages caused by the incorrect air relative humidity have been represented.

*Figure 5.2.2 – Degradations of several materials caused by the exposure in humid locations*

Very small fluctuations in the values of RH induce reduced flow of steam among the objects and the surrounding space, avoiding sudden dimensional changes.

The outdoor air relative humidity can vary greatly within a day, so it is necessary to control the indoor microclimate constantly within the 24 hours. The time gradients are the most frequent degradation cause, so that the HVAC has to control strictly the indoor conditions, being the outdoor hygrometric level variable between the 90% in a particularly muggy day and 10% in a very dry winter day.

Another risk connected to a bad relative humidity control regards possible interstitial condensation phenomena. This event, together with particular air pollutants (*$CO_2$, $SO_2$, NOx, $O_3$, etc..),* causes the formation of dangerous chemical solutions, that can induce, especially in presence of light, corrosion of metals, discoloration of cotton, weakening of organic fibres, such as textiles and papers [13.]

RH values higher than 65%, associated to values of the air temperature higher than 20 °C, facilitate also the proliferation of fungi and accelerate the life cycles of damaging insects [1]. The low temperatures, instead, are usually not dangerous for the artwork conservations, while the increase of the air thermal levels induces chemical processes (*being the physical and biological degradation accelerated*), and so causes great risks for the conservation. Briefly, some points of interest are in the following described (figure 5.2.3).

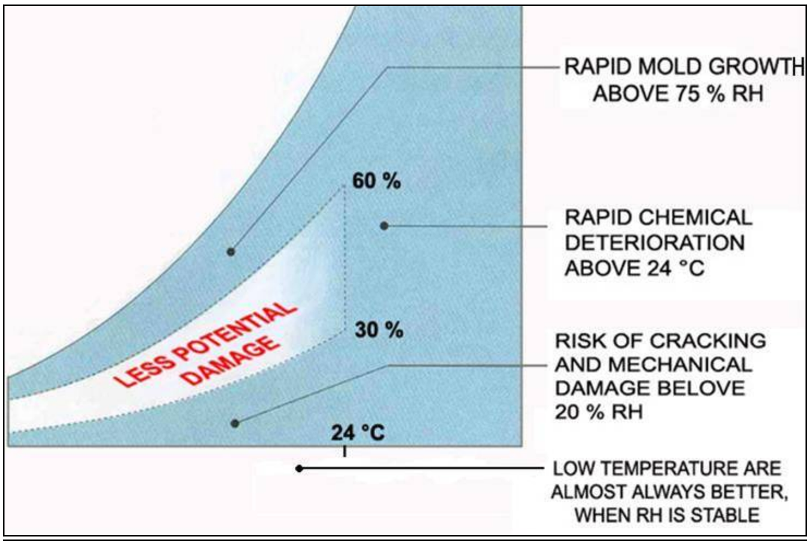


*Figure 5.2.3 – Psychrometric chart with description of t the conservation areas*

<u>*Effects of temperature on the works.*</u> Generally, the air temperature fluctuation effects, about the dimensional changes, act similarly to the relative humidity time gradients, inducing variation in shape and size of the materials. The increase of the temperature of an object produces changes in volume, pressure, mechanical strength and conductivity. Almost all materials increase their volume when their temperature raises up.

The velocity of many chemical reactions doubles, if the surrounding air temperature grows of 10 °C. Therefore, the objects of organic nature should be stored at low temperatures, but always in the range considered comfortable with reference to any material characterizing the collection. Guideline values of the air temperatures in the exhibition rooms are between 20 °C and 24 °C (*see Museum Ritter design conditions, paragraph 5.5*), while in the warehouse, deposits, and in closed areas (*without people presence*) also lower values can be provided.

<u>*Effects of temperature and humidity: the EMC.*</u> Microclimatic variations produce immediate changes in physical and chemical properties of materials. These variations, quite always cumulative and irreversible, grow exponentially when the relative humidity grows, and the risks

are multiplied when the environmental changes are rapid (*highly reducing, in this way, the lifetime expectancy of the conserved artworks*).

A high relative humidity favours the occurrence of bacterial infections that find, in a warm environment, the ideal conditions to proliferate and to become more aggressive. The moulds are fungal formations growing in environments characterized by elevated relative humidity and moisture, but the rate of growth depends also on the temperature conditions and is directly proportional to it.

Each material is characterized by a specific value of the moisture content at the equilibrium conditions (*the already introduced EMC*), which varies depending on the thermodynamic state of the indoor air. The EMC, which varies depending on the chemical nature of the material, although it depends heavily on the value of environmental relative humidity, cannot be associated only to this parameter, being also a little bit related to the thermal level. When the EMC takes values significantly too low or too high, the relative humidity values associated with this phenomenon are representing a significant risk factor.

The EMC is a good indicator of the deterioration level caused by an incorrect relative humidity values. In order to avoid even small dimensional variations, induced by changes in moisture content of the artworks, it is not enough to maintain constant the value of air humidity, but it is consequently necessary to correct also the temperature fluctuations.

<u>*Latent heat load connected to the people presence.*</u> The biggest part of the latent heat load within the museum environment is attributable to the presence of visitors and museum staff that causes release of moisture into the exhibition areas, through the breathing and the transpiration. This load has a high peak during periods of maximum crowding, and results absent when the visitors and staff leave the exhibition rooms. In the sizing of the dehumidification equipment of the HVAC system, this is the most important event that has to be taken into account.

In order to effectively control the humidity level in the exhibition areas, during the periods of high crowding, it may be also useful a controlled entry of persons, thinking, for example, a studied access point that counts the real presence inside the space. The removal of the latent load connected to the adsorbed water vapour, could be, in this case, obtained in the foyer areas or wardrobe, recurring to an installation of a dedicated air-conditioning system characterized by a greater dehumidification capacity compared to the HVAC adopted for the exhibition rooms. In this way, a great part of the humidity is removed before the people entry into the safety areas.

Moreover, it is important to remember that the water vapour, released by the people, is a function of the relative humidity level of the indoor air, so that, values around 50% - recommended for the conservation of the artworks - can be considered favourable also under this point of view.

<u>*Indoor air overpressure in wintertime.*</u> The concentration of water vapour inside the indoor environment is scarcely influenced by the outside air moisture content; this because the museum environments should be maintained in air overpressure with respect to the outside, in order to prevent pollution and uncontrolled air infiltration. However, it is necessary distinguishing seasonal conditions (*summer and winter*) that determine different phenomena [3].

Usually the humidity loads due to vapour flows through the building envelope are low if compared to the moisture quantities introduced by the visitors and by means of the ventilation loads, so that this amount results negligible. The eventual need for a wall vapour retarder is connected to another requirement, i.e. the avoiding of wall interstitial condensation phenomena in wintertime. In fact, the winter humidification (*e.g. indoor level of 50%)* of historical buildings requires, in cold climates, a particular attention. The high vapour pressure could, in fact, causes condensation phenomena inside a wall structure characterized by high permeable materials; it induces corrosion of metallic joints, degradation of hygroscopic materials and corruptions of the walls interested by the solidification-liquefaction cycles of the condensed water.

In order to limit this event, the wintertime indoor overpressure has to be not so accentuated, so that the vapour flow crossing the envelope walls results reduced and also the condensation possibility can be limited. Finally, in very cold climates, it is useful maintaining positive the indoor air pressure in summertime (*dehumidification season*), while in winter and in the cold periods it should results neutral.

*Ventilation load.* The load that affects for the biggest part the humidity control, and the most important hygrometric term that has to be taken into account in the estimation of the total capacity of dehumidification/humidification of the HVAC, is connected to the need of external air. The ventilation flow rate, that has to be supplied into the indoor environment, determines the main hygrometric load with reference to a museum, and it can result, alone, even higher than twice times the sum of the remaining latent loads [3]. On the other hand, in wintertime, in presence of cold and dry outdoor air, the ventilation air requires a significant humidification handling by the HVAC systems.

The above reported considerations suggest the use of Dedicated Outdoor Air Systems (DOAS), sized in order to control exclusively the ventilation air thermodynamic conditions. In fact, acting on the moisture content of the ventilation air (*for example, in summer time, also recurring to the chemical dehumidification*), the indoor relative humidity, if the indoor air temperature is well managed, can be maintained stable at the required values.

In the museum environment, also the demand control ventilation (*i.e. the variation of the external air flow rate supplied, depending of the present crowding*) could be an effective strategy (*see, in the next paragraphs, the Museum Ritter air-conditioning system description*), so that also energy savings can be achieved. Usually, the demand control ventilation is obtained by means the variation of the outdoor air dampers, ad suggested by $CO_2$ sensors or visitor counters.

*Superficial and interstitial condensation in the building envelope walls.* As previously mentioned, the formation of superficial or interstitial condensation in the external walls of museums is a quite typical problem. A strict relative humidity control is therefore required not only for the protection of the stored cultural Goods, but also in order to prevent condensation inside the building, that is, very often, itself precious and object of protection.

On the other hand, if the museums are located in historic buildings that require themselves protection, the use of a vapour barrier (*to avoid the risk of interstitial condensation*) could be architecturally inappropriate, so that the only one solution is represented by the low level of the indoor relative humidity (*due to a low level of moisture content*).

This problem is quite common all around the Europe, where, for example considering the central-Europe climates (e.g. *the Museum Ritter below described)* outdoor temperature very low are frequent in wintertime.

For example, assuming a typical external air thermal level, $T_{OUTDOOR}$ = – 8 °C, and indoor air conditions $T_{OUTDOOR}$ = 20°C and $RH_{OUTDOOR}$ = 50%, with a wall thermal transmittance typical for an historical building of 0.9 W/m$^2$K, an internal surface temperature around 16.7 ° C results (*assuming one-dimensional flow and steady-state calculation conditions*).

Under these boundary conditions, the dew-point temperature of the indoor air results equal to 9.3 °C, so that no condensation phenomena occur on the inner superficial side of the building envelope. But, if a sudden overcrowding of the exhibition room happens, together with a not good control of the indoor conditions, the relative humidity level can easy reaches values around 80%; in this case, the corresponding dew point temperature is equal to 16.4 ° C, and so superficial condensation phenomena could happen.

This simple example suggests the necessity of a very strict management of the indoor conditions, adopting active systems well designed as regards the temperature control and the humidification/dehumidification functions.

With reference to the formation of interstitial condensation, it is useful to underline that, in wintertime, the indoor air humidification may imply, sometimes, that the partial pressure of vapour rises to the saturation value in some points of the wall, thus leading to internal condensation, with all the consequent damages.

This risk becomes higher if the humidifier doesn't work properly, supplying into the conditioned space excessive water/steam amount. When possible, increasing or improving the thermal insulation of the building envelope can be useful in order to contain the energy consumption, and, if the new insulation is positioned on the external side of the wall, even the condensation events become remote. On the contrary, acting by means of new insulation of the internal side of the wall, even if the thermal behaviour of the building envelope can be improved, the water condensation possibility results incremented.

### 5.2.3 HEATING, VENTILATING AND AIR-CONDITIONING SYSTEMS

The modern communication culture changed the limitative concept of museum: *no more a simple place where the artworks are only stored and seen*. In fact, besides the primary functions, i.e. exhibition, collection, storage, management and administration necessities, today it is in large diffusion a new concept of museum such place of cultural diffusion, in order to promote and spread the human knowledge. Thus, the modern concept of museum provides new functions and related places, as conference rooms, laboratories, restoration places, study centres, reception and communications.

Following the technical standards and the best design practices, the different functions have to be kept separated, above all dividing the exhibition areas and the conservation zones from the other functions. This differentiation (*from one hand: exhibition and storage rooms, on* *the other side: offices, shops, cafeteria, conference hall, etc…*) limits the building costs, the air-conditioning managements and, above all, guarantee a better preservation of the artworks, reducing many risks.

The design of the air-conditioning is only one aspect of greater and difficult design criticalities, which affect the quality of the building construction and management factors. The conservation of the artworks requires conditions as much stable as possible, especially in the halls for temporary exhibitions, which, in fact are usually constrained to restrictive insurance policies.

An air-conditioning system, designed for the exhibition rooms, has to guarantee the following necessary peculiarities:

- a strict environmental control;
- quick management of the thermal-hygrometric transient phenomena;
- capability, in real-time, of a rigorous monitoring of the operational state and of the environmental thermodynamic conditions inside the conditioned space;
- high reliability;
- reduced working costs and energy demands;
- architectonical integration in the building, especially when these are historical ones.

It is not enough keeping (*within the planned ranges*) values of temperature and relative humidity meanly stable in the time, but, around the artworks placed in the environment, it is necessary to control the microclimate that is achieved, also ensuring a uniform spatial distribution. Thus, it is particularly important assuring airflow sized to balance the loads, and designing accurately the environmental air diffusion, avoiding the formation of stagnant areas and providing a low-speed complete circulation. It is important to underline that, in the evaluation of the supplied airflow amount for an optimal distribution inside the spaces, often the exhibition rooms are characterized by high elevations. Therefore, if the air changes are not adequate, significant vertical gradients (*about the temperature levels*) can happen, due to the low air circulation within the space [14].

The control of environmental air moisture content and relative humidity, as above mentioned, results vital both in the summer and in winter. About this, it is important to underline that the phenomena connected to the stability and diffusion of humidity are connected to the partial vapour pressure, while those related to the temperature distribution depend by on molecular activity. Therefore, even if stagnant air can be a thermal insulator, on the other hand while doesn't work as barrier for the moisture diffusion. From this consideration, it becomes quite clear that is more difficult maintaining, inside a building, different values of specific humidity compared to the thermal level uniformity [15].

In order to maintain stable the microclimatic environmental conditions and especially the humidity values, it is necessary that the HVAC works, at least for the exhibition spaces and deposits, all day long, so that air-conditioning systems that require moderate energy consumption are preferred.

The control of the transients is strongly linked to the variability of the thermal-hygrometric loads, which the air-conditioning system has to balance. For the time stability of the microclimatic conditions, the internal load connected to the people presence appears particularly critical; this is due to the regime of fruition, normally very variable, impulsive and not attenuated (*being quite frequent the alternation of periods of overcrowding and no-presence times*). This discontinuous visitor flow can induce significant and sudden changes as regards environmental conditions, so that the responses of the air-conditioning system should be fast, in order to restore, as soon as possible, the designed temperature and humidity conditions. The particular stratigraphy of many ancient building envelopes, used as museums (heavy structures), and the resulting high thermal inertia play a significant role about the attenuation and time lag of the external load transmission, so that, also when the external thermal-hygrometric conditions are characterized by a great variability, the HVAC can easy control the internal microclimate. In general, given an impulsive event that affects temperature, relative humidity or the concentration of pollutants, the necessary time to restore the initial conditions:

- decreases when the number of air changes rises up (*maintaining the same distribution system*);
- varies with frequency and modality of the indoor overcrowding, that, as mentioned, results the predominant cause of the indoor condition perturbation;
- decreases (*maintaining the same supplied air flow rate*) recurring to turbulent and non-isothermal air diffusion strategies.

Also with reference to the air pollution levels, the time necessary to restore the design conditions is function of the supplied air changes; generally the air changes necessary to guarantee the time stability of the thermal-hygrometric conditions are also sufficient to maintain, within acceptable limits, the indoor required air quality [13].

Several scientific literature sources [8, 16] suggest minimum air changes between 6 and 8 $h^{-1}$, so that usually all-air systems, with constant supplied airflow rate, are preferred.

Typical critical aspects, usually interesting the museum environments, include a not simple access to the air-conditioning devices (*i.e. doing complicate the maintenance of these*), with consequent risk of collection damage derived by possible water/refrigerant losses, when the equipments are placed directly on the artworks. Therefore, the heating and cooling systems provided with radiant ceilings should be very carefully designed, guaranteeing the monitoring of the operational.

The all-air HVAC usually are considered well-adapted: an air handling unit centralizes the functions of filtration, dehumidification/humidification, heating/air-cooling, maintenance and monitoring; furthermore, all this is obtained away from all the collections.

When the thermal loads are very impulsive, the choice is usually not oriented (*but not precluded, if correctly dimensioned*) toward air-water systems, because these are usually not well-adapted to respond, with the required velocity, to the load variations. Furthermore, in case of high indoor crowding, these systems are not effective in order to reduce the air pollution around the artworks. In fact, the presence of people around the stored cultural Goods causes high concentration of bio-effluent substances, and also high concentration and variability of sensible and latent gains. Thus, the most important need is guaranteeing the adapted airflow rate in order to limit and control these phenomena, as well as the necessity of an appropriate air distribution. These necessities cannot be obtained easily adopting the typical air-diffusion devices of a mixed water-air HVAC system. Instead, as regards the other museum spaces (*foyer, bar and offices*) mixed air systems with fan coil units may be conveniently adopted.

Variable Refrigerant Volume (VRV) and Variable Refrigerant Flow (VRF) can be sometimes also used for the exhibition rooms. The achievable advantages, in this case, are the easy installation and the low initial costs.

The all-air systems guarantee, when correctly sized, an easy control and uniformity of T and RH, as well as the environmental pollution limitation. On one hand, these systems avoid the presence of water pipes inside the exhibition areas, but, on the other, problems of integration in historic buildings occur, because of the significant dimensions of their equipments, in particular with reference to the sizes of the air ducts. Among these HVAC systems, the multi-zone plants can represent an effective solution with reference to the exhibition rooms, both under the technical and economic points of view, making saveable the energy traditionally used for the re-heating processes [17]. In order to improve the control of humidity in summertime, these systems can be equipped with an additional battery of dehumidification (*separate from the battery in the cold plenum*), located before the plenum separation [3]: it can improve the dehumidification, acting on the whole handled air (*also on the air crossing the warm plenum*).

The VAV (Variable Air Volume) systems present clear advantages of flexibility, smaller dimensions, lower operational costs and can be usefully employed - as the multi-zone ones - for different environments served by the same AHU (*air handling unit*). Moreover, these typologies of air-conditioners are interested by limitations related to the ability in compensating sudden thermal load variations, both sensible and latent. In fact, generally it is not advisable the reduction of the supplied airflow over than 25-30% with respect to the nominal amount; furthermore, these systems can present difficulties in ensuring the minimum outside air at the partial thermal load conditions. Finally, the double-duct plants are not suitable for the museum environments, because of the considerable space required and the high operational costs.

The use of systems with dehumidification by adsorption (*e.g. rotating desiccant wheel*) guarantee the reduction of the supplied air moisture content, even when the requested dew-point is very low, thus determining an easier balancing of high latent thermal loads. These systems, furthermore, guarantee significant energy savings, resulting more functional also from the hygienic point of view, because no water condensation occurs and also the drying substance has a germicidal effect, so that the presence of bacteria, fungi and microbes can be usefully reduced.

Instead, dehumidification systems by absorption (*liquid*) should be avoided, because it presents the risk of release, into the indoor environment, of absorbent droplets, with consequent damage for the collection safety.

About the air humidification for the museum environments, in wintertime, the steam humidification results often preferable compared to the one with liquid water, for the most valuable results achievable in terms of hygiene and the better control of the supplied air moisture content.

<u>*Outdoor air.*</u> Since the target is the strict control of the indoor microclimate, increasing the outdoor airflow can be beneficial, despite not economically convenient. In fact, even if free-cooling techniques are adopted, the external air can transport into the external environment particles and pollution, and also a latent load particularly high in wet days. Therefore, the external air should be supplied in the minimum amount required to provide fresh air to the occupants. An hourly dynamic analysis of the outdoor thermal-hygrometric conditions can be

well used in order to verify the energetic convenience and the possible environmental humidity control resulting by the adoption of free-cooling. In the next paragraphs, some results of these analyses will be shown.

Air diffusion. The exhibition areas are characterized by elevated indoor heights and therefore these are often interested by thermal stratifications. If the risk for the collections is significant (*due to differential thermal dilatations*), the supply terminals and the extraction equipments have to be properly studied, as regards typology, size, numbers and position. This is necessary in order to induce an air circulation such to avoid or limit stagnancy zones and thermal spatial gradients [18]. Moreover, the supply (*handled*) air should not be introduced directly on the collections. These aspects will be deeply investigated in the followings, in the paragraphs dedicated to the Computational Fluid Dynamic (CFD) simulations.

Automatic control. The environmental sensors of temperature and humidity should be preferentially installed in the exhibition space and not in the extraction ducts. Obviously, a rapid HVAC response and adaptation, in order to contain the fluctuations of the microclimatic parameters, requires high-performance sensors that should evaluate, quickly and accurately, the microclimate conditions within the space.

Dedicated Outdoor Air Systems (DOAS). The need to achieve significant energy savings and the growing tendency in separating the balancing of the latent and sensible heat gains (*at the same way of mixed air-water system work*) are encouraging the development of facilities dedicated exclusively to the handling of the outdoor air (*DOAS, i.e. Dedicated Outdoor Air Systems*). These systems are particularly suitable for the climatic control of museums; a separate HVAC, dedicated to the outdoor air, works in parallel with another air-conditioning that provides to balance the sensible heat loads. In the museum environment, as already mentioned about the risks associated with the use of mixed plants, it seems particularly well adapted the coupling of an air-conditioning devoted to the outdoor air handling and another one that works exclusively treating the recycled air.

The external air handling unit of a DOAS is similar to an AHU designed for the primary air of a mixed air-water HVAC, but usually characterised by devices designed for the energy savings (*in order to reduce the ventilation load*), e.g. enthalpy wheel and/or sensible heat recovery [19]. Adopting the DOAS, thus, reduced energy requirements can be possible, such as a better control of the hygrometric loads (*above all the impulsive ones, related to the visitor presence*) as well as a better air quality within the conditioned environment.

## 5.3 ENERGY SAVING STRATEGIES IN THE MUSEUM ENVIROMENT AIR-CONDITIONING

### 5.3.1 THE BUILDING ENERGY PERFORMANCE SIMULATION APPLIED TO THE MUSEUM

As above described, the museum environment requires a strict thermal-hygrometric control, necessary primarily for the correct artwork conservation and then for the visitor thermal comfort. Considering that the air-conditioning system has to operate constantly, the techniques that provide the obtainment of energy savings results very useful, if these determine, contemporarily, a good dynamic microclimatic control.

In this paragraph, a case study is presented about various strategies used to reduce the energy requirements for the HVAC systems in an exhibition room of a modern museum.

Using the dynamic simulation code DOE 2.2 and typical climatic hourly data sets, the annual energy use for an all-air system has been calculated, as well as the savings obtainable using different techniques, such as dehumidification by adsorption (*desiccant wheel*), total energy recovery from the relief air (*passive desiccant*), outdoor airflow rate variation (*demand control ventilation*).

Moreover, the correspondence has been analyzed between the energy request and the admitted variation of indoor temperature and relative humidity: changing the admitted indoor RH range from 50 ± 2% to 50 ± 10%, energy savings around 40% have been obtained. As regards the thermal-hygrometric performance, an optimal control of temperature has been guaranteed with all the configurations, while the best performance in RH control has been obtained with the desiccant system.

Considering a simple payback analysis, if the artworks preserved in a museum are particularly sensitive to the indoor humidity variation, a desiccant system should be properly used. On the contrary, when the indoor humidity control is not strongly needed, the use of a HVAC system with demand control ventilation is advisable (*this will be confirmed in the paragraph 4 about the Museum Ritter*), because of the lowest payback value. The system with total energy recovery presents intermediate features.

### 5.3.2 CASE STUDY AND HIGH EFFCIIENC HVAC SYSTEM ANALYSIS

The simulated modern museum (table V.I and figure 5.3.1) is represented in figure covers a total area of 1200 m$^2$, distributed on two floors, each of 600 m$^2$ approximately.

Table V.I: Main characteristics and design conditions for the simulated exhibition room

| | | | |
|---|---|---|---|
| *Area* | 272 m$^2$ | *Infiltration* | 0 exchanges/h |
| *Volume* | 1360 m$^3$ | *Lighting design thermal load* | 20 W/m$^2$ |
| *Indoor T* | * | *Outdoor ventilation airflow rate* | 6 L/s (21 m$^3$/h)/person |
| *Indoor RH* | 50 ± 5% | *Skylight thermal transmittance* | 2.00 W/m$^2$ K |
| *Climatic data* | Rome – TRY data [7] | *Skylight shading factor* | 0.764 |
| *Roof $U_{VALUE}$* | 0.37 W/m$^2$ K | *Exterior wall $U_{VALUE}$* | 0.48 W/m$^2$ K |
| *Occupancy (design)* | 0.3 person/m$^2$ (total: 82 persons) | *Gas utility rate* | 0.55 €/m$^3$ |
| *Metabolic rate* | 1.5 met/person | *Electrical utility rate* | 0.11 €/kW h |

**Annual fixed set point (22 ± 1 °C), or seasonal set point with T in the range 23 ± 1 °C - 23 ± 1 °C.*

At the ground floor, the administrative, commercial and accommodation areas are located, as well as a stock room. Upstairs there are three exhibition rooms, characterized by an inner height of 5 m. The main exhibition room has a total inside area of 272 $m^2$ and a volume of 1360 $m^3$. Particular feature of the exhibition space is the presence of skylights, typical in various museums (*e.g. Guggenheim in NY and Ara Pacis in Rome*).

It can be noted that, sometimes, the use of natural light could represent a net energy penalty and a risk for the collections [8]. Therefore, particular screens have been considered over the skylights.

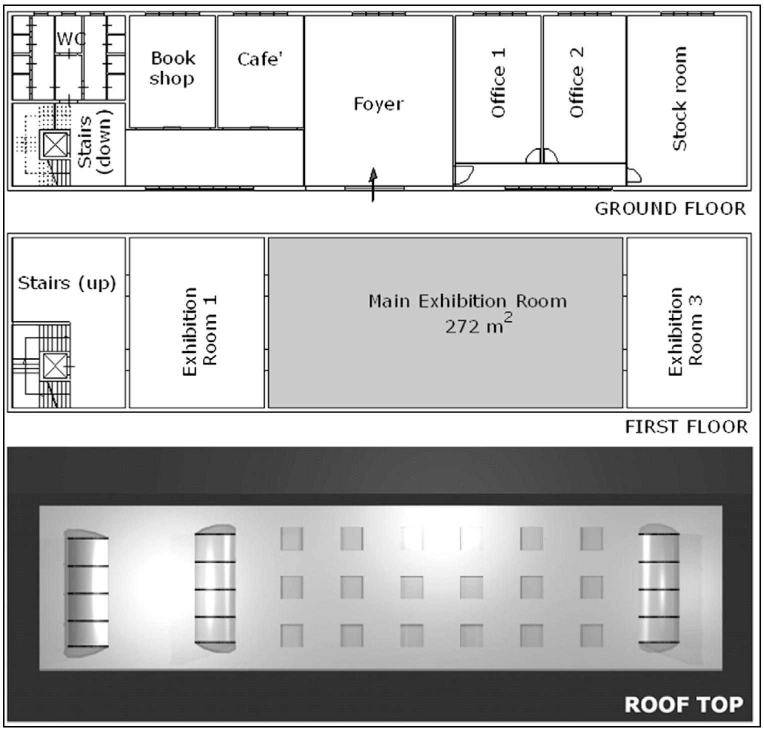


*Figure 5.3.1- Plans of the ground floor, the first floor and the roof top with the skylights*

The attention has been focused on the exhibition space, because of the interest both in the artwork conservation and in the comfort for occupants. The design conditions [20] and [21] and some building thermal–physical parameters are reported in Table V.I. In figure 5.3.2, average monthly outdoor temperature and relative humidity (*derived from TRY data*) are reported for Rome.

As regards the indoor temperature values, ASHRAE indications [20] relative to the admitted fluctuation classes for indoor T and RH for the museum environment have been taken into account. Thus, two different thermostat scheduling strategies have been considered: an annual fixed set point (22 ± 1 °C), strategy sometimes adopted in the museums, or a seasonal set point, with T ranging from 21 ± 1 °C (*December–March*) to 22 ± 1 °C (*April–May and October–November*) and 23 ± 1 °C (*June–September*).

Moreover, a scheduling of internal lighting has been considered too, as well as an annual scheduling of hourly occupancy for a typical museum (figure 5.3.3). The occupancy schedule is the same throughout the year; the museum is open every day from 9 a.m. to 8 p.m., except on Tuesday (closed).

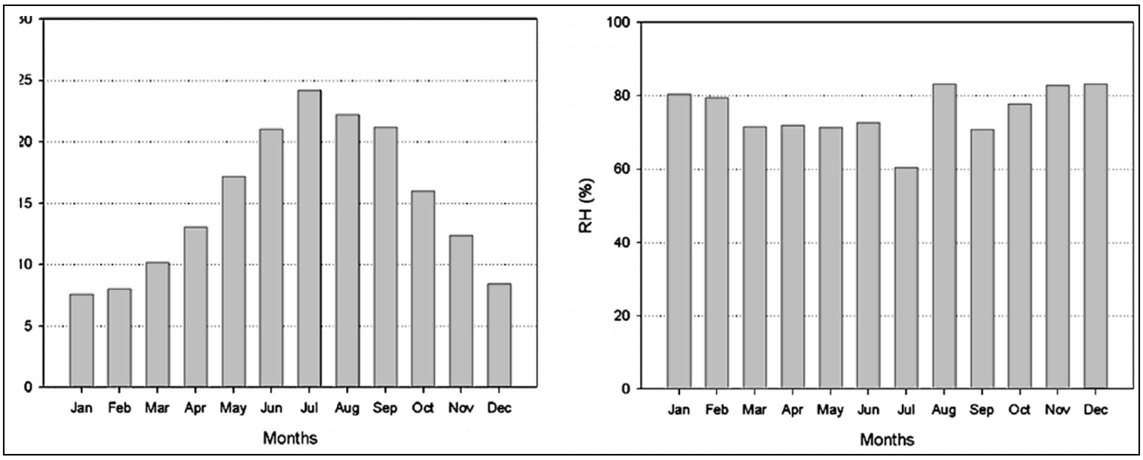


*Figure 5.3.2 - Average monthly outdoor temperature and relative humidity (from TRY data) for Rome*

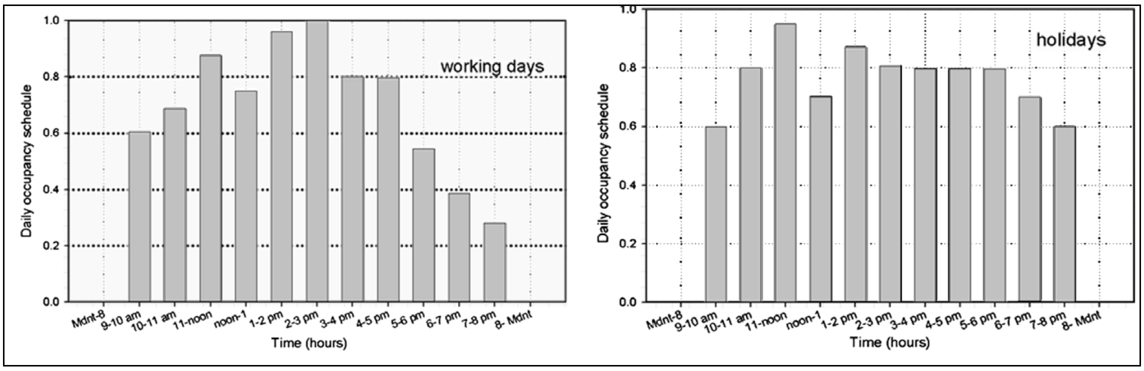


*Figure 5.3.3 - Hourly occupancy schedule for the museum examined*

The HVAC system chosen for the analyzed case study is an all-air system with constant air volume (CAV) for single zone (figure 5.3.4a): this simple configuration has been used as reference in the comparison with the systems reported in figure 5.3.4b-d, below described.

- System with desiccant module (figure 5.3.4b), indicated as CAV-DW in the figures, adopts adsorption dehumidification obtained with a desiccant wheel. The desiccant module presents also a regeneration coil, a sensible heat exchanger and an evaporative cooler;
- System with total heat recovery (figure 5.3.4c), indicated as CAV-ERV in the figures, presents an enthalpy wheel between the ventilation air and the exhaust air, considering a purge flow rate of 10% of the total ventilation flow rate in according to literature indications. The algorithm used to model the heat transfer takes into account the hourly variability of the effectiveness as a function of the make-up and exhaust airflows. The control sequences for the heat exchanger [22] have been chosen in order to maximize the energy saving. Thus, the recovery will operate only when the enthalpy difference between the outside and exhaust air is at least 2325 kJ/kg. Moreover, a bypass outdoor air strategy has been considered in order to both control the outlet air conditions after the mixing and to compensate for the overheating and overcooling effects.

- <u>System with outdoor airflow rate variation</u> (figure 5.3.4d), indicated as CAV-DCV in the figure, is characterized by the modulation of ventilation air depending on the number of occupants in the room at any given time; this can be accomplished by controlling the ventilation airflow to maintain $CO_2$ level under a fixed maximum value. The control strategy has been chosen according with the ASHRAE Standard 62.1/2004 [23]. In the case of more than one controlled zones, the system with demand control ventilation uses the highest $CO_2$ difference between the zone air and the outdoor air to set the minimum outdoor air fraction.

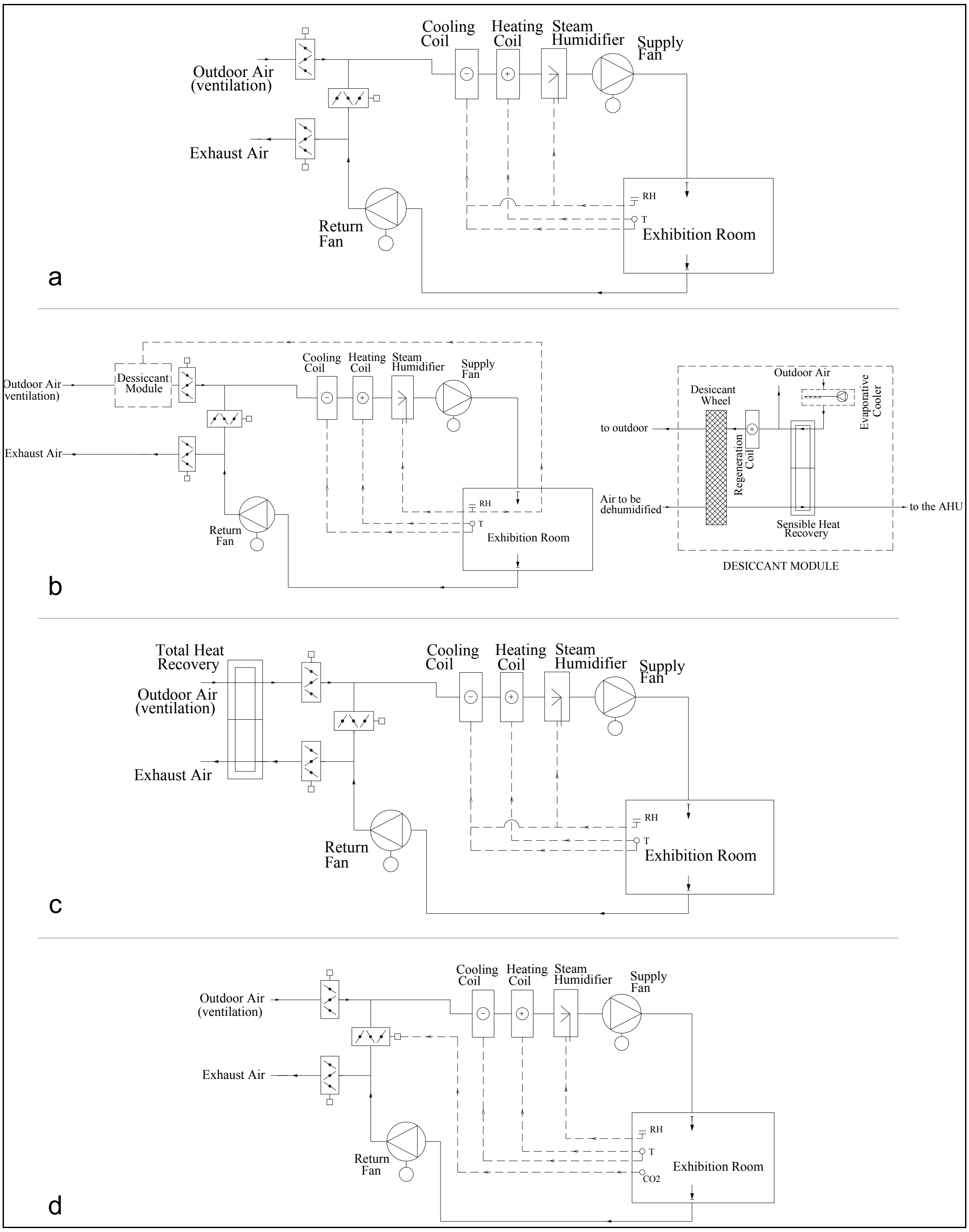


*Figure 5.3.4 - Constant Air Volume (CAV) systems – (a) CAV-BASE; (b) with desiccant module (CAV-DW); (c) with total heat recovery (CAV-ERV); (d) with demand control ventilation (CAV-DCV)*

The main characteristics of the compared HVAC systems are reported in Table V.II and in the followings:

Design total airflow rate = 8310 $m^3/h$.

- Design outdoor airflow rate = 1770 $m^3/h$ (*21.3% of the total*).
- Heating, re-heating and steam humidification by means of gas-fired heaters with mean seasonal effectiveness equal to 85% (*ultrasonic humidifier has not been considered in the analysis, as it is more suitable for local humidification rather than inserted in a AHU; moreover, for museum requirements, steam humidification is particularly appropriate also in terms of hygiene*).
- Packaged direct expansion unit (*often indicated as "roof-top"*) with a design COP equal to 3.5 $W_{THERMAL}/W_{ELECTRIC}$.
- The thermal loads vary during system operation.
- Efficiency of the total heat exchanger has been so defined (system with enthalpy wheel): sensible effectiveness equal to 75%, latent effectiveness equal to 70%.
- Efficiency of the sensible heat recovery (system with desiccant module): 80%.
- IEC efficiency: 90%.
- Ratio between primary and secondary airflows in the air-to-air heat recovery systems and in the desiccant wheel: 1.0.
- Supply and return fan efficiency (motor + fan): 55%.
- Supply (respectively, return) air side pressure drop:
  1. base system and system with demand control ventilation: 300 Pa (300 Pa);
  2. system with enthalpy wheel: 400 Pa (400 Pa);
  3. system with desiccant module: 500 Pa (500 Pa).
- The main features of the desiccant wheel are:
  1. desiccant material: silica gel;
  2. depth of the wheel: 220 mm;
  3. rotation speed of the wheel: 35 rph (*round pro hour*);
- the DW control system establishes a variable regeneration temperature (*for each hour the system evaluates the minimum value necessary for dehumidification requirements*).

Table V.II: Design thermal power values for the HVAC systems compared

| | CAV-BASE | CAV-DW | CAV-ERV | CAV-DCV |
|---|---|---|---|---|
| Cooling thermal power (kW) | 45 | 34 | 37 | 45 |
| Heating thermal power (kW) | 23 | 23 | 20 | 23 |
| Regeneration thermal power (kW) | – | 20 | – | – |
| Humidifier thermal power (kW) | 19 | 19 | 16 | 19 |

As regards the indoor temperature and relative humidity control strategies, related to the HVAC systems examined, these are briefly described in the followings. For all the configurations analyzed, indoor T (*respectively, RH*) is measured by a T (RH) sensor. In wintertime, the heating coil always controls the indoor thermal level, while RH is controlled by means of the steam humidifier. In summer, different solutions are adopted:

- for the system with desiccant module, the temperature is controlled by the cooling (*without dehumidification*) coil, while the relative humidity is handled by the desiccant wheel (*thus, re-heating of the handled air is not required*).
- with reference to all the other configurations, the re-heating of the treated air is always necessary in order to control both indoor T and RH: thus, the temperature is controlled by the re-heating coil, while the relative humidity is mainly handled by the cooling and dehumidification coil.

### 5.3.3 ENERGY PERFORMANCE SIMULATION: RESULTS AND DISCUSSION

In the figures 5.3.5 – 5.3.10 the simulation results are presented in terms of annual electric energy and gas used only by the HVAC systems analyzed, which work during all the year and 24 h per day (*lighting and all the other equipments are excluded*).

The figures 5.3.5A, 5.3.6, 5.3.7, 5.3.8, 5.3.9, 5.3.10 and 5.3.11 refer to seasonal temperature set point, while figure 5.3.5B is related to an indoor thermal level value fixed to 22 ± 1 °C thorough the year.

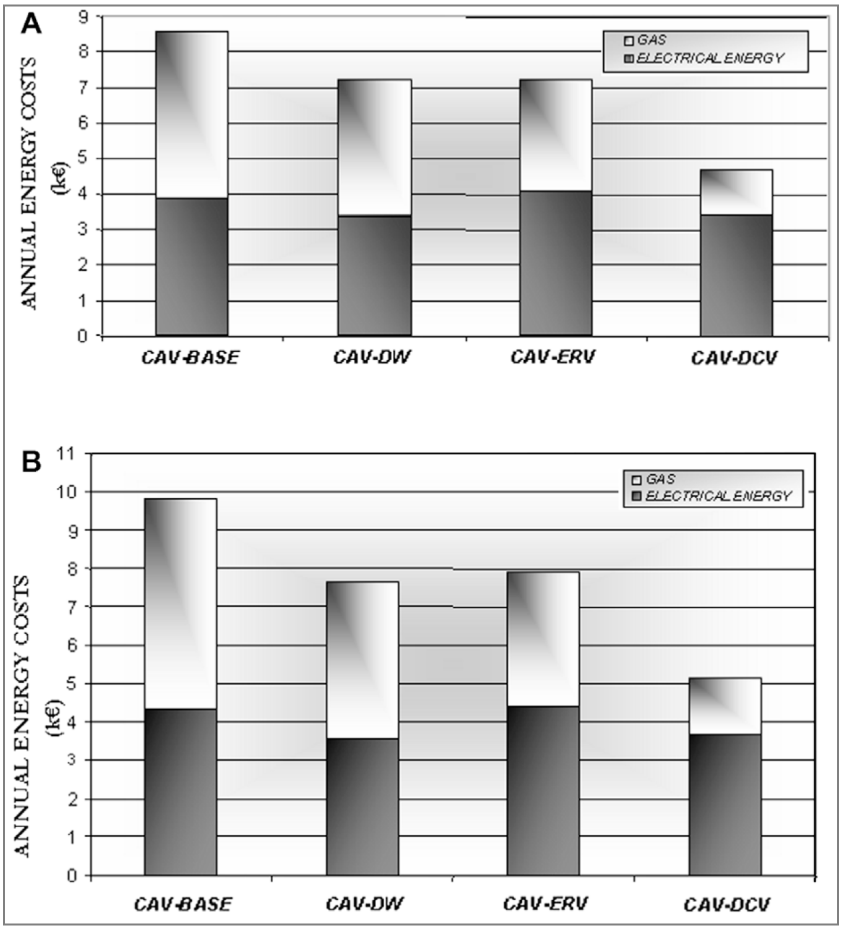


*Figure 5.3.5 - Annual energy costs: (A) Seasonal T set point; (B) Annual T set point*

The annual energy savings (figure 5.3.6), with respect to the base system, range from 15% (*systems with enthalpy wheel and desiccant wheel*) to 45% (*system with demand control ventilation*); the highest savings regard the gas use.

Moreover, considering figure 5.3.5, it can be noted that also the seasonal temperature set point induces annual energy cost savings (*ranging between 6% and 13%*) with respect to fixed temperature value, due to the lower *heating + humidification* in winter conditions and the minor *cooling + dehumidification* in summer conditions.

Annual electrical energy and gas uses, for different parts of the analyzed HVAC systems, have been also calculated and reported in figure 5.3.7.

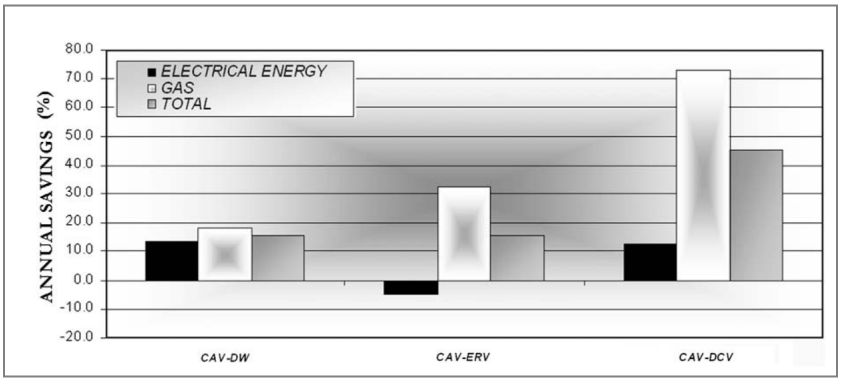


*Figure 5.3.6 - Annual energy savings with respect to base system*

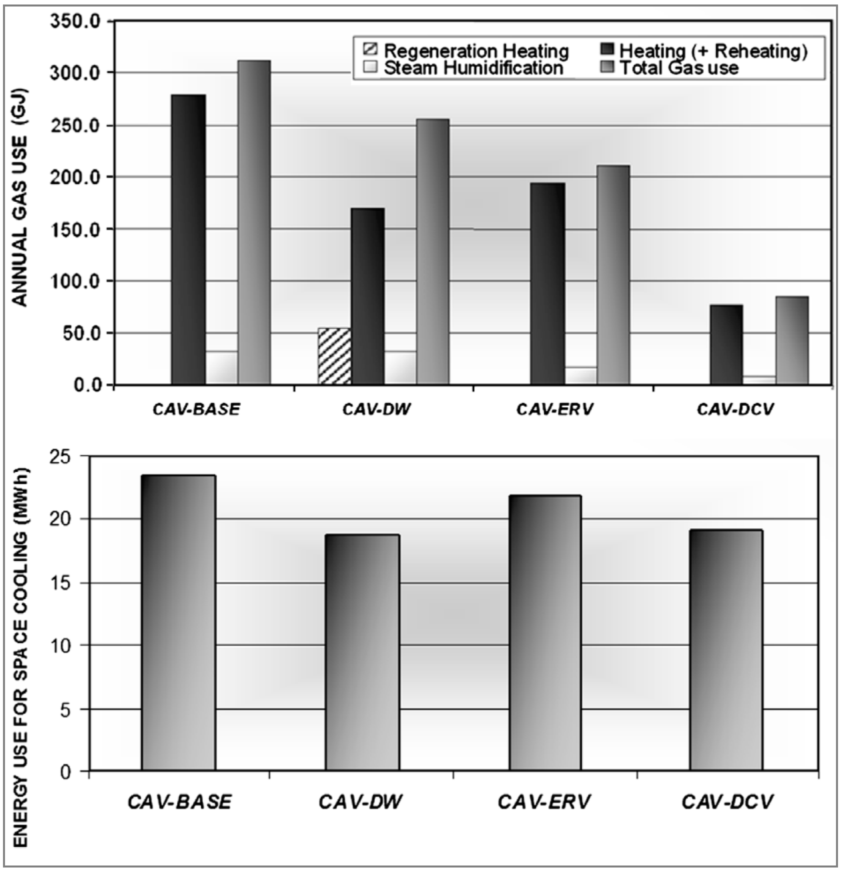


*Figure 5.3.7 - Annual energy use for different parts of the examined HVAC systems*

As regards the annual electrical energy used only for the space cooling, from the absolute values reported in figure 5.3.7, it can be inferred that the configurations which permit more consistent savings are the systems with desiccant wheel and demand control ventilation (about 20%). Instead, as regards the system with enthalpy wheel, it determines a saving around the 7%, compared to the base system that requires around 23.5 MWh.

Furthermore, with reference to annual gas use (figure 5.3.7), the system with demand control ventilation presents optimal performance, according to [24], with a total gas use lower of approximately 70% with respect to the base system, followed by the system with enthalpy wheel (32%) and desiccant wheel (18%).

Obviously only the desiccant system presents a further gas use, necessary for the desiccant regeneration. As regards the humidification (*with steam, figure 5.3.7*), the gas use for the system with demand control ventilation is hardly reduced (76%) compared to the base system, due to the minor ventilation latent load. Good performances are obtained also using the enthalpy wheel, which guarantees a pre-humidification of the outdoor air in wintertime, by means of the total heat exchange with the exhaust airflow: a saving around 50% in the gas use with respect to the base and the desiccant systems is obtained. These two last configurations require the same and the highest gas use, necessary in order to realize the steam humidification.

The same analysis relative to the annual electrical energy and gas uses has been carried out also considering a fixed annual set point, obtaining similar trends.

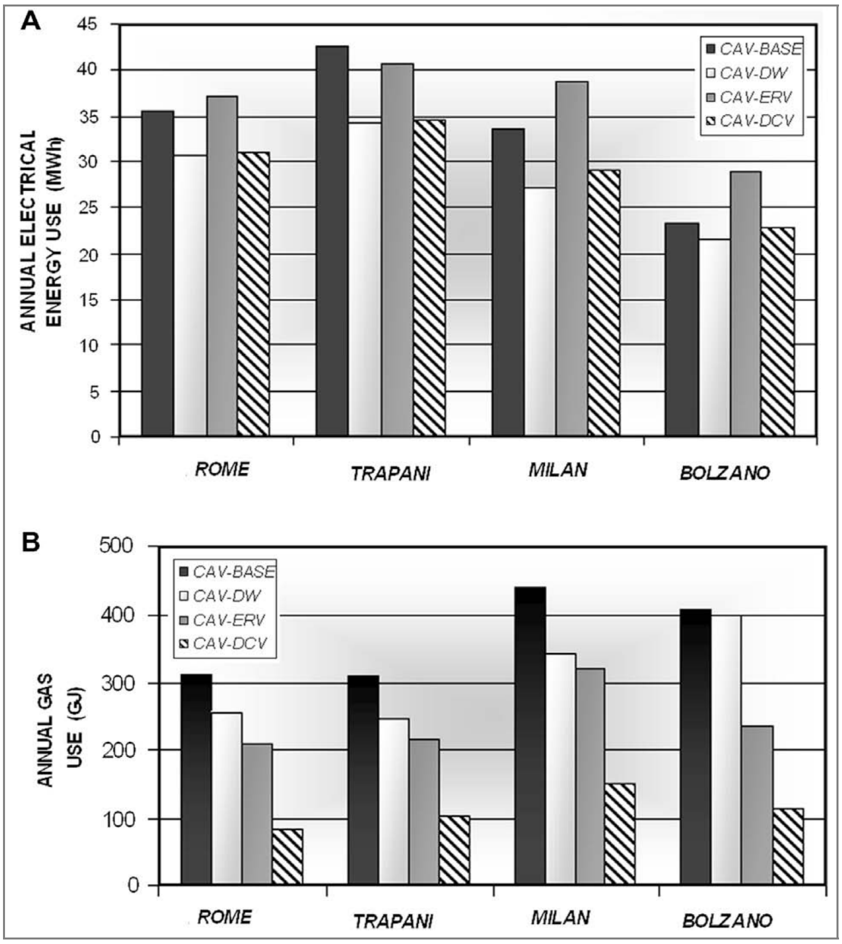


*Figure 5.3.8 - Annual electrical energy use (A) and gas use (B) for different Italian towns*

In figure 5.3.8, the annual energy use for different Italian climatic zones (*Bolzano is particularly cold and dry, while Trapani results very warm and humid*) is reported and similar trends (*with respect to the case of Rome*) have been obtained.

Also the annual gas use for the regeneration of the desiccant wheel has been calculated (*only the data for Rome are reported in figure 5.3.7*): the highest value is relative to Trapani (110 GJ), because of the highest ventilation latent load of this climatic zone in summer condition, followed by Rome (54 GJ), Milan (39 GJ), Bolzano (35 GJ).

As already mentioned in the section 5.2.1, recent ASHRAE studies about the museums [8] specify five possible control classes as regards the values and admitted fluctuations of the thermal-hygrometric parameters. The strictest classes (*AA and A*) provide a RH daily fluctuation lower than ±5% around the set point value, while larger ranges are admitted in the case of chemically stable collections (*classes B, C, D*).

In the followings, on varying the admitted RH fluctuations, the operating costs due to the HVAC work have been evaluated, according to [25], for the city of Rome.

Considerable energy savings (*figure 5.3.9*), around 40%, are achieved changing indoor RH range from 50 ± 2% to 50 ± 10%, due to the more critical working conditions of the HVAC systems in the case of stricter RH ranges. In particular, the energy costs relative to 50 ± 10% RH range are lower of 20–30% (*depending on the HVAC configurations*) with respect to 50 ± 5% range.

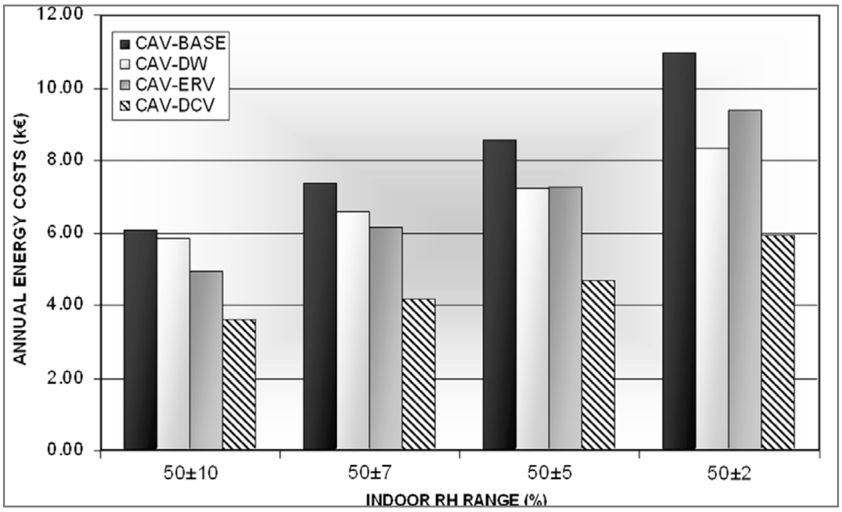


*Figure 5.3.9 - Annual energy costs for different indoor RH ranges*

A stricter control, characterized by 50 ± 2% RH range, is instead much more expensive, of approximately 28%, for the base system and for the systems with enthalpy wheel and desiccant wheel, with respect to 50 ± 5% RH range. This difference is smaller (16%) for the desiccant system, so that this solution shows an optimal performance in the case of required strict RH range.

In figure 5.3.10, considering the system with desiccant wheel, energy costs are reported for different parts of the system, for Rome, on varying the indoor relative humidity ranges.

It can be seen that, using a larger control band for RH, it leads to significant energy savings, as before emphasized with reference to figure 5.3.9. These savings arise from space cooling, space heating, and especially from regeneration and humidification energy requirements.

Results similar to those reported in figure 5.3.10 have been also obtained for the other HVAC systems examined (*obviously, there is no regeneration energy cost*).

As regards the performance in terms of dynamic thermal-hygrometric control in the exhibition room, the percent cumulative frequencies of indoor T and RH hourly values, for the various HVAC systems examined, have been analyzed, and the relative performance index values (PI) have been obtained.

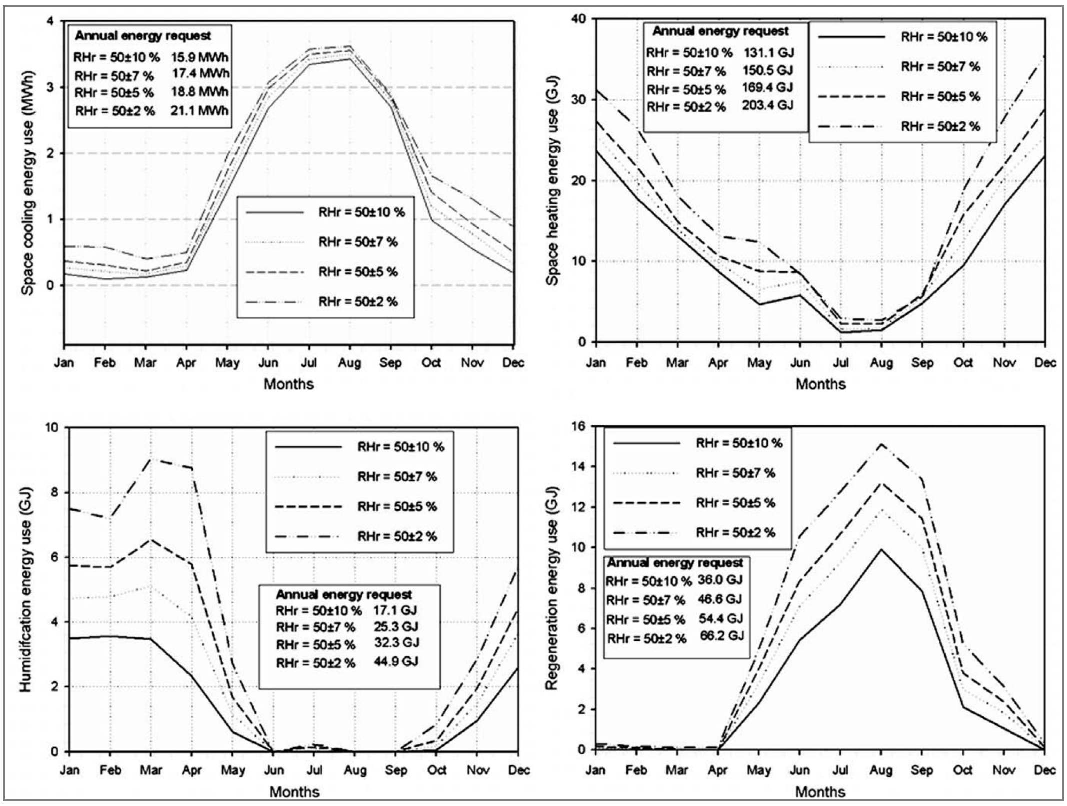


*Figure 5.3.10 - Energy costs for different components of the system with desiccant wheel on varying indoor RH ranges*

In this study, $PI_{RH}$ is intended as the percent period in which indoor RH design conditions are guaranteed [26].

In figure 5.3.11 $PI_{RH}$ is reported, while $PI_T$ (*i.e. the performance index related to the desired indoor temperatures*) is not shown because an optimal dynamic T control is guaranteed by all the configurations analyzed.

According to the literature indications, the relative humidity control (*figure 5.3.11*) is generally more critical for summer conditions, when cooling and dehumidifying are necessary, and the best performance is obtained by the system with desiccant wheel. Also the system with enthalpy wheel shows a good RH control, while the demand control ventilation strategy does not assure an optimal indoor control and stability of the indoor hygrometric rate.

Moreover, the system with desiccant wheel presents the strictest relative humidity hourly excursion with respect to the set-point value and therefore the best performance relative to the humidity short-time fluctuations; anyway, these results are not reported in this chapter.

In order to know whether the energy conservation measures proposed are cost effective, a simple payback analysis has been also carried out. Thus, with reference to the base system (figure 5.3.4a), the energy cost savings have been evaluated, as well as the equipment extra-costs, considering the Italian market.

These data are reported in the following:

- <u>system with desiccant module</u> (figure 5.3.4b): considering an extra-cost equal to 9800 € (*a reduction of the cooling coil side for the desiccant system has been also considered*) and yearly energy cost saving of about 1400 €, a payback of seven years has been obtained;
- <u>system with enthalpy wheel</u> (figure 5.3.4c): considering an extra-cost equal to 4100 € (*a reduction of the cooling coil side for the desiccant system has been also considered, even if lower compared to the desiccant system*) and yearly energy cost saving of about 1380 €, a payback of around three years has been obtained;
- <u>system with demand control ventilation</u> (figure 5.3.4d): considering an extra-cost equal to 3000 € (*no reduction of the cooling coil side occurs*) and yearly energy cost saving of about 4000 €, a payback not exceeding one year has been obtained.

The payback values obtained agree with those reported in the technical literature [27], [28] and [29].

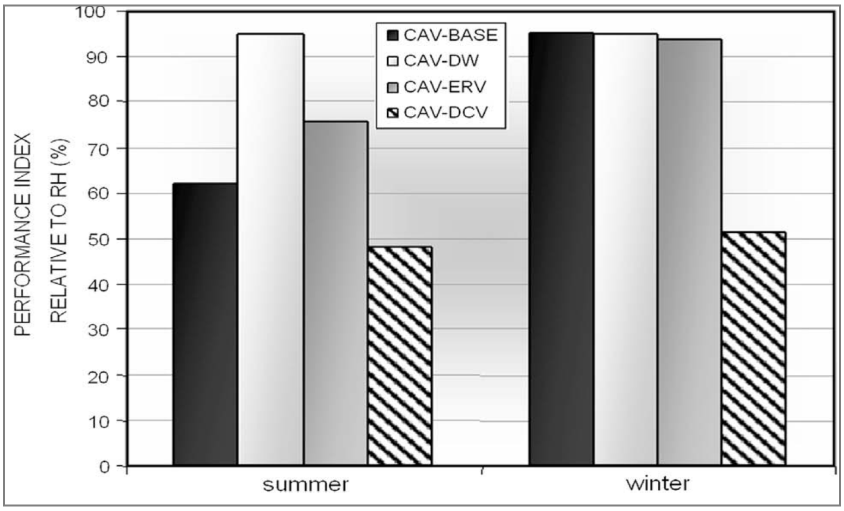


*Figure 5.3.11 - Performance Index for indoor RH in summer and winter conditions*

## 5.3.4 CONCLUSIONS: THERMAL-HYGROMETRIC CONTROL AND ENERGY REQUESTS

The potential energy saving, obtainable using various strategies for all-air systems with constant airflow in the museum air-conditioning, in this paragraph has been evaluated.

According to the international indications, a first saving strategy consists in an indoor T set point properly scheduled, instead of a unique fixed value for all the year. For example, ranging gradually from 21 °C in winter to 23 °C in summer, instead of 22 °C during all the year, an annual energy cost saving ranging between 6% and 13% has been obtained.

The use of a desiccant module, an enthalpy wheel, a demand control ventilation provide annual energy cost savings of, respectively, 15%, 15%, 45%, with respect to the base all-air system. Considerable energy savings are also obtainable if larger indoor RH range can be accepted for the artwork conservation: these savings amount to around 40% changing indoor RH range from $50 \pm 2\%$ to $50 \pm 10\%$; in particular, the system with desiccant wheel shows optimal performances in case of strict RH range.

As regards the performance in terms of dynamic thermal-hygrometric control, an optimal control of temperature is guaranteed by all the configurations analyzed. The best performance with reference to the relative humidity control, generally more critical for summer conditions, has been obtained by the system with desiccant wheel, followed by the system with enthalpy wheel, the base system and the system with demand control ventilation.

However, further investigation is required for the system with demand control ventilation, considering that this system provides the highest energy savings but appears not optimal as regards RH control.

Considering also the payback values obtained for the Italian market (*seven years for the desiccant system, about three years for the system with enthalpy wheel, less than one year for the system with demand control ventilation*), the following conclusions can be inferred:

- if the artworks preserved in a museum are particularly sensitive to indoor humidity variation, a desiccant system can be properly used, even if the equipment costs are higher (*however, today the desiccant technology applied to HVAC systems for museum applications represent an innovative technique, and so the related equipment cost, in the future, should decrease*);
- if the artworks are not much sensitive to indoor humidity variation, the use of a HVAC system with demand control ventilation is advisable, because of the lowest payback value. The system with enthalpy wheel presents intermediate features.

*In the next paragraph, in addition to the BEPS (i.e. Building Energy Performance Simulation), also the thermal, hygrometric and kinetic phenomena interesting the exhibition space have been evaluated, by means of another kind of numerical analysis: the CFD (i.e. Computational Fluid Dynamic) simulation applied in order to analyse the performances obtainable on varying the air diffusion solutions and equipments.*

## 5.4 AIR DIFFUSION PERFORMANCES IN THE MUSEUM ENVIRONMENT

### 5.4.1 INTRODUCTION: THE COMPUTATIONAL FLUID DYNAMIC APPLIED TO THE MUSEUM

In the previous paragraphs, in order to provide an appropriate conservation of the cultural Heritage, the most adapt HVAC systems have been presented and identified, both with reference to the achievable time uniformity of the indoor microclimate and with reference to the required operational costs. In particular, the energy analyses have been carried out considering the active systems for the microclimatic control working all day long, 24 h per day, such as required by the museum air-conditioning.

Besides the time stability of the microclimatic parameters in the exhibition rooms, also a high spatial uniformity is necessary and, thus, an optimal performance of the air diffusion systems is required. In this paragraph, using numerical codes based on Building Energy Performance Simulation (BEPS) and, above all, by means of Computational Fluid Dynamics (CFD) techniques, an extended analysis has been carried out in order to compare different suitable air diffusion equipments, as regards uniformity of thermal-hygrometric and kinetic fields in a typical modelled exhibition room.

As already explained, in the museums, time stability and spatial uniformity of microclimatic parameters are both necessary, primarily for correct artwork conservation [5, 30] and then for occupant thermal comfort. Thus, high performance air-conditioning systems, under several points of views, are required.

All-air systems are particularly well-adapted according to Bellia et al. [30]. They must operate constantly, so energy saving strategies are desirable [31, 15].

Numerical analysis is very convenient to predict the performances of a proposed system. A double numerical approach, both energetic and fluid-dynamic, according to Zhai and Chen [32] provides full prediction of the HVAC system performances, as regards the energy requirements and the control of the indoor thermal-hygrometric parameters in the time and within the space. In particular, the Computational Fluid Dynamics simulation referred to indoor microclimatic control has been largely used, as herein detailed. Chow [33] showed that the predicted results obtained applying the CFD technique to air-conditioning systems are useful in the system design and he verified the results by comparison with experimental data. Some authors considered CFD analysis for applications different from museums, such as offices [34], flats [35], theatre [36], lecture room [37], so the microclimatic control is oriented to occupant thermal comfort rather than to object conservation. Some other works predicted airflow and thermal comfort in indoor environments under different air diffusion models [38] or using particular air diffusers, such as nozzle duct air diffusers [39], or considering comparisons between displacement and mixing ventilation strategies [40]. Finally, some authors applied CFD to the museum microclimate evaluation [41, 42, 43], but there is little research work on the comparison of air diffusion terminals in museums, where the microclimatic control is very important as the degradation phenomena of objects are particularly sensible to indoor conditions. Moreover, previous research works on CFD techniques rarely refer to the indoor relative humidity control in museums.

In this paragraph, using a Building Energy Performance Simulation (BEPS) code and a CFD airflow program, a case study is analyzed to compare the performances of suitable air diffusion equipments for a modelled typical exhibition room.

For various part load conditions, the thermal-hygrometric parameters in different zones of the room have been evaluated, and an innovative spatial thermal-hygrometric performance index has been presented. The analysis has been carried out for two heights of the room, also in terms of variation and uniformity of the controlled parameters, in order to choose the optimum solution.

Globally estimating indoor temperature, relative humidity and their uniformity, for high exhibition rooms (5 m) the swirling diffusers have shown the best average performances, followed by the perimetrical stripes of slot diffusers, while for very high rooms (9 m) nozzle diffusers have resulted preferable.

### 5.4.2 CASE STUDY: ENERGY AND FLUID DYNAMIC ANALYSES

The modelled room is representative of many exhibition halls in typical museums, being characterised by dimensions and shape very common (*see also the Museum Ritter in Waldenbuch, paragraph 5.5 of this Thesis*). The main characteristics and design conditions of the exhibition room (see also figure 5.4.1) are:

- exterior wall and window U-values: 0.52 $W/m^2K^1$, 2.54 $W/m^2K^1$;
- indoor T: seasonally variable, as explained in the followings;
- indoor RH: 50±5 %;
- outdoor conditions: Rome - TRY data;
- occupancy level: 0.3 persons $m^2$, *i.e. 60 persons*;
- occupant metabolic rate: 1.5 met per person;
- light equipment thermal load: 15 $W/m^2$, i.e. 3 kW;
- outdoor airflow rate: 6 L/s per person.

Only the long side with the 5 large windows (*5 * 3.75 $m^2$ for the 5 m high room, 5 * 5.1 $m^2$ for the 9 m high room*) is interested by thermal loads through the wall, while the other vertical and horizontal walls separate the room from locals at the same temperature and relative humidity.

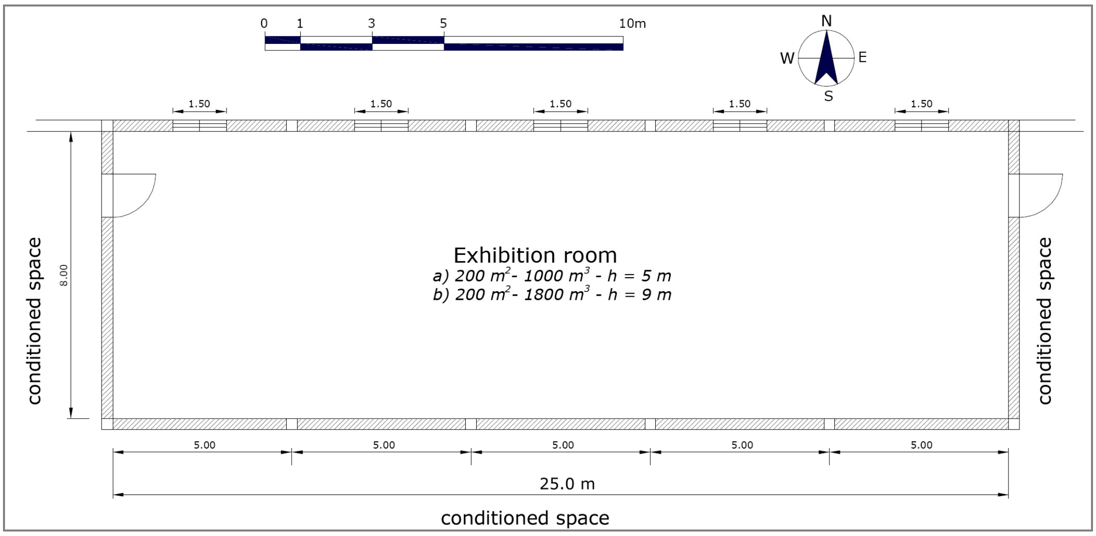


*Figure 5.4.1- Plan of the exhibition room*

The HVAC system chosen is a constant air volume system for single zone (*with a separate control of T and RH*), and its control system is based on two sensors located in the preferential artwork space. The attention has been focused primarily in the artwork conservation, considering the admitted fluctuation classes for indoor T and RH [8, 15]. As regards the indoor temperature values, a seasonal set point value has been considered for energy saving purpose [31]: 21±1 °C for December-March, 22±1 °C for April-May and October-

November, 23±1 °C for June-September; this provides, in the same time, good conservation and relevant energy savings (*as already seen in the previous paragraph*). Moreover, the occupancy and the indoor artificial lighting power for a typical museum have been hourly scheduled as time variable.

Using the BEPS (*Building Energy Performance Simulation*) code DOE 2.2 [44] a preliminary energy analysis has been carried out, in order to calculate only the data necessary to the fluid-dynamic simulation, i.e. the room thermal loads, the required airflow rates and the thermal-hygrometric conditions of the supply air. The calculated airflow rates are (*in brackets the values for the 9 m high room*):

- supply rate of 4240 $m^3$/h (*7640 $m^3$/h*);
- extraction rate of 4030 $m^3$/h (*7250 $m^3$/h*).

Three part load conditions have been considered (Table V.3): simulation A (summer), B (intermediate season) and C (winter).

The microclimatic spatial distribution in the room is evaluated through a CFD analysis, on varying the air diffuser type; the CFD boundary conditions are provided by the BEPS program, as previously described.

The conservation laws are the same for all indoor applications, while the boundary conditions change for each case. The diffusers are modelled using the momentum method [45], which represents a diffuser like an opening characterized by geometrical dimensions, outlet flux and momentum flux.

Table V.3: Main characteristics of the simulation conditions

| | Day | Day time | Visitor number | $Q_S$ (kW) | $Q_L$ (kW) | $Q_T$ (kW) | Indoor T Set Point (°C) | Indoor RH Set Point (%) |
|---|---|---|---|---|---|---|---|---|
| Sim. A | June 24th | 10.00 | 36 | 6.4 | 2.8 | 9.2 | 23±1 | 50±5 |
| Sim. B | May 20th | 14.00 | 18 | 5.1 | 1.4 | 6.5 | 22±1 | 50±5 |
| Sim. C | February 11th | 7.00 | 0 | -2.2 | 0 | -2.2 | 21±1 | 50±5 |

The outlet boundary conditions are specified establishing the airflow rate of 4 extraction grilles [20]. The indoor thermal loads are assigned using people models and lighting equipment.

The Fluent application Airpak® [46] has been used, in particular the zero-equation turbulence model, considered a valid approach in the indoor airflow numerical solve procedures, and less onerous (*as regards the compute*) than the standard k-ε approach [47].

The simulations are carried out with different thermal loads (table V.3), each in steady-state condition. A sensitive analysis has shown that the results are independent of the grid mesh structure.

Considering only mixing ventilation air diffusion strategy, the following supply equipments have been modelled:

- 1a) 12 ceiling circular diffusers (2 lines of 6);
- 1b) 10 ceiling circular diffusers (2 lines of 5);
- 2) 10 ceiling swirling or vortex diffusers (2 lines of 5);
- 3a) 5 wall grilles (on the long wall without windows);
- 3b) 9 wall grilles (on the same wall);
- 4a) ceiling slot diffusers (2 parallel stripes, on the two long sides);

- 4b) ceiling slot diffusers (4 perimetrical stripes);
- 5a) 12+12 wall nozzles (on the two short walls);
- 5b) 24 wall nozzles (all on one short wall).

A layout of the exhibition room with the different air diffusion equipments above reported is shown in figure 5.4.2. Note that the displacement ventilation strategy has not been analysed as it effectively operates only if the supply air is colder than room air, also in winter: but this doesn't occur in winter for the all-air system, here considered.

The ceiling circular diffusers and the wall grilles have fixed vanes, while, for the other diffusion equipments, the deflection angle is sub-horizontal in summer and sub-vertical in winter. The air is extracted from the room using 4 grilles situated down at the corners.

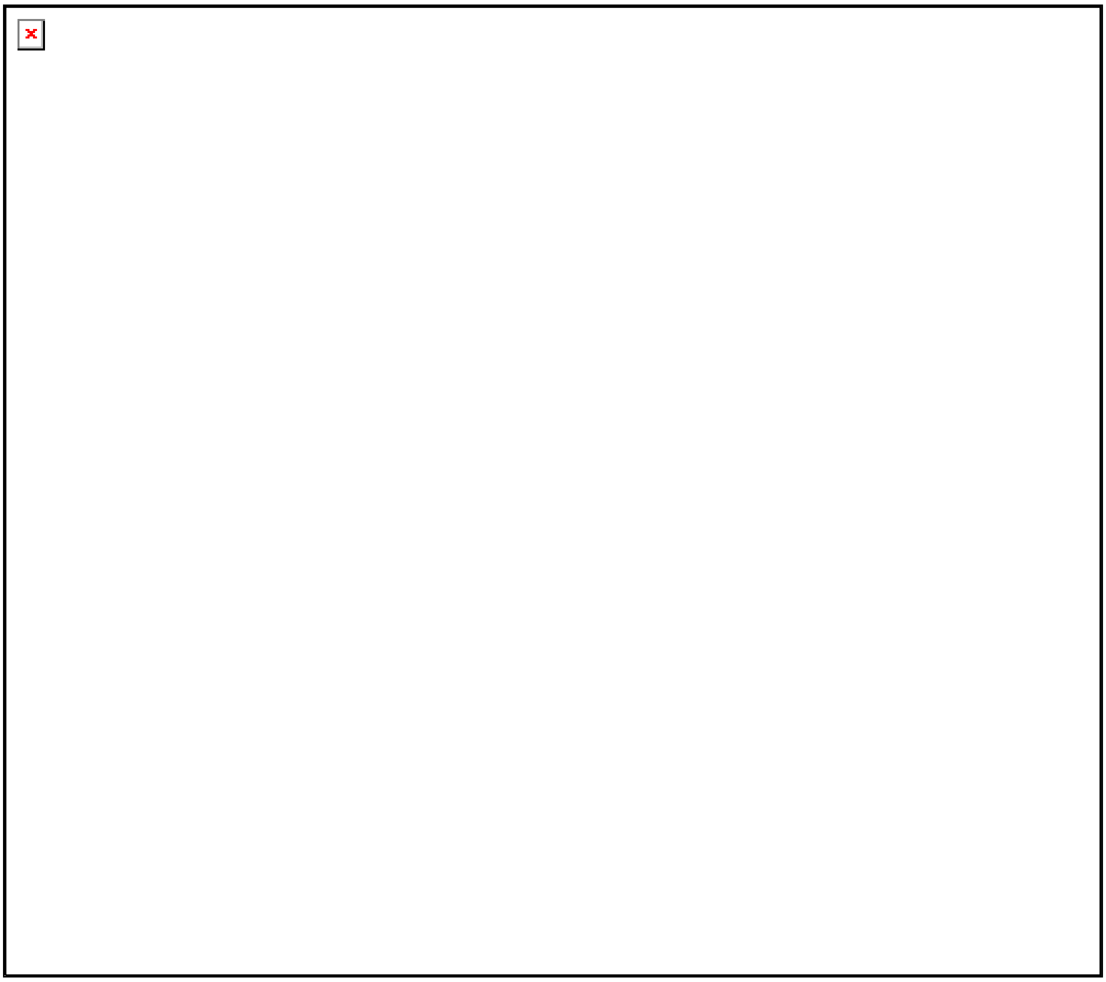

*Figure 5.4.2 - Layout of the exhibition room with the different air diffusion equipments analyzed*

Table V.4: Geometric characteristics of the analyzed volumes

| VOLUME | X LENGHT (from…- to…) [m] | Y HEIGHT (from…- to…) [m] | Z WIDTH (from…- to…) [m] |
|---|---|---|---|
| 1) preferential | 0.5 - 24.5 | 1- 4 (*) | 7.5 - 7.9 |
| 2) left side | 0.1 - 0.6 | 1- 4 (*) | 0.1 - 7.9 |
| 3) right side | 24.4 - 24.9 | 1- 4 (*) | 0.1 - 7.9 |
| 4) central volume | 0.2 - 24.8 | 1- 4 (*) | 0.2 - 7.8 |

*(*) 1 - 6 m for the 9 m high room*

The 54 simulations (*3 load conditions * 9 diffusion equipments * 2 different height rooms*) have been analyzed, particularly as regards the temperature and relative humidity spatial distribution in different regions of the room. The analysed volumes are shown in figure 5.4.3 and described in table V.4. Each CFD simulation must guarantee the T and RH set point values, measured by a double sensor installed in the preferential artwork volume (figure 5.4.3): this simulates the real automatic control system.

Therefore, the required thermal-hygrometric conditions of the supply air depend not only on the thermal loads, but also on the diffuser type, because these are function of the thermal, hygrometric and kinetic fields in the room.

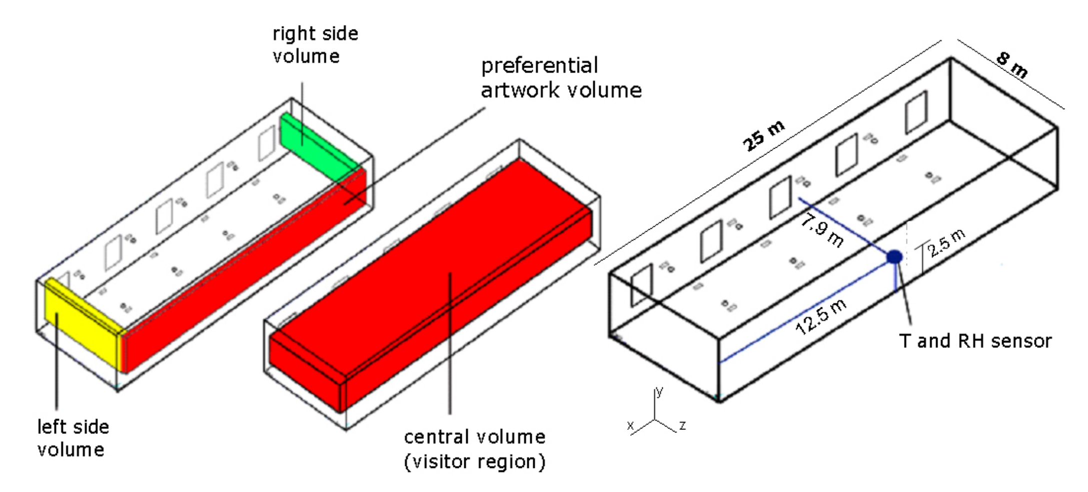

FIG. 2

*Figure 5.4.3 - The analyzed volumes of the exhibition room and the position of the T and RH sensors (for both the 5 m high room and the 9 m high room)*

Various admitted ranges have been considered for indoor T and RH, progressively more restrictive. In particular, the admitted ranges, around the set point values, are:

- ±1.0 °C, ±0.6 °C, ±0.4 °C, ±0.2 °C for the temperature;
- ±10 %, ± 5 %, ±2 %, ±1 % as regards the relative humidity.

In order to estimate the capability of the air diffusion equipments in controlling temperature and relative humidity, the spatial performance index (PI) has been introduced: it represents the percentage of the spatial points characterized by values of a parameter included in the admitted range. The PI derives from the percentage cumulative frequencies and has been calculated for both the indoor temperature and the relative humidity.

Some results are relevant, beginning with the method. For a specific indoor environment, various typical air diffusion equipments are designed, meanly as regards size, number and position of diffusers. To this end, the ASHRAE method based on ADPI (*Air Diffusion Performance Index*) has been considered.

Successively, the different air diffusion equipments considered are simulated. The optimization of supply air thermal-hygrometric conditions follows, in order to guarantee the set point values at the temperature and relative humidity sensor. The performances are evaluated with reference to the four volumes, above described (see figure 5.4.3). In particular:

- one volume represents the preferential artwork zone;
- the central volume is usually for visitors only;
- two side volumes can be used occasionally for the artworks.

The analysis of temperature and relative humidity is carried out passing gradually from wider ranges of accepted values to stricter ones; then, the spatial PI (*i.e. performance indexes*) and the mean values are calculated. Moreover, vertical thermal stratification and thermal-hygrometric spatial uniformity are analyzed.

Finally, collecting the data in medium values, it is possible to choose the most suitable air diffuser types for the specific case.

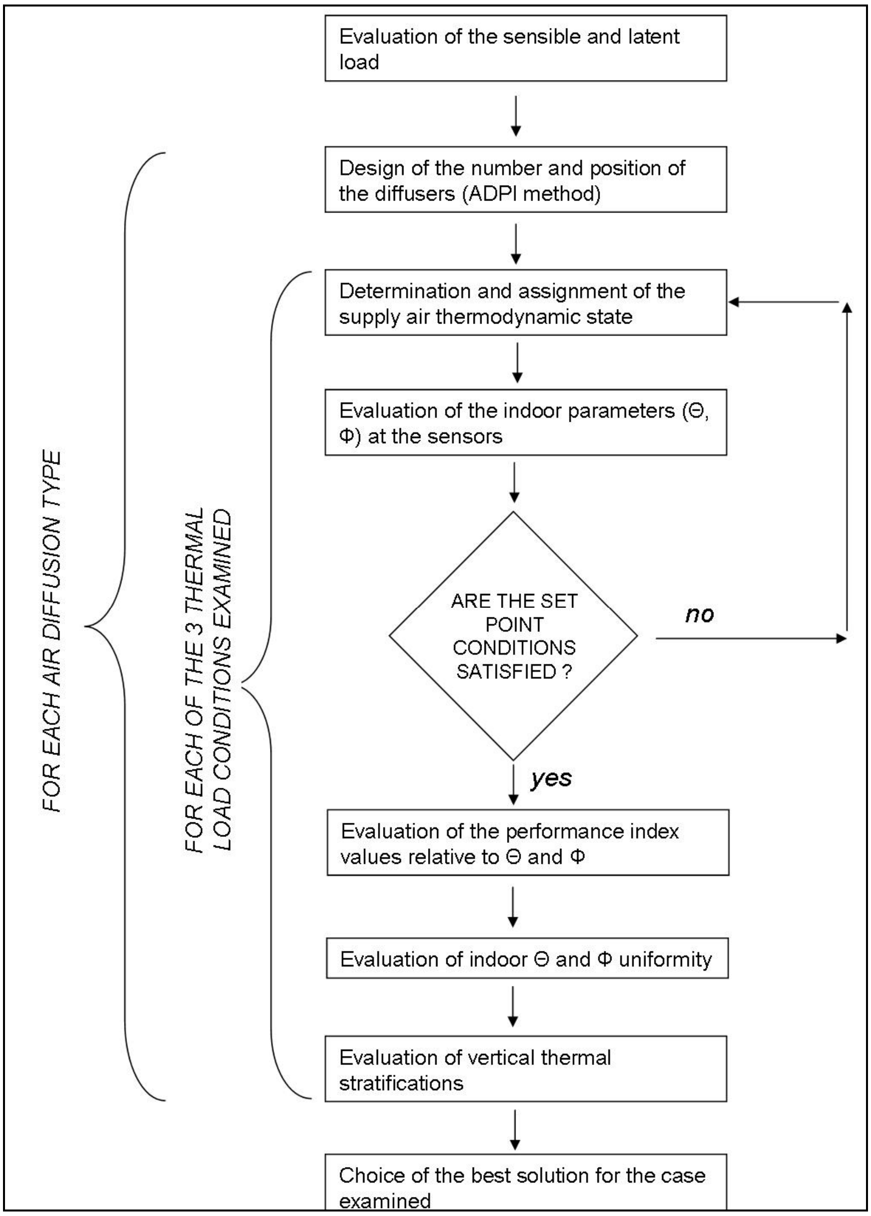


*Figure 5.4.4 – Flow-chart diagram showing the main analysis steps for the comparison of the different air diffusion equipments*

In order to describe more accurately the analysis carried out for the comparison of the different air diffusion equipments, the flow-chart diagram reported in figure 5.4.4 is useful.

A preliminary clarification is necessary about the position of the extraction grilles. According to authoritative technical literature [20] when the supply air outlets are placed in the upper zone, the best position of the return grilles is in the lower zone, in order to avoid probable short-circuits between supply and extracted air. This effect has been analysed simulating the same supply diffusers (10 swirling diffusers) for two different positions of the extraction grilles: in the upper and lower area. In wintertime and for a 5 m high room, the thermal excursion has been evaluated along the vertical direction in a central area of the room, not directly influenced by the presence of diffusers and extraction grilles.

In particular, figure 5.4.5 shows that the thermal differences along the vertical direction are lower when the extractors are down at the corners (*thermal excursion = 0.9 °C*), while the vertical excursion is 1.6 °C with ceiling extraction.

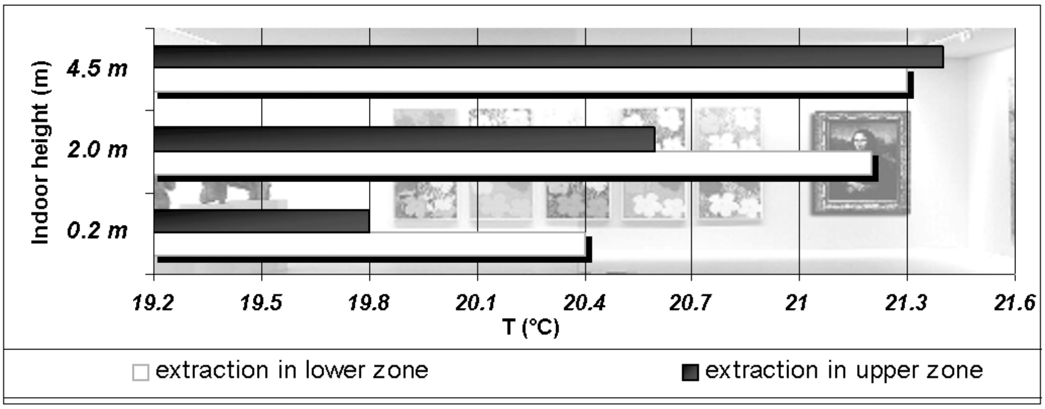


*Figure 5.4.5 – temperature values along the vertical direction in the 5 m high exhibition room, on varying the extraction grille position*

In fact, when both the warm supply air and the exhaust air are introduced / extracted from the ceiling, this causes thermal stratification phenomena, with consequential uniformity lack about the indoor temperature and relative humidity. Other negative effects are then represented by the low air circulation in the low part of the room (*stagnancy air zones*), because there isn't a complete air circulation within the space.

Contrariwise, extracting from the lower zone, the pressure differences support a better air mixing. This result is confirmed also using the performance index (PI) relative to temperature and relative humidity (*figure 5.4.6, referred to the same conditions of figure 5.4.5*).

With the ceiling extraction, on reducing the temperature and relative humidity admitted ranges, the PI diminishes much more compared to the extraction from the lower zone. Considering very strict safety conditions in the preferential artwork conservation region (*T = 21±0.4 °C; RH = 50±2 %*), $PI_T$ is about of 50 % with the ceiling extraction, 96 % with the extraction from the lower zones. Moreover, with the ceiling extraction, $PI_{RH}$ is more than 4 times worse (19 % versus 87 %).

Slightly different values, but identical meanings, are obtained analyzing the other volumes. This result would be even more glaring using other supply air diffusers, considering that the swirling diffusers guarantee optimal thermal-hygrometric performances, as shown after. Therefore, in the followings only extraction from the lower zone has been considered.

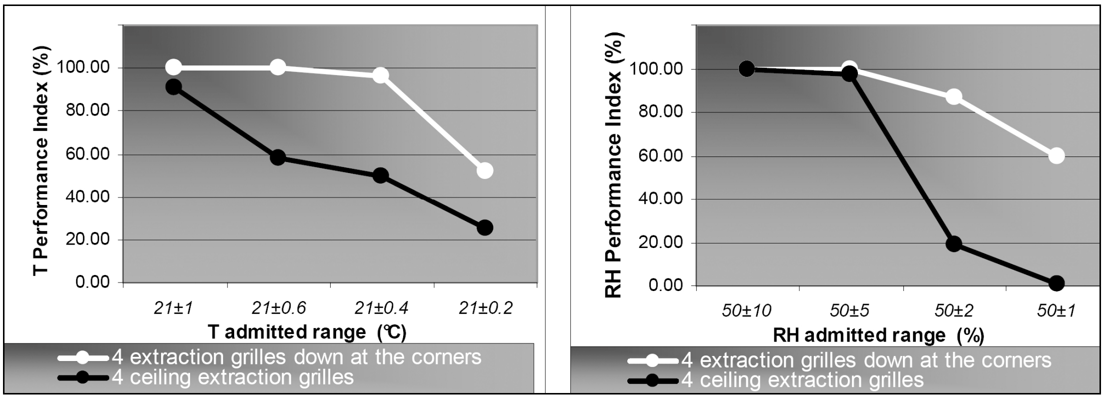


*Figure 5.4.6 – Performance index values relative to T and RH in the preferential volume of the 5 m high exhibition room, on varying the extraction grille position*

### 5.4.3 RESULTS: INDOOR T AND RH CONTROL, TEMPERATURE AND RELATIVE HUMIDITY UNIFORMITY, KINETIC FIELDS

*a) Environmental microclimatic control*

The analysis on the indoor temperature has been carried out calculating in the 4 volumes the $PI_T$ values relative to the admitted ranges (set point T ±1.0 °C, ±0.6 °C, ±0.4 °C, ±0.2 °C). This methodology has been applied to each air diffuser kind and for each simulation condition (A, B, C); as regards the first two ranges, the values obtained are always very close to 100 %. With reference to the admitted variations ±0.4 °C and ±0.2 °C, the average values of the $PI_T$ in the 4 volumes are reported in figure 5.4.7a.

As regards the 5 m high room, the best performance competes to the perimetrical slot diffusers ($PI_T$ = 74 %), due to the dedicated diffusion stripes. In fact, 3 of the 4 volumes (*preferential, left side, right side*) have overhanging diffusers, providing a capillary covering of these zones; this capability is minor in the case of 2 parallel slot stripes.

Good performances (*mean $PI_T$ around 70-80 %*) are obtained using swirling diffusers, 10 ceiling circular diffusers, 5 wall grilles, 12+12 wall nozzles. The other diffusers show minor performances. As regards the 9 m high room, the nozzles show the best performance ($PI_T$ higher than 80 %) in both the configurations; good performances (*mean $PI_T$ around 70 %*) are obtained with swirling diffusers, perimetrical slot diffusers, 9 wall grilles.

As regards RH, three ranges of acceptability (50±5 %, 50±2 %, 50±1 %) have been considered. The RH control performances of the various air diffusion equipments are reported in figure 5.4.7b. The $PI_{RH}$ is calculated considering mean values relative to the 4 volumes, the 3 load conditions (A, B, C) and the three ranges of acceptability.

For the 5 m high room the swirling diffusers (*$PI_{RH}$ slightly higher than 80 %)* show cleanly the best performance, followed by the nozzles (*$PI_{RH}$ higher than 60 %*), while the other diffusers present $PI_{RH}$ values between 40 % and 55 %; for the 9 m high room all the diffusion types show good performances ($PI_{RH}$ values between around 70 % and 85 %).

Considering globally the results for the 9 m high room, they are generally better compared to the 5 m high room: this can be explained considering that the supply airflow rate for the higher room are much higher, while the number of diffusers is the same. Therefore, with reference to the 9 m exhibition room, are verified both higher supply air velocity and major related induction effect.

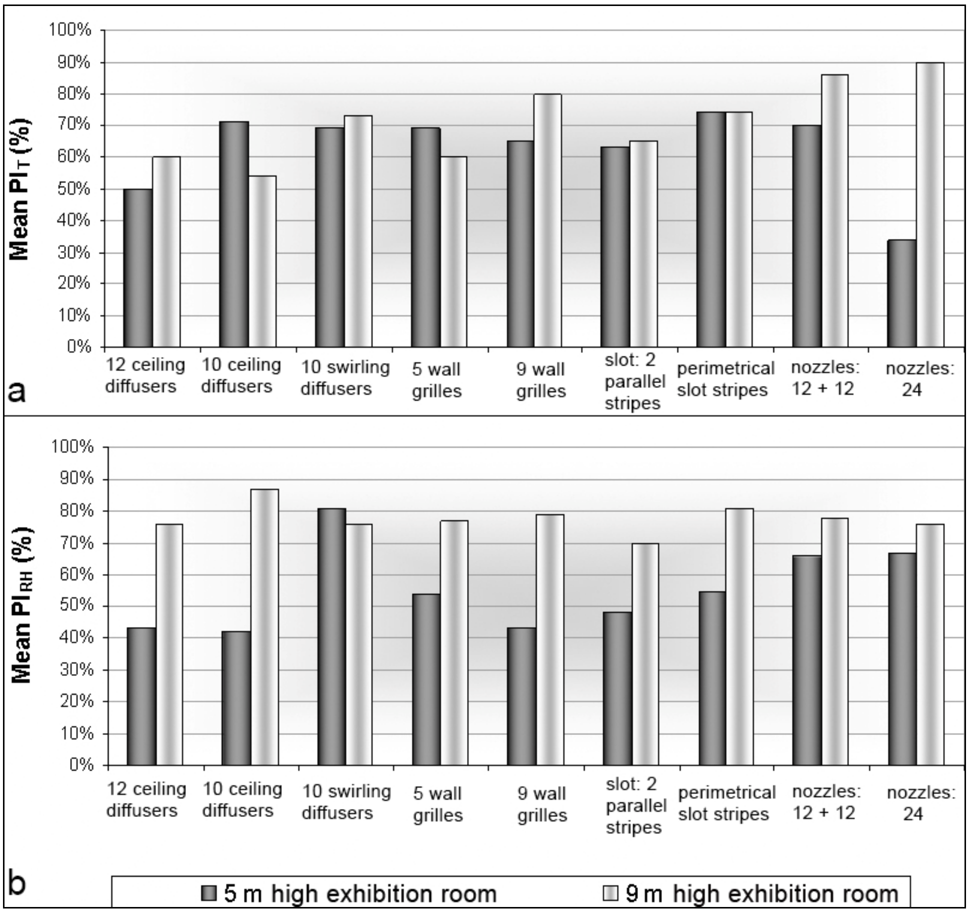


*Figure 5.4.7 - $PI_T$ and $PI_{RH}$ mean values relative to the four volumes of the exhibition room and to the three simulation types (A, B, C). a) $PI_T$ mean values relative to $T_{SET\,POINT} \pm 0.4°C$ and $T_{SET\,POINT} \pm 0.2°C$; b) $PI_{RH}$ mean values relative to RH=50±5%, 50±2% and 50±1%*

Focusing the attention on the preferential artwork region (*analysis not reported in any figure*), where an optimal RH control is particularly influent, the performance obtainable using swirling diffusers becomes much better compared to the other diffuser types. In fact, considering air diffusion by means of swirling diffusers, during a typical summer part load conditions (for example), the RH values calculated all around the exhibition room are very similar, with a spatial excursion smaller than 2.5%.

Analyzing what happens relatively to the three load conditions (*summer, intermediate season, winter*), the swirling diffusers guarantee very high performances, also when the RH admitted range is very strict (50±2 %). In particular, only these diffusers are "*seasonal indifferent*", providing optimal results in all the load conditions.

The swirling diffuser high performances have to be underlined, considering that the hygrometric control should be optimal, in order to assure that in the artwork materials there are not vapour absorption or desorption. This because the differential adsorptions, inducted on the same artwork exposed to different spatial RH values, can cause the same physical damages inducted by temporary lack of stability [3].

*b) Spatial and vertical thermal-hygrometric parameters excursions*

As regards indoor the indoor temperature uniformity, $\Delta T_{MAX}$ (= $T_{max}$ - $T_{min}$) has been evaluated for the central volume and reported in figure 5.4.8. The results show that, meanly, all the diffuser typologies guarantee good uniformity.

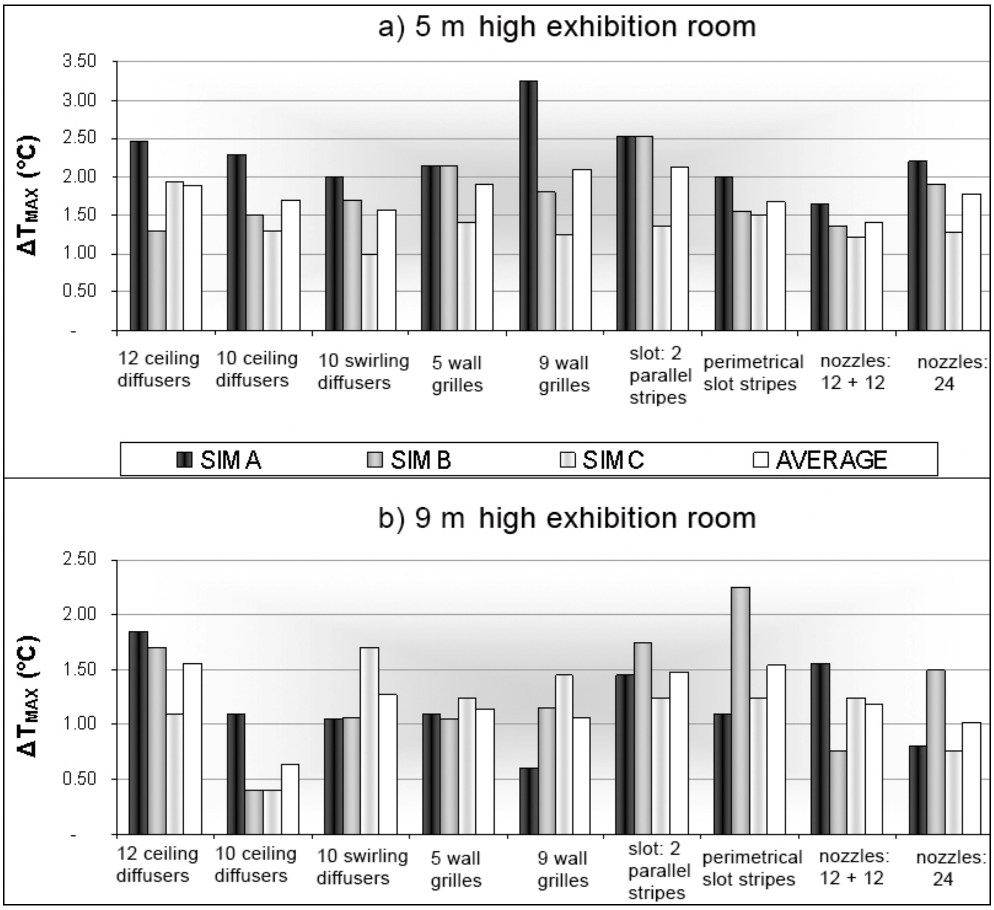


*Figure 5.4.8 - $\Delta T_{MAX}$ (i.e. $T_{max}$-$T_{min}$) in the central volume of the 5 m (a) and 9 m (b) high exhibition room*

With reference to indoor relative humidity uniformity, $\Delta RH_{MAX}$ (= $RH_{max}$ - $RH_{min}$) has been calculated for the central volume and reported in figure 5.4.9.

For the 5 m high room, the swirling diffusers show one of the best results (an average $\Delta RH_{MAX}$ of about 3.5 %), while some other diffusers show average $\Delta RH_{MAX}$ higher than 4.5-5 %; this gap is even larger along the vertical direction, because the stratification effect (*see figure 5.4.8, below described*) increases the lack of uniformity. For the 9 m high room, swirling diffusers and nozzles are ones of the best equipments.

*Moreover, from figure 5.4.9, it can be also inferred that containing the RH spatial excursion is usually more complicated in winter than in summer.*

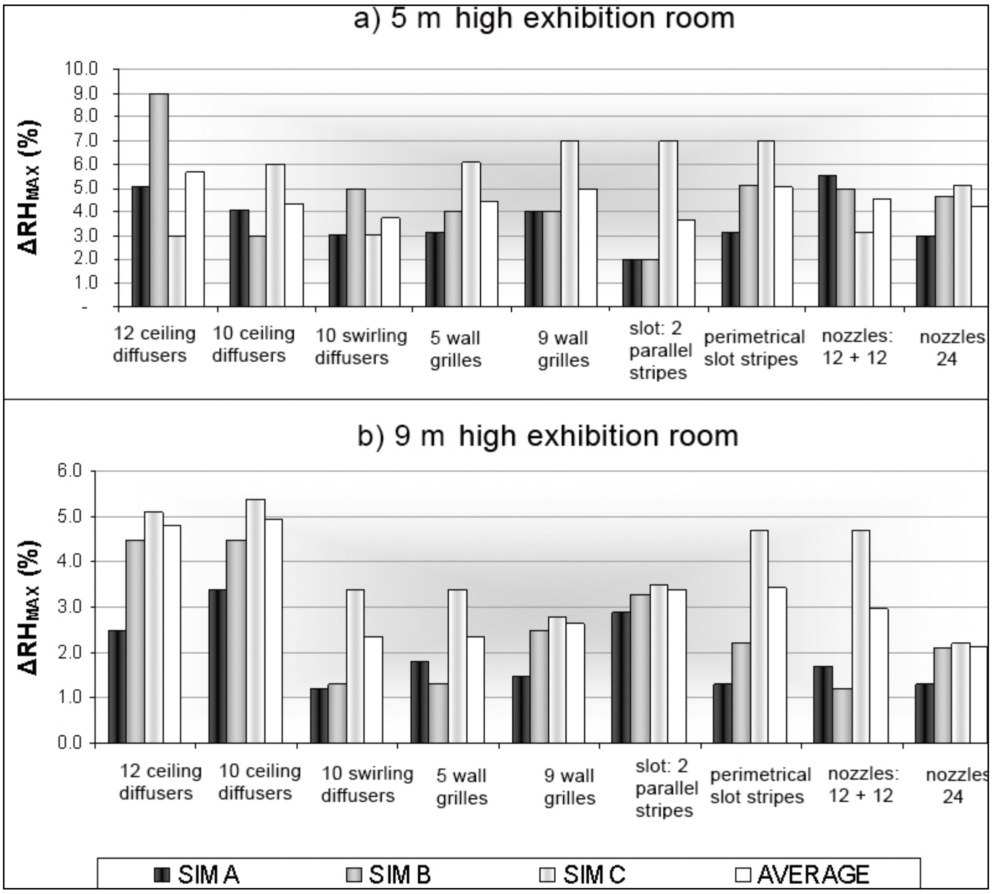


*Figure 5.4.9 - $\Delta RH_{MAX}$ (i.e. $RH_{max}$-$RH_{min}$) in the central volume of the 5 m (a) and 9 m (b) high exhibition room*

As regards the vertical thermal stratification, considering thermal levels values at different elevations (*0.2 m, 2.0 m, 4.5 m for the 5 m high room; 0.2 m, 2.0 m, 4 m and 6 m for the 9 m high room*), $\Delta T_{MAX}$ is reported in figure 5.4.10.

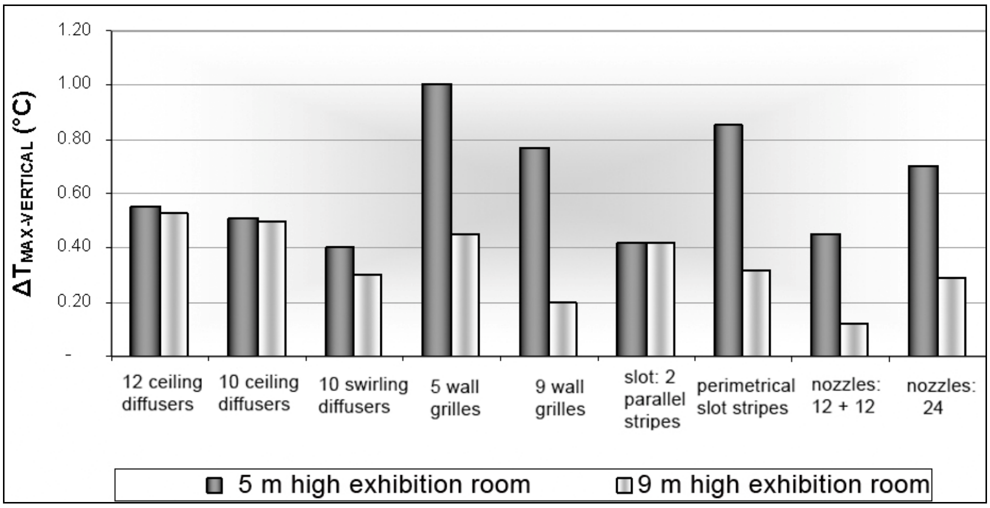


*Figure 5.4.10 - $\Delta T_{MAX}$ in the vertical direction of the exhibition room, obtained averaging the results relative to the three simulations (A, B, C)*

For the 5 m high room, the swirling diffusers show the best performance ($\Delta T_{MAX}$ *around 0.4 °C between the elevation of 0.2 m over the floor level and 4.5 m*). For the 9 m high room, the 12+12 wall nozzles result the best ones (figure 5.4.10).

For the 9 m high room, the 12+12 wall nozzles represent the best solution ($\Delta T_{MAX\text{-}VERTICAL}$ of about 0.1 °C between the elevation of 0.2 m above the floor level and 6.0 m).

Also in this case, the results for the 9 m high room are generally better compared to the 5 m height: this has been already explained above (*i.e. the supply airflow rate for the higher room is increased, while the number of diffusers is the same.).*

*c) Air speed and age of air*

With reference to each load condition and diffuser type analyzed, the air speed values calculated are suitable for both the artwork conservation and the thermal comfort. In a zone between 1 m and 4 m of height, the maximum speed doesn't exceed 0.31 m/s, while the average value is generally comprised between 0.1 and 0.15 m/s. In wintertime, the air speed is usually lower, as there is not the fall-down of cold supply air.

The results have not shown significant differences among the various diffusion types; in fact, each air diffusion strategy has been carefully designed and modelled, in order to optimize type, number and position of the diffusers; therefore, the performances of all the diffuser types are goodish.

Also with reference to the 9 m high exhibition room, the results have not shown significant differences among the various diffusion types; in this case the air speed is higher but anyway acceptable.

As regards the "age of air", this parameter has been calculated in the occupied zone, therefore considering the entire volume until a height of 2 meters: even if this index usually is not evaluated, anyway it gives information on the freshness and so on the quality of the indoor air [48].

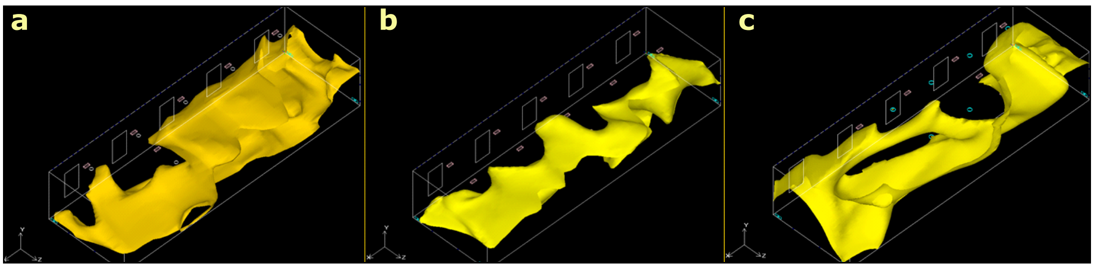


*Figure 5.4.11 - Room zones with age of air equal to 850 s, in winter time, for: a) swirling diffusers, b) 5 wall-grilles, c) ceiling circular diffusers*

With reference to the 5 m high exhibition room, collecting and averaging the results of the three part load conditions, this study showed that each diffusion modality analyzed provides a good air freshness. The highest local mean age of air (*however lower than 920 s, i.e. ≈ 15 minutes*), in the occupied zone, is induced using the 5 wall-grilles; the other diffusers show slightly better results. As regards the maximum age of air (*also in this case in the breathing* *region*), the highest value has been obtained using the 9 wall-grilles (1220 s). Globally, the best results are obtained using the swirling diffusers, that guarantee values lower of 150 s with respect to the wall-grilles, also in winter time, when the age of air is averagely higher because of the stratification of the supply air.

In figure 5.4.11, the room zones in which the age of air is equal to 850 s are reported, in wintertime, for three kinds of diffusers (*the other zones of the room are generally characterised by higher values*). The swirling diffusers show the higher air freshness and uniformity and this results has been confirmed also in the 9 m high exhibition room.

### 5.4.4 CONCLUSIONS: THE COUPLING OF BEPS AND CFD ANALYSES APPLIED TO A MODELLED EXHIBITION ROOM

A double numerical approach (energy and CFD analysis) has been presented with reference to the air-conditioning system for a typical exhibition room of a simulated museum in Rome, considering an all-air system and different supply air diffusion equipments. The room simulated is representative of many exhibition rooms in museums. The air is extracted always using 4 grilles situated down at the corners of the room; in fact, some preliminary analyses have shown that extraction from the ceiling is penalizing when the supply air is introduced from the same zone. It is important to note that:

- many advantages can be obtained applying a coupled numerical approach to the museum environment; in particular, the use of CFD analysis provides detailed evaluations of the spatial distribution of the main indoor microclimatic parameters (*such as temperature, relative humidity, air speed*), and this is very important for the choice of the best diffusion equipment for each case;
- a spatial performance index has been introduced, in order to evaluate separately the performances of the different air diffusion equipments in various zones of the room (*both the zones containing the artworks and those for the visitors*).

As regards the rooms analysed, the following conclusions can be drawn. All the air diffusion equipments considered result well-adapted to the museum microclimatic control.

For the 5 m high rooms, globally estimating indoor the indoor temperature, relative humidity, and microclimatic uniformity, the air diffusion equipments showing the best average performances are the swirling (vortex) diffusers; they are also the best in containing the vertical stratifications.

Above all as regards the relative humidity control, the swirling diffusers guarantee much better results (*performance index slightly higher than 80 %*), followed by the nozzles (*performance index higher than 60 %*), while the other solutions present performance index values between 40 % and 55 %. Considering that relative humidity is the most influent indoor microclimatic parameter for the conservation of the artworks, the swirling diffusers represent an optimal design solution.

Good performances are also obtained using also perimetrical stripes of slot diffusers, which determine a capillary covering of all the volumes analyzed, due to the dedicated diffusive bands); this is not true for the same diffusers assembled in 2 parallel stripes.

For the 9 m high rooms, the best average performances have been obtained by the nozzles, above all when located on two short walls (12+12 nozzles) instead of on only one wall (24 nozzles); however, also in this case the swirling diffusers present still good performances.

Focusing the attention on the preferential artwork region, where an optimal RH control is particularly required, the swirling diffusers become much better compared to the other diffuser types; besides, only these diffusers are "*seasonal indifferent*", guarantying optimal results in all the load conditions. Using any air diffuser type, containing the hygrometric spatial excursion is usually more complicated in winter than in summer.

Finally, as regards the air speed in the rooms, the values calculated are fairly suitable for both the artwork conservation and the thermal comfort, with reference to all the analysed load conditions and diffuser types. The same satisfactory results have been achieved also as regards the parameter *age of air*.

## 5.5 THE MUSEUM RITTER EXPERIENCE[3]

### 5.5.1 INTRODUCTION: THE MUSEUM RITTER AND THE ENOB PROJECT

The museum was built during the years 2004 – 2005, designed by the Berlin architectural office headed by Max Dudler, in order to host the private collection of Marli Hoppe Ritter, the granddaughter of Alfred Ritter, the founder of the World famous chocolate factory.

*Figure 5.5.1 - The Museum Ritter in Waldenbuch (source: EnOB)*

The Museum is located in Waldenbuch (*Germany*), a little village near Stuttgart. According to the studies previously reported (*that underline the high energy request quite typical in museums, for the necessary functions of lighting, heating, ventilation and air-conditioning*), the designers of the Ritter conceived a high energy effective building, thinking accurately both the envelope structures and the installed technical equipments.

*3 This paragraph has been written studying and reassuming the design and monitoring documentation that the research unit of the FBTA, Division of Building Physic & Building Services of the University of Karlsruhe, showed me during a visiting period in the Winter 2008 – 2009. Thus, all the analyses here reported have been entirely carried out by the FBTA and EnOB teams. I apologize for eventual incorrect interpretations.*

The Museum Ritter architecture was inspired toward a high sustainability direction, following design criteria of high ecological compatibility and energy and economic efficiencies. Despite the very strict indoor conditions required, as regards the temperature levels, the air relative humidity values and the necessary environmental lighting, a significant part of the energy requirement is satisfied using renewable energy sources; in particular:

- solar radiation → *thermal solar collectors and photovoltaic panels;*
- biomass → *wood pellets;*
- geothermal energy → *earth buried water pipes.*

When in 2005 the construction operations finished, the achievable energy performance have been monitored, continuously, by the FBTA - Institute of Building Physics and Building Services of the University of Karlsruhe (TH). This academic institution already was involved in other environmental monitoring projects, being a referent of the German Government as regards the EnOB program, a federal republic project that promotes and funds the energy efficiency in the building sector[4]. In particular, within a European context oriented towards a future characterized by higher efficiency referred to the energy uses, the German Republic, with legal prescriptions aimed to limit the building sector energy requests (*EnEV 2007*) and with federal programmes (*EnOB*) that fund best practices, tries to orient the actor of the building activity towards new energy efficiency concepts. Therefore, the building energy efficiency is strongly promoted, with reference to both the new construction (EnBau) and the building renovations (EnSan). The main targets of both these programmes, exhaustively explained in the Chapter 4 of the Thesis, involve the necessity in reducing energy use, environmental carbon emissions, in order to fight effectively the climate changes.

In particular, the aim of the research program "*Energy Optimized Building - EnOB*" is the target to cut of the 50% the primary energy consumption, such as identified as maximum admitted limit by the current energy saving regulations (*Energieeinsparverordnung - EnEV 2007*).

In the previous paragraphs of this Chapter, the museum energy requirements and the design critical aspects, characterizing this application, were described. In particular, the very restrictive microclimatic conditions (*e.g. temperature equal to 22 °C in summertime, with a RH of 50%*) require an energy demands that, considering the elevated external (*cold winter, warm summer*) and internal (*high crowding, high natural and artificial lighting*) gains, are very hard to reduce. Thus, the best technological solutions, with reference to the energy performances of the technical systems (*e.g. air-conditioning and lighting*) and the adoption of all the available renewable energy sources are absolutely necessary for this kind of application.

The Museum Ritter was designed focusing the attention on the environmental compatibility and the energy efficiency. Also the owners were very interested in these concepts, so that they were available to support and pay the financial extra-costs *(not so higher*) derived from the design and the adoption of non-standard technical solutions.

The Berliner architect Max Dudler, in order to achieve the best synergy required for a high quality project, coordinated the whole design team. In particular, the technical equipments and the energy aspects were designed by the Karlsruhe IP5 engineering office.

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*4 Energy optimized Buildings EnOB: see more on www.enob.info*

### 5.5.2 THE ARCHITECTURE: BUILDING DESCRIPTIONS AND THERMAL PHYSIC BEHAVIOURS

The building plan is characterized by a well-defined geometry. In particular, the plan shape, a quadrate of 44 x 44 metres, clearly calls to mind the famous shape of the chocolate tablet. The plan is divided, functionally, in two separate wings, between which there is an open atria, covered by a skylight. The two wings (*each one constituted by two floors*) are defined as a trapeze, connected by a covered passage, with the aim to create a connection among the forest that lies behind, the near factory and the town that, on the contrary, are located on the main side of the Museum. The higher wing (*figure 5.5.1, red coloured area*), hosts the Museum. In particular, at the ground floor are positioned the foyer (*with an open space book-shop*), the cafeteria, the wardrobe & services, and a big exhibition room. The second floor, instead, was exclusively dedicated to the exhibition spaces.

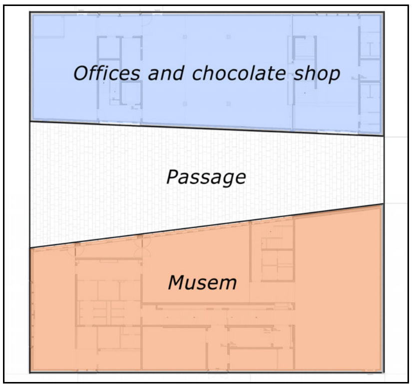


*Figure 5.5.2 - The plan of the museum and the two different wings (source: FBTA for EnOB)*

As regards the smaller trapezoidal wing (*figure 5.5.2, blue coloured area)*, it hosts the chocolate shop (ground floor), offices and educative laboratories (second floor).

As above-mentioned, each trapeze contains two floors. Several mezzanine floors and technical intermediate spaces have been realized, designed to place the heating and cooling coils and machines, the equipments for the central ventilation, and above all to provide an innovative and interesting solution about the lighting. In particular, at the second floor, the space lighting is obtained mixing (*in an dedicated technical space*) daylight and artificial illumination equipments. In particular, over the main exhibitions rooms at the second floor, a space of 1.3 meters has been projected to host the described lighting mezzanine.

The main museum floor (*figure 5.5.3*) is the second one (*even if an important exhibition room is positioned also at the ground floor*); in particular, three exhibition spaces are here placed.

At the ground floor, together with cafeteria, bookshop, services and exhibition room also other spaces are located, among which the cafeteria kitchen, a computer room and the wardrobe.

The second (*smaller*) wing contains the chocolate shop at the ground floor, while, at the upper level are located the administration office (400 m$^2$), the chocolate exhibition and laboratory; in this spaces, visiting schools can assist to the chocolate process production and manufacture.

In table V.5 the main dimensions of the Museum are reported. The envelope structures have been designed choosing the best technological solutions in order to achieve high thermal performances, both under the environmental comfort and the energy efficiency points of view.

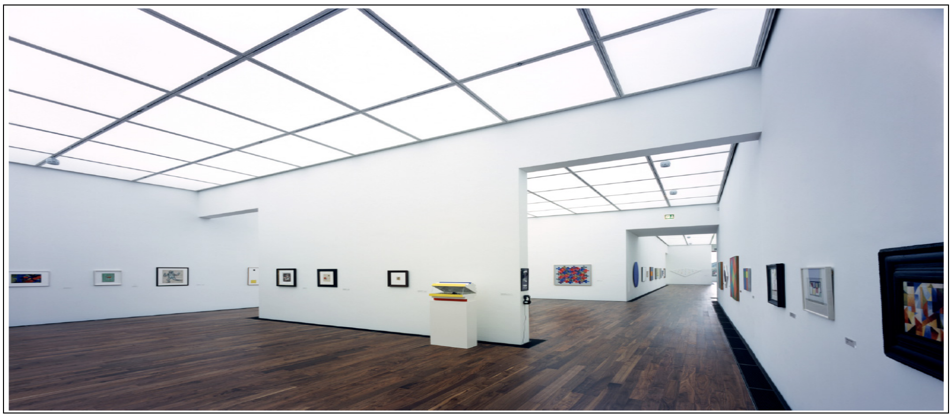

*Figure 5.5.3 - The exhibition rooms at the first floor*
*(source: FBTA for EnOB, photo: Victor S. Brigola)*

Table V.5: Geometrical characteristics of the Museum Ritter

| | | |
|---|---|---|
| *Gross Floor Area* | *3.910* | *$m^2$* |
| *Net Floor Area* | *3232* | *$m^2$* |
| *Museum net floor Area* | *1063* | *$m^2$* |
| *Chocolate Shop net floor Area* | *1152* | *$m^2$* |
| *Adaptable space Volume* | *13100* | *$m^3$* |
| *Surface to Volume Ratio (S/V)* | *0.54* | *$m^{-1}$* |

The external coating of the building was constituted by a surface realized in limestone; the glazed surface (*considering the whole exposed shell and so also the skylight*) represents about the 30% of the whole building external surface.

Generally, the main exhibition rooms do not present windows, except two smaller spaces at the second floor (*the so-called "landscape rooms"*). The outer walls present quite diversified windows amounts, ranging by the 17%, with respect to the wall opaque surface of the eastern façade, to the 50% of the north-exposed one. This because, in summer time, the north-exposed windows don't cause elevated penalizing radiant heat gains.

The wall structures present very high insulation, containing 14 cm of rock wool, so that that the stationary thermal transmittance results equal to 0.23 $W/m^2K$. An elevated insulation characterizes also the basement structure, with an $U_{VALUE}$ equal to 0.38 $W/m^2K$, while, with reference to the ceiling structure, 16 cm of rock-wool have been designed, so that the resulting $U_{VALUE}$ is equal to 0.21 $W/m^2K$.

About the window thermal behaviours, a three-glazing system was initially thought, but, because of the high costs (*higher than the achievable energy benefits*), considering that some windows are height more than 4 meters, finally a double-glazing system was installed, anyway with an $U_{VALUE}$ quite reduced - 1.3 $W/m^2K$. At the same time, in order to reduce the solar radiation entering, in summertime, into the indoor space (*and so inducing a great penalizing heat gains, also dangerous for the impact of the direct radiation on the artworks),* highly selective sunscreen glasses have been studied ($g_{VALUE}$ *equal to 0.34*). For the 3 large windows south-exposed, integrated external shading has been designed,

### 5.5.3 INDOOR CLIMATE AND CONSERVATION CONDITIONS

As already described in the paragraph 5.5.1, the energy demand inside the Museum environment is related both to the visitor and employed people environmental comfort (*and so including air temperature, relative humidity, clean air*) and to the necessity of a well controlled microclimate, in order to guarantee an enduring conservation of the exposed artworks.

Table V.6: Storage conditions for some materials and compatibility with the human comfort

With reference to the first necessity - *the environmental comfort for the visitors and the workers* - the usually boundary conditions of any other application can be adopted as regards the temperature and relative humidity set-points, as well as about the minimum outdoor air changes. In order to obtain the cited comfort conditions, an operative temperature between 20 and 25 °C can be appropriate, with, of course, the first value referred to the wintertime and the second one related to the summer season. Instead, as regards the relative humidity, hygrometric comfort conditions are guaranteed within the range 30 – 70%. Finally, about the air velocity inside the indoor space, usually the technical literature considers values lower than 0.12 m/s fully acceptable, while, about the fresh outdoor air, an hourly amount of 22 $m^3$/person could be considered an adequate reference value.

Instead, in this kind of application (*i.e. Museums, Libraries and Archives*), as shown in the initial paragraphs of this Chapter, the indoor conditions necessary to guarantee a good conservation of the artworks are much more restrictive. In particular, for an adequate conservation, the temperature has to be as much reduced as possible, in both the climatic season. In the table V.6, the comfort conditions of some common artwork materials have been compared with the human comfort conditions and in different colours the achievable compatibly has been evidenced (*red: no correspondence, yellow: intermediate correspondence; green: coincidence*).

In particular, with reference to typical materials, the good storage conditions in terms of temperature and humidity are reported, evidencing <u>when</u>, <u>how much</u> and <u>if</u>, these values can ensure the human comfort too. Above all in summertime, the low temperature required for the conservation, even if not extreme, often does not guarantee the human thermal comfort. In this case, several solutions can be thought. For example, when the required temperatures are particularly low, the only one possibility is the adoption of microclimate controlled museum glasses.

*Factors influencing the indoor climate.* The well-insulated building shell and its elevated massive structures determine a poor influence of the external climates on the indoor conditions, in both the climatic seasons, retarding, reducing and attenuating the heat transfer phenomena. Contrarily, the large windows have a great influence on the indoor microclimate, so that, such as it has been provided in this building design, a good choice consists in reducing the glazed amount, adopting low solar transmittance glasses and frameworks, and, above all, protecting the artwork by the risks of the direct solar radiation.

As already shown in the previous paragraphs, the ventilation air, necessary in order to ensure a good quality of the indoor air, represents a critical aspects, because this requires a thermodynamic handling before that it can be supplied into the environment. Anyway, a well-sized air change rate is necessary not only for the human (*visitors and workers)* comfort, but also in order to preserve the artworks from the risks derived from a polluted environment around them.

Thus, the right amount of external air has to be properly defined, and, about this, a good solution could be represented by a variable airflow rate, depending on the real people presence inside the space (*i.e. adopting $CO_2$ sensors*). About this, the DVC (*Demand Control Ventilation)* system, already introduced in the paragraph 5.3.3 of this study, is also adopted in the Museum Ritter. The endogenous heat gains connected to the people presence, both as regards the sensible and latent parts, are quite typical for the specific kind of application.

About the light, as previously described, elevated values of illuminance could induce direct and indirect degradations of the artworks, acting under several mechanisms (*i.e. heating processes due to radiation, physical and chemical effects induced by the light picking up...*).

Usually, values lower than 250 lux have to be guaranteed inside the exhibition spaces, even if, as regards the conservation of very delicate artworks, an upper limit lower than 50 lux sometimes is necessary too. The natural daylight offers a quite satisfactory spectrum quality in order to guarantee both a good fruition of the artworks and an elevated luminous efficiency, so that, when possible, a carefully use of this is suggested (*anyway, avoiding the direct radiation on the artworks*).

A good solution, when the costs become sustainable, is represented by the mixed luminous ceiling, which adopts, both and in the same time, natural and artificial light; this kind of lighting technology is adopted in the Museum Ritter, providing reduced shadows in the rooms, higher surface available on the vertical walls, uniform lighting conditions

### 5.5.4 THE ENERGY CONCEPTS: HEATING, COOLING, VENTILATION, LIGHTING AND ELECTRIC EQUIPMENTS

The owners and the clients immediately showed high interest regarding an ecological design of the Museum, being this building also representative of the chocolate factory mission. In particular, the adoption of natural and renewable energy sources was immediately considered as the main energy concept of the building. The choice results quite appropriate, above all considering the particular destination, characterised by an elevated energy requests. In particular, the exhibition spaces and the storage rooms have to be kept in very restrictive thermal-hygrometric conditions (Table V.7), above all in summertime, when an indoor temperature of 20 - 22 °C and relative humidity lower than 50% require an intensive use of air-conditioning systems.

Table V.7: Design conditions inside various spaces of the Ritter Museum

| KIND OF SPACE | T SET-POINT | RH SET-POINT |
|---|---|---|
| *Exhibition rooms* | *20 – 22 °C* | *50 – 55%* |
| *Storage 1* | *18 – 20 °C* | *40 – 45%* |
| *Storage 2* | *18 – 20 °C* | *50 – 55%* |
| *Chocolate Shop* | *18 – 22 °C* | *free range* |
| *Offices* | *20 – 26 °C* | *free range* |

Under the same "*eco-compatibility*" criteria, also large windows had to be realized, determining a communication between the internal and external environments, in order to provide a perfect "*contextual*" and "*landscape*" integration.

As regards the main exhibition rooms, instead, in order to guarantee the best possible fruition, no vertical windows were designed, while the lighting, mixed natural and artificial, was realized by means of technical mezzanines in which day lighting and artificial lamps work together. For the technical mezzanine skylights, high performances glasses have been selected (*with anti-sun and low solar transmission treatments*), under which internal blinds characterized by high reflective slats have been chosen and installed; in this way, working together with the ceiling artificial lighting, the shading system guarnatees modulation of the light amount, glare shield and also thermal protection.

In the ceiling mezzanine, the natural light is integrated with high efficient fluorescent lamps. The sun exposed sky glass consists in a low transmittance transparent system ($U_{VALUE}$ = 1.1 W/m$^2$K, $g_{VALUE}$ 0.25), while the transparent and diffuser surfaces, between the mezzanine and the exhibition rooms, were realized adopting double glasses. The installed artificial lamps consist in 800 fluorescent tubes.

The main "*design approach*", that aimed the building, was the maximum integration in the natural context, thus, above all under the energy point of view, the use of natural sources and the high energy efficiency assume a central role in the whole design operation. For these reasons, geothermal and solar (*both thermal and photovoltaic*) sources, such as waste natural materials (*wood pellets*) have been used largely; moreover, high efficient technologies, as buried water pipes, waste heat recovery, absorption refrigeration have also provided.

### *A) Heating, ventilating and air-conditioning*

In figure 5.5.4, the energy flows have been represented, as regards the summer and winter indoor air-conditioning energy concepts.

The cooling and heating processes, in the operational working criteria adopted for the Museum Ritter, are not drastically separated. The heat production was initially realized by means of 4 wood pellet boilers, each one sized for an output thermal power of 32 kW. In a second moment, during the 2008, these 4 boilers were changed with 3 (*still wood pellet ones*) boilers, characterized by higher thermal power (*56 kW each one, i.e. 168 kW globally available*).

On the building roof, around 195 m$^2$ of CPC evacuated solar collectors are placed, with a peak power of about 100 kW (*high temperature thermal energy).*

Furthermore, an absorption chiller of 110 kW has been also installed, in order to produce medium temperature vector-fluid both in summer and in winter times, and so requiring adapt kind of thermal exchanges inside the environment, in particular demanding medium temperature heat emitters. When a high temperature heating in wintertime becomes necessary, the wood pellet boilers, besides the solar collector, support the work of the absorption chiller (*figure 5.5.4).*

<u>Wood pellet boilers.</u> The original 4 boilers (*3 at the present moment*) were installed "*in series*" and are fired by fuel pellet silos of around 10 tons as regards the storage capability (*about 15 m$^3$ of wood*). These boilers are placed above the sanitary services placed at the first floor, in a designed technical inter-floor.

<u>Solar system.</u> The solar thermal collectors convert the picking up solar energy in thermal energy characterized by an elevated temperature level (*higher than 90 °C*). The high temperature vector

fluid is used both for the wintertime environmental heating and, above all, in summertime to support the working of the absorber (*inside the absorption chiller*).

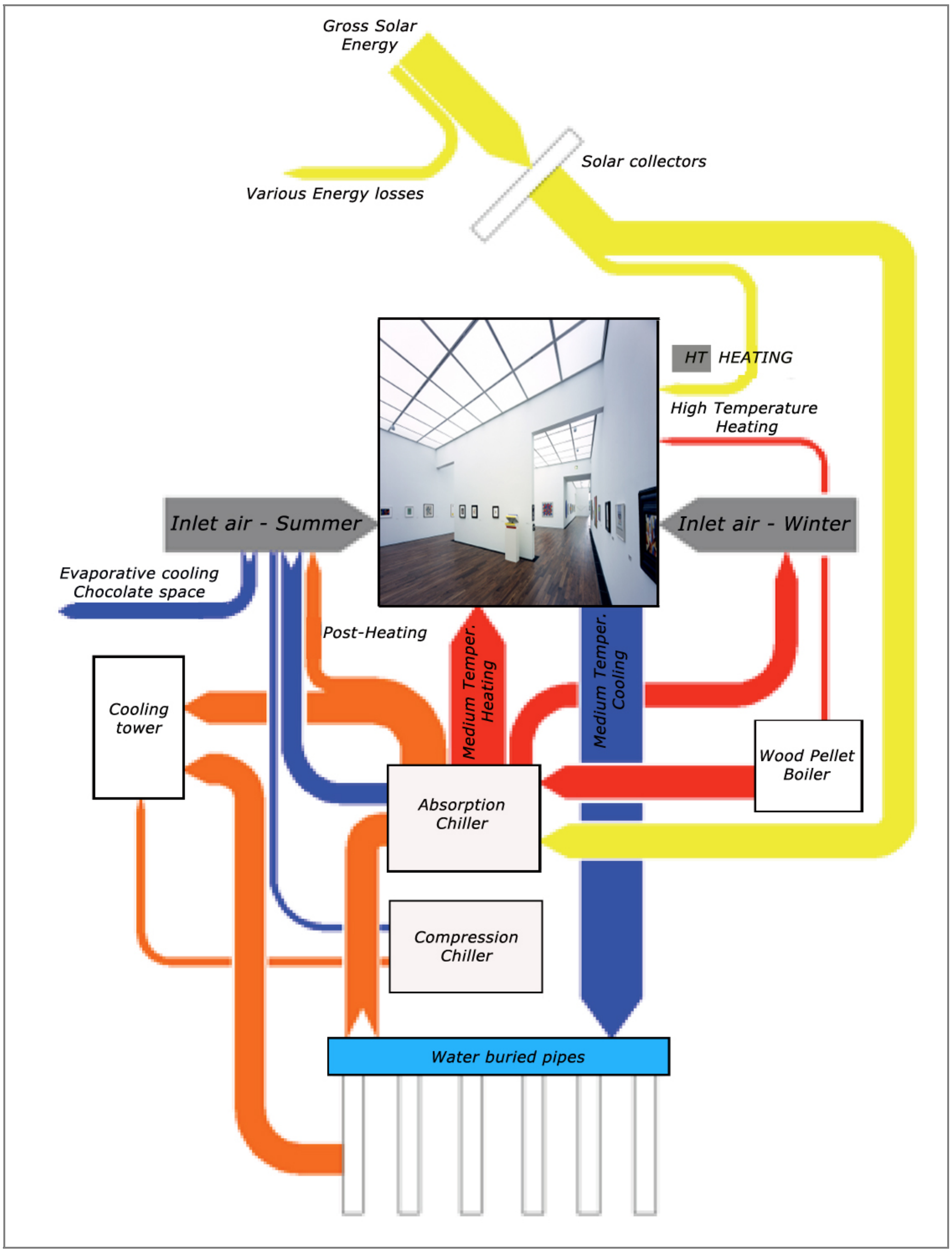


*Figure 5.5.4 – Energy flows for the Museum Ritter air-conditioning (source: IP5 Designer)*

The evacuated solar collectors are placed on the roof of the building, upon the construction wing dedicated to the chocolate shop and laboratories (*figure 5.5.5*).

The required low environmental impact imposed, for the solar system, a very low tilt angle with respect to the horizontal plan of the roof, so that only an inclination of 7° has been chosen; in this way, the solar collectors result not visible. For this reason, the solar system does not work well in wintertime (*the sun, at these latitudes, is quite "low" on the horizon)* while, in summertime, thermal losses around 10% are determined compared to an optimal tilt angle.

The solar system is not separated by an intermediate heat exchanger. In other words, contrarily with respect to the usual design methods, there is not a secondary hydraulic circuit, and, despite the presence of 4 storage boilers (*without heat exchange with a secondary fluid*) the same fluid circulating in the collectors is also used for the absorption process. This strategy raises up the global efficiency of the system. Of course, in wintertime, an active heating is provided, if necessary, to prevent the freezing of the solar fluid. Globally, the high quality of the thermal insulation induces, anyway, reduced heat losses.

*Figure 5.5.5 – The vacuum solar collector placed on the roof (source: FBTA for EnOB)*

In summertime, when the fluid temperatures become too hot and also the 4 storage boilers are "*in overheating*" risk, an emergency system is provided to cool the solar plant, by means of a connection with the cooling tower. This solution was adopted to prevent the system malfunctioning, caused by the steam eventually produced in the collectors, because of too high reached thermal levels. In this case, a restarting operation of the solar system would be possible only after the cooling and the condensation of the vapour.

The solar collectors are also connected to the domestic hot water system, by means of a heat exchanger placed in a boiler that provides the thermal transfer between the solar fluid and the water used in the bathrooms and in the cafeteria kitchen.

<u>The absorption refrigerator / heat pump.</u> The nominal cooling power results equal to 54 kW. The same chiller, in wintertime, operates like heat pump. In particular, by means of 73 buried water pipes, in wintertime, the soil, heated during the summer season by the geothermal cooling, can be thermally discharged (*being the soil used as cool sink*). Globally, the 40% of the heat available by means of the absorption heat pump comes from the ground.

With reference to the thermal levels of the fluids, both in summer and winter, the absorption side of the chiller was fired by a thermal vector characterized by temperature values around 90 °C (*in*) and 75 °C (*out*), produced in the solar system plants or by means of the wood pellet boilers.

In summertime, the fluid handled in the cooling side (*evaporator*) is characterized by temperature level of 10 °C (*out*) and 16 °C (*in*), and so useful for a medium temperature cooling. In winter, the fluid temperature obtainable after the handling in the condenser reaches, usually thermal levels around 36 °C (*out*) and 30 °C (*in*), being adapt, in this way, for the heating of the indoor spaces by means of large radiant panels (*displaced under the floor*).

<u>*Heat distribution.*</u> Several heat distribution systems are present, because not only the Museum Ritter hosts several functions and so many hydraulics pipes and air ducts are provided, but also because the heat distribution is realized by different circuits that work transporting fluids characterized by several temperature levels.

As regards the Museum exhibition rooms and deposits, three heat distribution systems are present. This in order to handle the ventilation air (*openings placed around the perimetrical sides of the exhibition rooms - figure 5.5.6*), supplying the hot water (*70 °C in, 50 °C out*) for the thermal convector placed near the windows (*figure 5.5.7*) and for the medium temperature fluid firing the radiant panels (*36 °C in, 30 °C out*).

Moreover, different heat distribution circuits are provided for the Museum, the "*chocolate wing*" and the cafeteria area.

*Figure 5.5.6 – Thermal water convectors placed around the perimetrical walls of the rooms, in the ventilation openings (source: FBTA for EnOB)*

*Figure 5.5.7– Thermal water convectors placed near the windows (source: FBTA for EnOB)*

<u>*Cool fluid distribution.*</u> The primary cooling effect was realized by means of the absorption refrigerator that, usually in summertime, was supported by the hot fluid coming from the solar

collector system. The refrigerated fluid temperature, after the heat exchange in the evaporator, is usually characterized by thermal levels of 10 – 16 °C (*inlet and outlet, to and from the water pipes*). The absorber works with temperatures of 86 – 72 °C (*largely obtained by means of the vacuum solar collectors, being this designed for hot water even higher than 90 °C*), while the thermal levels of the fluid crossing the condenser are 32 °C (*out*) ÷ 27 °C (*in*) , and so apt for the ventilation air re-heating. The post-heating process of the ventilation air is necessary because the dehumidification is achieved cooling the airflow below the dew-point temperature.
The real cooling capability, achievable through the use of the absorption chiller (*the nominal one is 54 kW*), greatly depends by the thermal levels above described, and, as it will show in the followings, when the operative conditions are not ideal the energy efficiency ratio (*and so the cooling effect*) can be significantly lower than this. The absorption refrigeration cycle is obtained using a water (*refrigerant*) - lithium bromide (*absorber fluid*) solution.

In these conditions, the refrigerant water evaporates (*in the evaporator*) approximately at 4 °C, while the condensation happens approximately at 40 °C. The chilled water (*10 °C out – 16 °C in*), produced in the absorption chiller, is supplied firstly into two buffer boilers, placed in series and each one containing 2’000 stored litres. From there, the chilled water is then given to the air-handling unit, in order to treat the ventilation air. By means of the waste heat in the absorption machine condenser, the air re-heating, after the mechanical dehumidification, was realised.

Then, the evaporative tower cools the water coming from the condenser from 35 °C to 27 °C. About the re-integration of the evaporated water amount, this is obtained by means of a rainwater cistern (40 m$^3$ capacity). The system does not require water purification.

Really, against the design assumptions, the re-cooling temperature achieved of 27 °C is not reached (*usually, this is around 28 - 29 °C*), and it reduces the absorption chiller performances; according to the manufacturer indication, this causes a loss of performances around 20%, and so this malfunctioning becomes very significant. Despite various solutions have been tried, acting on the hydraulic circulation, presently this is an unsolved problem. In summertime the buried water pipes provide cold water to the indoor radiant panels, while, in wintertime, these pipes work as cool sink for the heat pump. Therefore, partially, the building cooling in summertime is obtained pumping the water coming by the ground pipes into the radiant panels (*placed on the indoor floors or ceilings*). The water leaves the ground pipes with temperatures around 16 - 18 °C, and in the indoor space the water inside the radiant panels (*figure 5.5.8*) is characterised by a thermal level of about 20 – 21 °C.

<u>Heat emission.</u> The radiant panels, placed in the room floor structure, guarantee the main heating emission. These heat transfer solutions can be very well guaranteed by the thermal levels reached in the absorption heat pumps, being required low-temperature fluid vector (*due to the large heat exchange surface*). The exhibition rooms are characterized by the presence of special capillary tubes. These are posed under the floor and designed accurately in order to work, in wintertime, using low temperature fluid. The capillary floor systems are shown in figure 5.5.8. Also the floor structure is designed in order to minimize the thermal inertia of the radiant heating system, with a very small mass and so with a quick heating/cooling obtainable effect. The concrete-based liquid screen posed upon the capillary is very small, i.e. 13 mm

(*while a traditional one is around 50 mm*), and, upon this, a hard-wood parquet of 13 mm is installed [49].

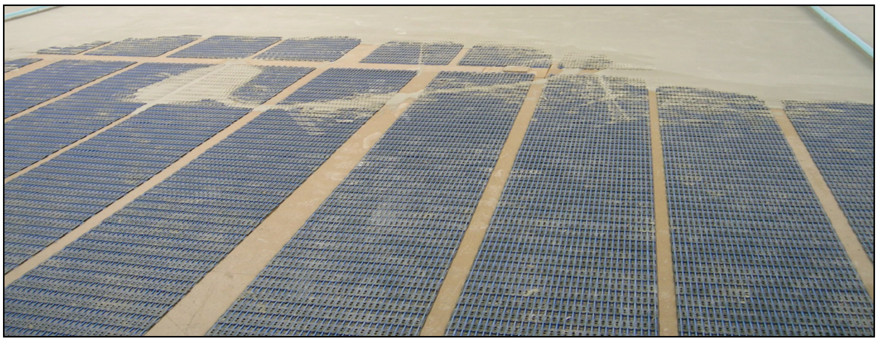

*Figure 5.5.8 – Thermal water capillary tubes posed under the floor (source: FBTA for EnOB)*

Considering the achievable thermal efficiency of this solution (*about 45W/m$^2$*) and designing a system of 573 m$^2$, a total heating power of 26 kW can be achieved in wintertime.

The under-floor heating cannot balance the total heating load, above all in the spaces characterized by elevated thermal losses due to the presence of high windows. Therefore, in the museum areas with large transparent surfaces, as well as in the entrance hall and in the "*landscape rooms*", additional heating elements are necessary. In particular, water pipe convectors have been installed and these operates with a fluid vector characterised by thermal level of 70/50 °C, preventing and stopping the cooling effect due to the window presence (*high sky and surrounding ambient radiation and high conduction thermal losses; figure 5.5.7*).

Other spaces (*cafeteria, exhibition rooms, chocolate shop*) are equipped almost exclusively with a conventional under-floor heating.

With reference to the second floor of the "*chocolate-wing*", a ceiling heating systems was realized by means of capillary tube ceilings, in order to guarantee space indoor flexibility.

<u>Cooling systems.</u> The cooling effect, similarly to the heat emission, is guaranteed by the capillary systems placed under the floor surface, enough large in order to provide a high temperature cooling (i.e. water cooled inside the soil buried pipes). The distribution circuits are thought in order to provide, adopting several distribution devices (*primary and slaves distributors, inlet-outlet collectors, central control and switching equipments*), a well-adapted switching, so that, in the same time, some thermal zones can be cooled while others are heated.

Globally, the cooling loads are quite moderate (*approximately 20 W/m$^2$*) so that through the soil (*73 buried water pipes*) about the 65% of the thermal energy need is obtained. The most critical point, about the cooling work, is instead due to the ventilation air, that is supplied with a temperature around 15 – 18 °C. The ventilating systems are designed in order to vary, with respect to the needs of each room, the supplied airflow amount. In particular, the supply air temperature and humidity content, leaving the centralized air handling unit (*cooled below the dew point in order to be dehumidified, at – 9 °C, and then re-heated at 15 – 18 °C*), is controlled by a reference room, depending on the indoor measured thermal level. In the other exhibition spaces, the airflow amount is then varied, depending of the real needs. The first control strategy consists in a temperature based control system, even if, secondarily, also $CO_2$ sensor can induce the ventilating damper modulations.

<u>*Air Ventilation Systems.*</u> The building is characterised by the presence of three main ventilation systems and several smaller equipments to extract the exhaust air, placed in the WCs and in the Cafeteria kitchen. All the ventilation systems are designed in order to reduce the pressure losses inside the ducts.

<u>*a) Museum.*</u> The exhibition rooms are provided with a full air-conditioning system, with a nominal design flow rate of 12’100 $m^3$/h. The maximum air change amount (*when all the dampers are open*) induces 2.5 ACH. This value can seem a little bit low, but, really, it is not so; in fact, considering the air distribution system *(a kind of displacement ventilation*) the air is supplied by the lower part of the rooms and extracted in the upper zone (*figure 5.5.9*).

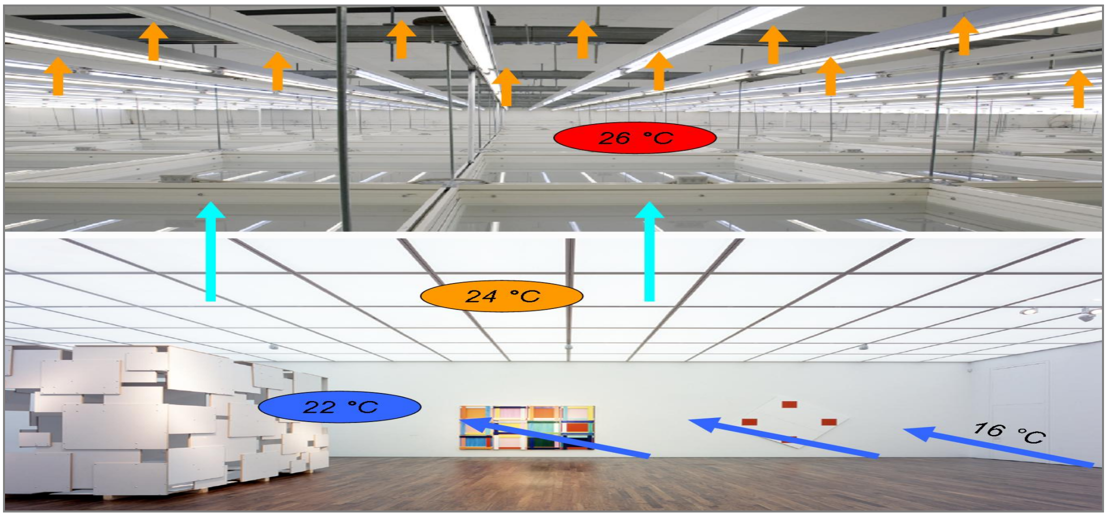


*Figure 5.5.9 – Air distribution inside the exhibition spaces*

In this way, temperature stratifications are opportunely studied, and high quality air and useful temperatures are always obtained in the occupied region. For example, even if the exhaust air temperature (extracted in the ceiling mezzanine floor) is of 26 °C, thermal levels of 22 °C are usually measured in the occupied volume. The vertical stratification, designed for the exhibition room, can be in this way described (*i.e. summer time design values*):

- thermal volume lower than a height of 2 m → indoor air temperature ≈ 22°C;
- thermal volume around the ceiling → indoor air temperature ≈ 24°C;
- thermal volume inside the ceiling mezzanine floor → summer air temperature ≈ 26°C.

Therefore, temperature stratification around 8 °C can be globally reached. The necessary air change is reduced, in this way, of about 30 – 50 % compared to a traditional mixing ventilation strategy.

The supply air is sent into the exhibition rooms, the “landscape” rooms and foyer by the floor ventilation grilles, while this is extracted by the open slots placed on the luminous ceilings and so it arrives to the mezzanine technical floor. As above cited, dampers regulate the airflow at the desired amount. If no cooling is required, the system supplies an airflow amount evaluated in order to provide anyway the necessary minimum ventilation. The thermal-hygrometric conditions of the supply air are calculated, in the centralized air-handling unit, considering the exhibition room characterized by the higher loads. The AHU is provided by heating, cooling-dehumidification, water humidifier and post-heating coils, but also with an enthalpy wheel with an efficiency rate of 73%. In particular, the rotating air-to-air heat exchanger is characterized by a sensible heat recovery efficiency of 80% and latent recovery coefficient of 50%. Above all in summer, a great part of the air is re-circulated (about 70%), in order to reduce the mechanical dehumidification and related post-heating.

In wintertime the enthalpy wheel and the warm fluid coming by the absorption heat pump provide a supply air of 30 °C, that, after the water humidification was supplied at 22 °C (design condition). The water humidification has been chosen in order to avoid high temperature thermal energy required by a steam humidifier. On the other hand, in summertime, the mechanical dehumidification does necessary a re-heating process, that in the Museum Ritter is been totally guaranteed by the heat exchange with the waste heat available at the condenser of the absorption heat pump (*and so this operation is totally free of costs*).

*b) Cafeteria.* This function was served by a heating/cooling ventilating system, without humidity control. The nominal airflow rate results of 5’000 $m^3/h$, and it corresponds to 10 AHC. The air is supplied through opening slots integrated into the furniture. Also in this case, the flow rate amount depends on the exhaust air quality and/or temperature regulated. The central ventilation equipment contains also a total heat recovery wheel.

*c) Chocolate Wing.* In this case too, the ventilation system is used also for the environmental heating and cooling, without the relative humidity control. The nominal value of the airflow is of 7’000 $m^3/h$. The whole chocolate part of the museum is served by a central air-handling unit, with a rotating heat recovery, heating and cooling coils. Also in this case, direct driven axial fans have been adopted.

### 5.5.5 Energy performances and the 2-years FBTA monitoring: analyses of the results

The energy performances of the Museum Ritter are strictly monitored as provided by the EnOB program of the German Government. The measured data, in the following described, are in real time transmitted to the FBTA – Division of Building Physic & Building Services of the University of Karlsruhe, where all the values and the relative building performances are analysed and compared with the designed ones.

All the data, 500 technical values continuously monitored, are remotely transmitted, by means of an ISDN transmission data system. The main measured parameters are: energy fluxes, thermal levels, temperatures and relative humidity inside the rooms, ventilations rates, position of valves and pump/fan running, consumption of pellets, solar radiation and conversion in thermal and electric energy.

Such as intended by the EnOB program, the activity was divided in an intensive short phase and a long-term monitoring. The intensive monitoring is required for a period of two years, and so including two heating seasons and the same number of cooling periods [48].

With respect to the EnOB requirements, the museum application cannot be respectful of the same standards of other buildings hosting different function, being, in this application, the required set-point conditions too restrictive.

All the collected data, since the first monitoring period (October 2006) have been used to calculate the *coefficient of performance* and *energy efficiency ratio* of all the machine and equipments installed, in order to understand the critical working conditions and, finally, to improve the global performances of the building-HVAC system. Inside a co-work between the Fbta and the research center Fraunhofer ISE (*Instituts für Solare Energiesysteme*), the Museum Ritter monitoring becomes useful also in order to evaluate the building overall energy balance, according to the German technical Standard DIN 18599 – *Building Energy Evaluation*.

As regards the building and its system efficiency, immediately, the high complexity of the technological equipments was observed, and it gave problem above all as regards the perfect interrelation among the different devices. Therefore, the need of a complex but necessary control optimization was immediately shown.

The main noted defects are related to malfunctioning occurred during the construction operations. In particular, the control systems are very innovative, because no standard adequate instruments were available. About this, a longer test phase should be required, while, really, no time for a good optimization was spent, above all because the spring and autumn climate conditions are not well adapted to do it. Therefore, many studies were carried out later, during the normal work of the systems.

The most critical aspect, immediately evident, was that the absorption chiller, in summertime, was no able to balance the entire cooling load under the most critical climate conditions. Therefore, during the spring 2006, a new compression chiller was installed, chosen with a cooling capacity of 50 kW; no complicated adjustments were required for the cooling tower, already sized considering also an eventual upload of the HVAC, so that it results enough powerful also considering the compression chiller needs. To improve the bad performances of the re-cooling circuits of the absorption chiller, a new pump was realized and installed, showing immediately good performances. The compression chiller was indispensable also because the number of visitors was double compared to that originally evaluated.

The building automation system manages all the connected technical equipments, working with over then 1.000 data inputs, mainly evaluating in real time the energy uses and the energy parameters. Starting by the measured values of temperature, humidity, air quality and flow rates, works of the pumps, fans, valves and other components, the building automation operates the auto-regulation. The building was divided in four zones: exhibition, café, visitor center (*chocolate shop, chocolate exhibition and laboratory*), at the ground floor, and the administrative part at the second floor of the "*chocolate wing*".

Various retrofitting actions, in order to guarantee a perfect monitoring, have been implemented during the last two years, above all increasing the number of controllers. With reference to any function and energy parameter, each device has been monitored, with particular attention to the energy uses due to the space heating, cooling, ventilation and lighting. Also the used software, adopted in order to manage all the parameters, is not a standard commercialized one, but it was adjusted appositely for this project. The monitoring was and is aimed to various targets, among which the optimization of the systems and of all the technical equipments, understanding malfunctions or defects, and, above all, verifying if the EnOB targets are achieved.

The limit of 100 kWh/m$^2$a (*as regards the maximum primary energy requirement imposed by the EnOB program*) is evidently too much restrictive for this kind of application. In particular, the elevated amount of lighting (*much more high than in an office building*) and the strict thermal-hygrometric control conditions imposed within the exhibition spaces make not possible the same energy performances achievable in common office buildings.

According to the current German method, passing from “*end*” to “*primary*” energy the conversion factor of 0.2 and 2.7 have been respectively considered for the wood pellets and the electric energy.

Above all about the installed artificial lighting, the demanded electricity resulted much higher than the designed one (*that, instead, was compatible with the EnOB requirements*). This happened because the luminous ceiling works above all by means of artificial lighting, while, in the original idea, meanly the 69% of the light need was guaranteed by the natural daylight.

The overall energy requirement, determined by the designer (*IP5 - Karlsruhe Technical Bureau*), was calculated considering a level of luminance, as regards the vertical direction, equal to 300 lux, while it resulted higher than 700 lux; this explains the accentuated no-accordance between the projected energy performances and the measured ones. In particular, has visible in figure 5.5.10, the overall energy requirement, for the several energy uses, was calculated in 163 kWh/m$^2$a, and the greatest part of this was due to the artificial lighting. On the contrary, as shown in figure 5.5.11, the measured energy demand is much higher.

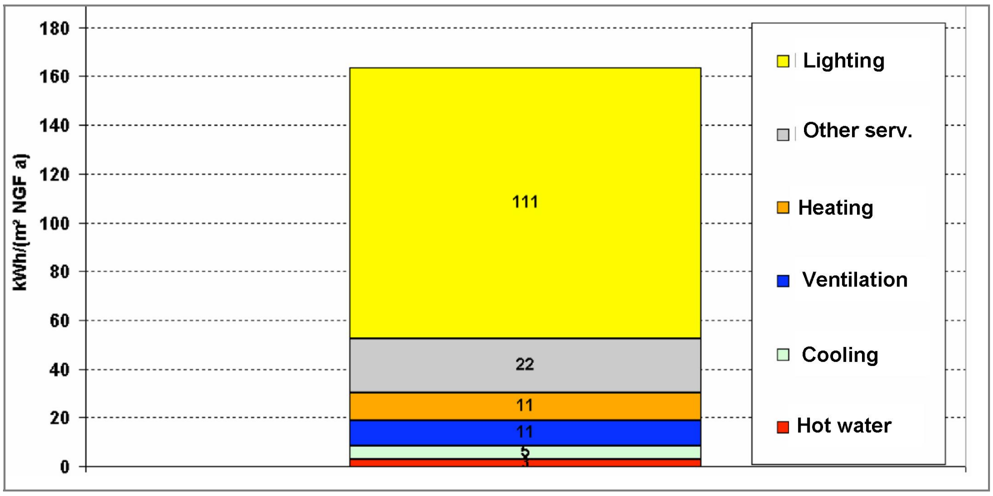


*Figure 5.5.10 – Estimated primary energy needs (ip5 bureau, Karlsruhe) (source: FBTA for EnOB)*

In a second phase, the initially considered 45 W/m$^2$ for the artificial lighting became 75 W/m$^2$, and the considered daylight amount was estimated around the 30% with respect to the total lighting effects (≈ *70% in the first consideration*). Under these new boundary conditions, obviously the primary energy demand raised up, becoming similar to the measured one.

As regards the primary energy required for the space heating and the hot water production, the simulations of the ip5 engineers and the monitored performances are in a good accordance, while, as regards the ventilation and the cooling energy requests, these results much higher compared to the designed amounts.

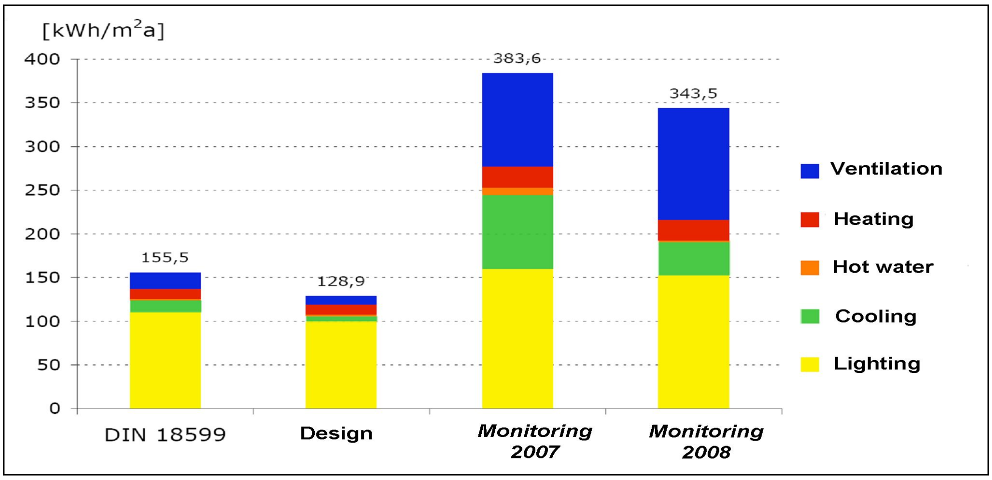


*Figure 5.5.11 – Overall primary energy need, adopting the technical standards, the design simulations and the measured values during the 2007 and 2008 monitoring (source: FBTA for EnOB)*

This because the real crowding and so the required ventilation airflow, as well as the endogenous cooling loads, resulted much higher than the estimated ones. In particular, considering all the energy uses, compared to the design values (*about 130 – 150 kWh/m$^2$a*), the measured energy requirements are very different, in particular resulting about 3 times higher with reference to the 2007.

As regards the heating and cooling energy fluxes, these have been represented in figure 5.5.12.

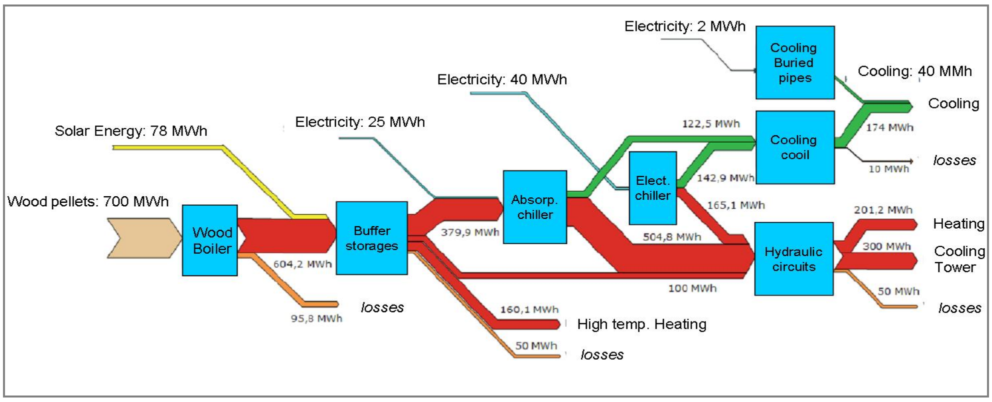


*Figure 5.5.12 – Energy fluxes (Heating and Cooling) (source: FBTA for EnOB)*

The higher monitored energy requirements are those for the museum area and of the cafeteria. As regards the Museum, the most relevant end energy demand is due to the lighting and to the summer air-conditioning, while in the cafeteria the largest energy uses are related to the ventilation and the heating requests.

PRIMARY ENERGY. According to EnOB, the primary energy requirement (*calculated considering the space heating/cooling, lighting and ventilation*) has to be computed and monitored. Contrariwise with respect to other buildings, the conversion between end energy and primary energy is, in this case, quite complicated, because the Ritter Museum is interested by the adoption of several energy sources and vector (*electricity, wood pellets, solar sources, ground…*), each one characterised by a different energy conversion factor.

The primary energy conversion coefficient for the refrigeration has been calculated considering the absorption chiller, the compression refrigerator and the auxiliary functions. For the 2007, the compression chiller has a primary energy factor of 0.76, including the auxiliary, whit a good value obtained thanks to the high COP of the machine (3.8), while the absorption chiller has a primary energy factor of 1.28, also in this case, considering the auxiliaries too.

Considering the whole building; the consumption of energy for the lighting is of about 50% higher than the planned one, while compared with the DIN 18599 targets, the heating demand is about two times higher.

HEATING. The heating requirements for the museum building are achieved using the solar collectors and the three wood pellet boilers (*4 in a first period*). The solar collectors are used above all to support the absorber working in the absorption chiller. According to the design, about the 80% of the necessary heat for the absorber would be given by the solar source; with respect to this calculation, the solar system gives very appreciative performances, with a good accordance between the measured efficiency and the technical documentation. The measurements, during the year from April 2007 to March 2008, document a thermal energy conversion higher than 460 kWh/m$^2$ (*a very good value considering the solar irradiation in this climate context*). Minor performances are achieved using the 3 wood pellet boilers, being required, in order to drive the absorber solution, thermal energy with a temperature value around 80 - 90°C, while this kind of boiler gives the best performances working with a thermal level of the water around 70 °C.

During the spring of 2008, the 4 wood pellet boilers (*each one of 32 kW*) were substituted installing 3 higher boilers, each one characterized by a nominal power of 56 kW; the overall heating capacity was thus raised of about 40 kW (128 → 168 kW). Also the circuit and the buffer boilers were opportunely modified and improved. In the 2007, the utilization factor of the converted energy was of about 86%, and with reference to the 2008, the value become lower (around 80%) while the desirable one, for this kind of heating system, should result around the 90%. The lower results during 2008 depend on the new 2 storage boilers that imply further energy losses.

The heat production, recurring to the wood pellet boilers, resulted a little bit higher during the 2007 compared to 2008; it depends also by the working of the absorption chiller (as heat pump) during the 2008. With reference to 2008, some operational problems occurred; in particular, at the beginning of the summer season, not immediately the absorption system was switched for the summer working, so that a useless extra-energy demand occurred. The conversion was operated only in July.

The absorption refrigerator was used also in wintertime with the aim of a drastic reduction (*around one half*) of the primary energy factor for the heat production, passing from 0.20 to 0.11, even if, the monitored results didn't show these results. The absorber functioning was allowed by means of the wood pellet (*free of costs because of locally available*) hot fluid, with a primary energy factor of 0.2. About the energy performances, some problems occurred during the autumn 2007 and during the following winter season, so that only the performances of the winter 2006/2007 could be considered as representative. In the period December 2006 – February 2007, the COP of the absorption heat pump was of 0.39. Also after some improvements, the COP and the connected primary energy factor showed no sensitive advantages compared to a direct water boiler.

Both the solar collectors and the wood pellet boilers produce thermal energy, characterized by a high temperature, then stored inside apposite boilers. These storage boilers, of course, determine thermal energy losses (≈ 4%), but are anyway necessary in order to provide thermal energy also in critical cases, ensuring the correct amount of hot fluid in each operational and climatic condition.

During the monitoring several problems occurred, due to the loss of measured data, so that various technical improvements, about the monitoring systems, have been successively realized. The present heat requests and consumption are divided in high temperature and low temperature thermal energy, respectively for the convectors (*high temperature*) and as regards the radiant floor panels (*low temperature*). Thermal energy is also request for the heating of the ventilation air, the post-heating in summertime after the mechanical dehumidification, and in order to produce the hot water used in the cafeteria kitchen and for the toilettes.

Globally, the thermal energy necessary to heat the hot water is higher than the energy required for the air heating; this happens because of the high endogenous heat gains, so that the air heating energy requests is not so high.

The hot water needs are very elevated in the cafeteria and in the visitor center too. In figure 5.5.13, the end energy heat requirements are reported.

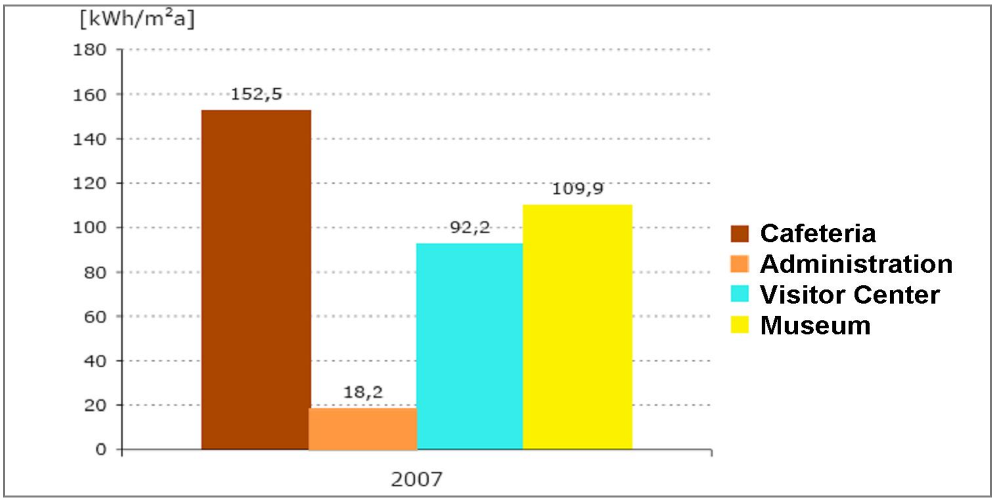


*Figure 5.5.13 – Specific heat consumption (end energy) of the zones in 2007 (source: FBTA for EnOB)*

The elevated heat consumption of the cafeteria (*around 153 kWh/m²a*) was due to the high heat losses (*geometry, windows, opening of the doors*) and to the high hot water energy demand.

As regards the Museum, the dehumidified air in summer time requires a post-heating (*the dehumidification is guaranteed cooling the air below the due point temperature*).

Furthermore, also some malfunctions in the regulation system occurred, especially because the control system is centralized and the several rooms are instead characterized by very different thermal loads. During the 2008, some improvement actions have been carried out, varying the regulation of the heating radiant panels (*and so acting on the hydraulic circuits*).

Considering a better regulation, without re-heating in summertime when not necessary, a saving around 15 kWh/m²a has been calculated as possible.

COOLING. According to the design, the building cooling had to be realized recurring only to regenerative cooling, and so without using traditional energy sources. The absorption chiller plays a central rule, working by means of the hot thermal fluid produced in the solar plants or by means the pellet boilers. Furthermore, the use of the buried water piles represents a no-active environmental refrigeration. Actually, the relevant endogenous heat gains, above all due to the high illumination level, make too elevated the thermal loads, so that the designed targets could not be achieved.

In the figure 5.5.14, the cooling energy provided by the absorption and compression chiller is represented. With reference to 2008, a reduction of the global demanded cooling energy has been obtained (*around -100 MWh*), and, at the same time, the work of the absorption chiller raised up (*around + 30% compared to the previous season).*

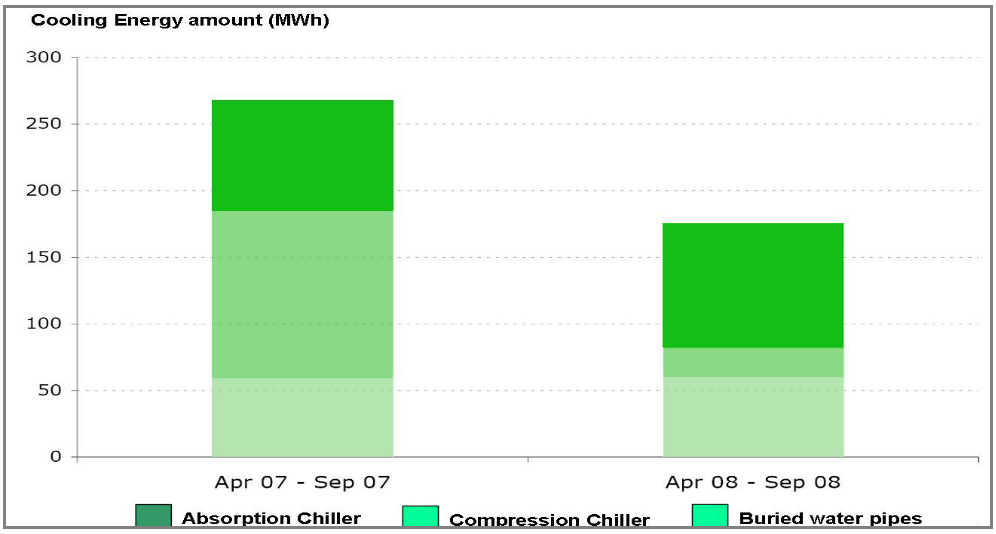


*Figure 5.5.14 – Cooling needs in the period April – September, both in 2007 and 2008 (source: FBTA for EnOB)*

Initially, the performances obtained by the absorption refrigerator were very poor, due to the fixed set-point temperature of the outlet water (*8 - 9 °C*). A first improvement was adopted working on the inlet temperature of the water; the efficiency of the system, in fact, was strictly related to the thermal level of the vector fluid, so that when low thermal levels are required, the energy performances are characterized by a descendent trend. After the improvement of the water temperature regulation, immediately (*summer 2005*) it was clear that, anyway, the installed cooling capacity was not enough, so that during the spring 2006 another chiller was installed, and the chosen one was a traditional compression refrigerator.

Monitoring 2007. After the optimization and the installation of the new compression chiller, (spring 2006), until the autumn 2007 the absorption chiller worked well, even if at the begin and in the central period of the same year, the COP of the system resulted very low, with a mean value of 0.32, both as refrigeration chiller and heat pump.

Bad coefficient of performances mean bad primary energy conversion factor, so that, globally, no energy convenience compared to a traditional compression chiller in this year (2007) was obtained. Also with reference to the $CO_2$ emissions, the obtained performances are very low. Considering a good compression chiller, it induces, approximately, 209 g/kWh as regards the polluting emission. The adoption of an absorption chiller is useful to reduce drastically this value, because, when coupled with renewable thermal energy sources (*solar and/or wood pellets*), low emissions related to the thermal energy required by the absorber are considered, so that the emitted pollution could be strongly reduced. Furthermore, considering that the electric energy required by an absorption chiller is around 1/10 of the energy need of a compression chiller, the performances regarding the $CO_2$ emission obtained during the 2007 by means of the Museum Ritter absorption chiller (164 g/kWh) are really unsatisfactory.

Also the cooling capacity of the absorption chiller, with reference to 2007, was quite lower than the expectations; in fact, the absorption chiller gave more than 30 kW only for 500 hours (*with respect to the 4'000 hours characterized by a full operation)*

At the end of the 2007, the absorption chiller was removed for maintenance, guarantying the necessary improvement actions. This operation was possible because the heating could be guaranteed also using, directly, the wood pellet boilers. In the spring 2008, the manufacture operates some optimization actions, first of all adjusting the water mass crossing the circuit (*measured around 9.7 $m^3$/h, while the data sheets suggest 7.7 $m^3$/h*).

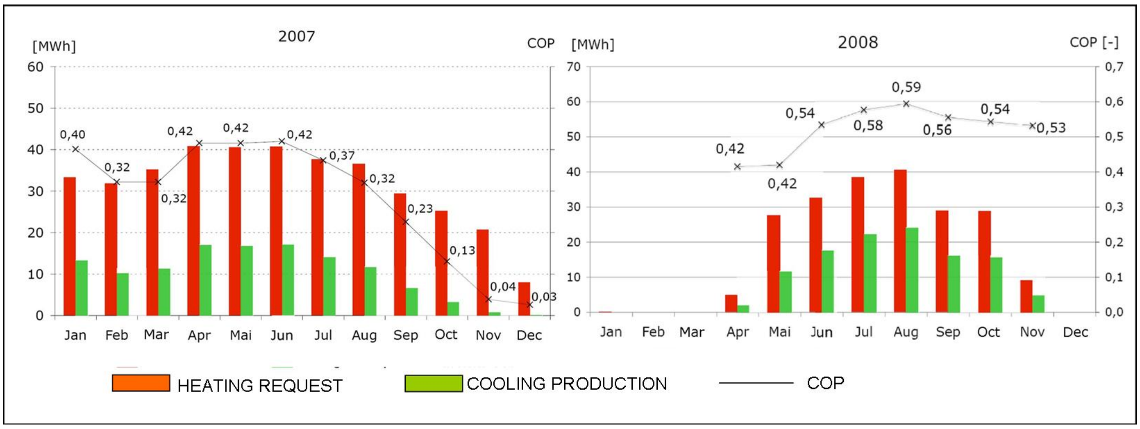


*Figure 5.5.15 – Absorption chiller energy performances (left 2007, right 2008)*
*(source: FBTA for EnOB)*

After the optimization of the hydraulic circuit, above all as regards the *cooling tower – heat exchangers* water lines, a COP around 0.5 was monitored (figure 5.5.15), thus better than the value characterizing the previous season (0.30), but still unsatisfactory.

During the following continuous work, surely the performances resulted much better compared to the previous year (*higher COP, lower emissions, lower primary energy factor*), even if, considering the technical data and the consequent expectations, it was clear that something didn't work perfectly. Other improving actions have been so applied on the coupling between the absorption machine and the compression chiller, working on the hydraulic circuits and, above all, on the water mass crossing the two refrigerators.

Monitoring 2008. Starting form April 2008, the performances of the absorption chiller became much better compared to the previous year. Passing by April to June, the COP raised up from 0.42 to 0.6, and considering this value as the mean one of the month, it consists in a quite good result. Also the cooling capacity of the chiller was now much higher, close to the designed value, and always around 30 kW. How much the parallel operation of the compression chiller influences the performances of the absorption machine is not so clear. Anyway, during the August 2008, the electrical COP of the absorption chiller was of 11.3 (*around two times higher compared to 2007*), while the overall COP was around 0.54. In wintertime, when the absorption machine works as heat pump, the solar collector contribute was quite reduced also during the 2008 winter, when, sometimes, only the 30% of the required thermal energy is provided by the solar collectors, so that the COP went down (≈ 0.4).

*Museum compression refrigerator.* This machine is used only in order to cover the peak load and as "*replacement*" machine when the absorption one could not work. During the 2007, the compression machine, installed in the spring 2006, worked a lot, because of the poor performances achieved using the absorption chiller.

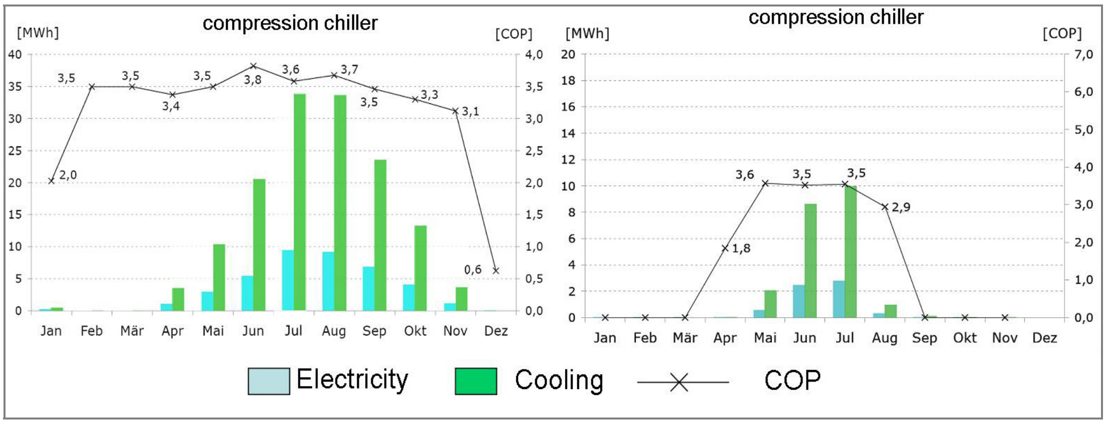


*Figure 5.5.16 – Compression chiller energy performances (left 2007, right 2008)*
*(source: FBTA for EnOB)*

After the optimization of the absorption chiller, the work of the compression one decreased, above all during the 2008 summer. The monitoring of the energy performances of the building declared, both for the 2007 and 2008, very good performances (*figure 5.5.16*) achievable using the compression chiller, with seasonal coefficient of performances around 3.5 (*very good accordance with respect to the value defined by the manufacturer*).

Buried water piles. Using the cold ground temperature in summertime, a cooling production, totally clean and renewable, equal to 91 MWh and 89 MWh was obtained respectively during the summer 2007 and 2008 (*figure 5.5.17*).

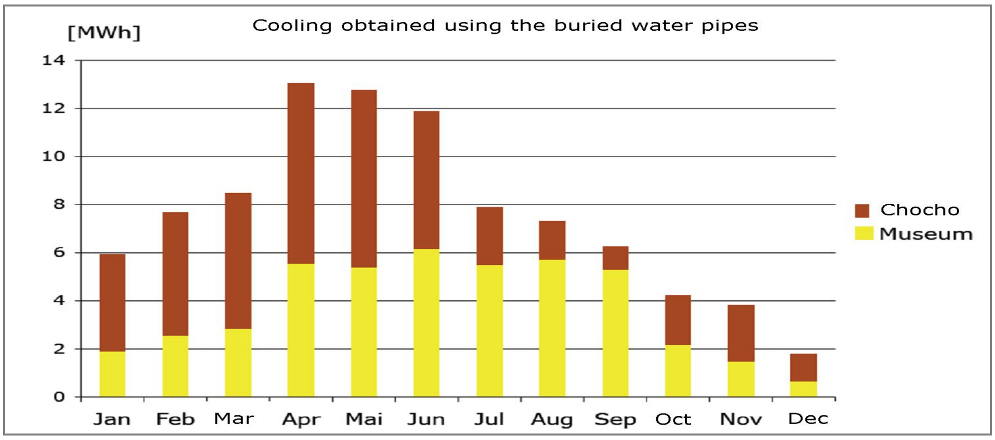


*Figure 5.5.17 – Buried Water pipes performances during 2007 (source: FBTA for EnOB)*

The coefficients of performances, with reference to the summer seasons 2007 and 2008, results respectively equal to 34 and 40, and these are quite usual for this kind of cooling solution, where the only one active energetic need is due to the pump working, so that only a low amount of electrical energy is necessary. The overall contribute obtained using the buried water pipes is, with reference to the summer cooling, only around 10÷20% of the global thermal needs, and this is significantly lower than the expectations.

Furthermore, it is necessary a fit regeneration of the soil, so that the piles are used, in wintertime, as heat source (*cool sink*) for the absorption chiller work.

Cool storage. The cold water produced in the two cooling generators (*absorption and compression chillers*) is stored in two insulated boilers. Thanks to these buffers, it is possible a temporary de-coupling between cool productions and cool use. During the 2007, the energy losses due to the storage was around 25% and this value was too high considering the thermal levels (*cold water – environment*) and the good insulation of the boilers, so that, probably, this scarce performance was due to the complicate, and somewhere ineffective, hydraulic schemes.

Cool consumption. The refrigeration is strongly diversified with reference to the different thermal zones, being different the loads conditions and, above all, the indoor thermal-hygrometric required values. At the same way of the heating, also the refrigeration was divided in high and low temperatures, the first one obtained by means of the water buried piles and the second one actively guaranteed using the cool generators (*absorption and compression chillers*). During the design phase, it was estimated that, for the summer cooling needs, could be enough the use of the high-temperature cooling obtained adopting the water buried piles, in order to give cool water to the floor radiant panels. Only in order to cover and satisfy the peak necessities, the ventilation air would be supplied also in order to achieve a cooling effect.

Really, during the operations, the Museum showed a thermal load, in summertime, three times higher than the estimated one (*high internal artificial lighting and high endogenous – metabolic heat gains are the main causes*), so that the cooling of the ventilation air became necessary, also in order to provide the not dispensable dehumidification. Presently the low temperature refrigeration (*guaranteed by the chillers*) provides around 80 – 85% of the overall cooling request.


*Figure 5.5.18 – High temperature and low temperature cooling energy production Museum wing (source: FBTA for EnOB)*

In figure 5.5.18, the cooling energy needs, *both in terms of low temperature and high temperature fluids*, have been reported, with reference to the years 2007 and 2008. During the 2008, it is quite evident the reduction of the low-temperature cooling (*active chillers*). Anyway, it is important to underline that, during the spring 2008, the passive cooling system by the water piles didn't operated, and the reasons are not well known.

VENTILATION. Usually, the energy required for the building ventilation represents a significant part of the building energy demand, above all in the old buildings where an optimal air distribution is not so easy to obtain, so that the air transport, by means of electrical fans, plays a great role about the electric (*i.e. high-primary*) demanded energy. With reference to Museums, there are not significant reference values about an efficient ventilation, while, for example, in an energy efficient office building, the limit of 25÷30 kWh/m$^2$a (*primary energy*) could be considered as a reference.

As regards the Museum Ritter, the medium value of the electric energy required is around 50 kWh/m$^2$a in terms of electric energy, and so around 3 times higher considering the conversion in primary energy (≈ *150 kWh/m$^2$a*), and it represents a value 4 – 6 times more elevated compared to an energy efficient office building. The air mass flow rate is of 24'000

$m^3$/h (*nominal value*), and the original ventilators had an output power of 4 – 5.5 kWh, with an efficiency ratio around 0.4 Wh/$m^3$.

With reference to the Museum Ritter, each zone is equipped for a specific control of heating, cooling and ventilation, with the airflow amount regulated inside specific boxes, provided with ventilation adjustable dampers. During the winter 2007, the mean opening of the dampers was 65 – 75% of the nominal airflow, while in the following year (2008), in the same period, the single room dampers induced a flow rate significantly lower (around 45 – 50%). About the heat recovery system, a perfect evaluation of its efficiency cannot be estimated, even if, evaluating the operating conditions (*outside air and thermal-hygrometric characteristics, re-circulated airflow and its thermodynamic conditions, etc.*) a mean energy efficiency of 70% could be evaluated.

With reference to the summer 2008, it has been estimated that about 20 – 25% of the cooling energy requests was due to the air dehumidification.

LIGHTING. As regards the office building applications, there are several standards usable as reference in order to evaluate the amount of energy for the artificial lighting inside a well-designed construction; in particular, common values, for an energy efficient building, are in the range 10 ÷ 20 kWh/$m^2$a. As regards the museum applications, no many information (*standard or literature-derived*) could be used as reference, so that, according to the DIN 18599, an approximate value of 40 kWh/$m^2$a is here adopted as benchmark.

Usually, according to international indications, in the exhibition rooms, two different targets should be obtained:

1. a correct fruition of the artworks adopting the right level of the lighting parameters;
2. avoiding possible damage deriving from the lighting effects (*e.g. direct radiation*).

As regards the second aspect, sometimes, while for an office building horizontal luminance of 500 lux are quite typical, in a museum also values of 50 – 100 lux could be dangerous for the conservation of sensitive artworks.

In the Museum Ritter, the kind of the collected artworks requires horizontal luminance of 1000 lux, without any dangers deriving from this lighting amount. This luminance levels are usually obtained recurring to both natural and artificial lightings, even if the artificial lighting was designed (*thinking to the evening hours*) in order to be fully sufficient to provide a correct fruition. The installed lighting power results of about 40 W/$m^2$, meanly considering the whole building.

As regards the exhibition rooms, the adopted lighting equipment (*lighting ceiling, natural light, "spot" reflectors*) have been previously briefly described.

About the monitoring, several electrical counters have been installed and, both in 2007 and 2008, the electric absorption was much higher than the designed value. The average power results of 82 W/$m^2$ during the 2007, 90 W/$m^2$ with reference to the 2008, with a specific annual consumption respectively around 174 kWh/$m^2$a and 192 kWh/$m^2$a, considering about 2'100 working hours with reference to each year.

The total installed power is of 30 kW. About the daily consumption, this varies from 100 kWh/d (*in a sunny day*) to 270 kWh/d (*in a cloudy one*).

The discrepancy between the design and the monitoring has to be researched in the required uniformity of the luminance, that, in this case, induces higher energy consumption. The artificial ceiling lighting requires much more energy compared to the designed one. At the ground floor, the power is quite constant, being not possible a good use of the daylight.

The foyer of the museum meanly requires an artificial lighting of 9 – 12 kWh/m$^2$, while the cafeteria induces a medium lighting specific consumption around 8 kWh/m$^2$a, with a specific power of 17.5 W/m$^2$.

ENERGY REQUESTS OF AUXILIARY SYSTEMS. The cooling, heating and ventilation of the Museum Ritter are guaranteed by several distribution systems, and so air ducts, pipes and other hydraulic plants. Several fans and pumps are present, and these require relevant electric energy. The energy consumption due to the ventilation has been already described previously, and so now only the pump energy requests will be shortly introduced and explained. Totally, the Museum has 34 pumps, with an overall required electrical power equal to 1.65 kW.

The single pump energy demand is too difficult to measure, so theses were grouped and studied as in the followings described:

- primary heating installations: boiler pumps and pumps for heating of the low-temperature heating area;
- primary cooling equipment: pumps of the absorption refrigeration machine and for the buried pipe water flows;
- museum heating: distribution pumps for the museum heating;
- chocolate wing heating part: distribution pumps for the heating;
- museum cooling: pumps for the cooling systems;
- chocolate wing cooling: pumps for the cooling systems;
- water heating: pumps for the heating of the hot water tank in Museum.

Globally, the whole building requires around 12.5 $kWh_{ELECTRIC\text{-}ENERGY}$/m$^2$a for the pumps; in terms of primary energy, it means around 34 kWh /m$^2$a. These values are obviously too high, so that a better regulation of the systems has to be urgently implemented.

INDOOR MICROCLIMATE. As above mentioned, the required thermal-hygrometric values of the air in this building are very strict and rigorous, in order to preserve the artworks, and, with reference to the chocolate wing, in order to guarantee the best product quality (*in this last thermal zone, thus, the temperature has to not exceed 24 °C*).

With reference to the other zones - administration, service, foyer - of course the requests are different, being admitted, in these other spaces, larger ranges for the air temperature and relative humidity, and, above all, as regards their admitted fluctuations.

In each exhibition room, mechanical thermo-hygrographs measure continuously the air thermal-hygrometric conditions. With reference to the exhibition rooms, several problems, as regards the air temperature, happened above all during the 2006. Also in the 2007, in two exhibition rooms, for 2'500 – 3'000 hours the thermal level exceed 22 °C, while in the other three exhibition spaces, for 1'500 – 3'000 hours, the temperature was below the minimum set point of 20 °C. Of course, in both the cited case, also the relative humidity went out the design range (*i.e. too low RH in the first case, too high in the second one*).

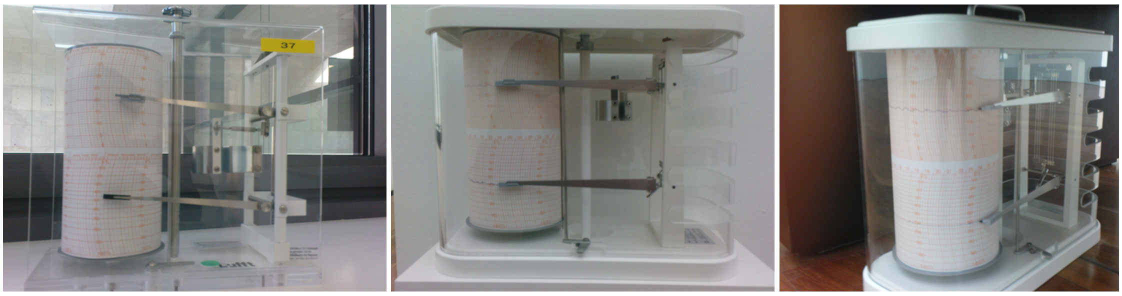

*Figure 5.5.19 – Museum Ritter exhibition rooms: the placed thermo-hygrograph*

The most critical problem is, as regards the temperature and relative humidity control, the connection (always opened) among the several rooms of the museum, so that, even if the HVAC regulation works well, the communication and the airflow crossing the spaces determine perennial disturbs and perturbations.

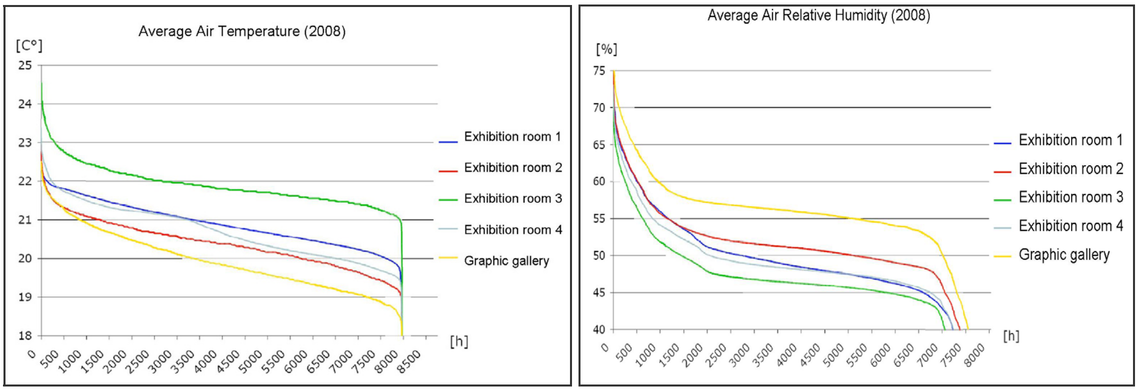


*Figure 5.5.19 – Monitoring 2008: temperature and relative humidity in the Museum (source: FBTA for EnOB)*

Anyway, as regards the relative humidity excursions, these are usually contained in ± 5% with respect to the design set point. As regards the "*landscape rooms*", here a different analysis is required, because of the very different load conditions characterizing these spaces. In particular, the large windows, despite the presents of external shading systems, induce quick changes within the indoor space, as regards the temperature and, thus, about the relative humidity too.

Anyway, even if the mean indoor temperatures are higher in the landscape rooms compared to the exhibition rooms, during the 2008 much better results have been achieved with respect to the 2007, with a drastic reduction of the number of hours characterized by thermal levels higher than 22 °C (figure 5.5.20). However, in July, also temperatures of 24 – 25 °C were measured.

### 5.5.6 Conclusion, possible further improvements, conceptual optimization proposals

The Museum Ritter was designed with the aim to achieve optimal energy performances, by means of a large use of renewable energy sources, very well adapted in this kind of applications because of the high specific energy consumptions characterizing the Museums. Even if significant targets have been anyway obtained, after two years monitoring, the results, in terms of energy performances, show quite high energy requests, due to the rigorous required indoor conditions, as regards the lighting, ventilation, and, above all, indoor temperature and relative humidity.

The Museum Ritter overall energy request (*primary energy*) results equal to 380 $kWh/m^2a$ and 340 $kWh/m^2a$, respectively with reference to 2007 and 2008. Thus, it is quite evident that, even if a good improvement under the achieved energy performances has been obtained, actually the energy demand is still too high, around two times the value provided in the German technical standards (*about energy efficient building*) DIN V 18599.

Thanks to the intensive monitoring, many causes of this “low” (*compared to the high level of the adopted technologies*) performances have been found, for example the unsatisfactory energy performances achieved by the absorption chiller during the 2007. About this, thanks to the strong monitoring, during the 2008, the manufacturer was been involved in the reparation of the refrigerator, well knowing the machine working critical aspects. After the improvement actions and reparations, during summer 2008 the absorption chiller gave surely better results, significantly reducing the work of the auxiliary compression chiller.

Even if the performances achieved by the absorption refrigerator are quite good during the 2008, with satisfactory COP, unfortunately this is not enough in order to minimize the use of no-renewable energy sources, which remain largely applied. Also the use and the performances of the solar collector plant evidence all the complexities characterizing a solar cooling system (*above all as regards the integration and the perfect synergy among the several components, i.e. solar collectors, storages, absorption and compression chillers, hydraulic circuits, pumps, regulations and so on …*).

Furthermore, the Museum Ritter experience evidences how the control and regulation of the technical systems can influence the energy performances, requiring a well useful adaptation to the several part load conditions. Also simple actions, e.g. a fan substitution, could largely penalize the required energy; in particular, this event happened during the 2008, when a fan was replaced and changed with a greater one, without correctly setting the air volume flow controller, and then the required electric energy (i.e. *high primary energy conversion factor*) became twice compared to the previous period.

Furthermore, the continuous and accurate monitoring suggested possible further improvements and conceptual optimization proposals.

Surely, the main reason of the high energy request, in the Museum Ritter, is due to the artificial lighting, that requires around 44 % of the overall primary energy requests. About this, no many improvements could be thought and realized, if the required luminance levels remain the same requested at the present moment.

About the heating energy needs, during the spring 2008, the primary energy system was completely re-built, changing the wood pellet boilers and implementing several modifications to the auxiliary equipments. Two technical improvements can still be realized, in particular as regards the reductions of the energy losses due to the storage. During the 2007, the absorption machine used as heat pump gave very poor performances, so that during the following winter this was not used. After the adjustments during the spring 2008, now the absorption chiller could again be used also in wintertime, inducing significantly saving in the wood pellet required quantity (*used to guarantee the hot fluid necessary for the absorber cycle*).

Table V.8: Museum Ritter – Main characteristics and Energy Performances *(source: FBTA for EnOB)*

| | | |
|---|---|---|
| *Year of Construction* | | 2005 |
| *Costs of construction* | | |
| | a) Building | 972 €/m$^2$ |
| | b) Technical systems | 384 €/m$^2$ |

| | | |
|---|---|---|
| *Dimensions* | | |
| | Gross Floor Surface | 3'910 m$^2$ |
| | Net Floor Surface | 3'232 m$^2$ |
| | Gross Volume | 13'098 m$^2$ |
| | Surface to volume ratio (S/V) | 0.54 m$^{-1}$ |
| *Place* | 27, Alfred Ritter Strasse, 7111 Waldenbuch – Germany | |

| | | |
|---|---|---|
| *Energy performances* | | |
| | Primary energy demand –design | 125 kWh/m$^2$a |
| | Primary energy demand required - 2007 | 384 kWh/m$^2$a |
| | Primary energy demand required - 2008 | 344 kWh/m$^2$a |

| *Primary Energy 2007 (kWh/m$^2$a)* | *Museum* | *Cafeteria* | *Visitor Center* | *Administration* |
|---|---|---|---|---|
| Heating | 29.6 | 51.6 | 20.8 | 6.1 |
| Ventilation | 111.4 | 417.4 | 117.1 | 0.00 |
| Cooling | 110.8 | 72.8 | 84.5 | 1.8 |
| Artificial lighting | 235.8 | 225.5 | 107.6 | 18.2 |

| *Primary Energy 2008 (kWh/m$^2$a)* | *Museum* | *Cafeteria* | *Visitor Center* | *Administration* |
|---|---|---|---|---|
| Heating | 25.7 | 31.0 | 26.7 | 7.4 |
| Ventilation | 111.7 | 318.5 | 191.1 | 0.0 |
| Cooling | 63.9 | 19.3 | 17.7 | 1.2 |
| Artificial lighting | 212.5 | 260.1 | 113.9 | 23.4 |

A good use of the absorption chiller in wintertime has to guarantee, primarily, two targets. The first one consists into the use of renewable sources (pellets and solar radiation), the second, instead, is connected to the necessity of the soil regeneration in wintertime, downloading, into the ground, the thermal energy (*cooling*) useful in summertime, for the buried water pipe works (*when a cool soil is necessarily required*). In fact, when in the winter 2008 the absorption chiller was not used, in the following summer the soil temperature was higher than the previous season, reducing the cooling potential of the geothermal system.

Finally, other improvements have to be though about the indoor set-point conditions and humidity regulation systems. In fact, sometimes in wintertime, an indoor temperature level of 22 °C was measured (*and it is, evidently, too high*) and often also contemporaneous cooling and heating (*with enormous energy waste*) were evidenced by the monitoring.

About the cooling needs, instead, after the necessary modifications of the absorption chiller during the spring 2008, now it offers good performances; further improvements could be realized installing new more efficient components, for example pumps and other circulation systems. Other minor actions could be applied on the optimization of the coupled work of the absorption and compression chillers (*e.g. better controlling the hydraulic circuits and the work of the circulators*).

On the other hand, a great improving potential interests the cooling effect obtained using the buried water pipes. In particular, the poor performances of the hydraulic system, until now, induced energy performance much minor than the technical possible one.

As regards the ventilation, during the summer 2008, a very simple (*and effective*) optimization action was realized, turning off the system because the outdoor air conditions were quite favourable. Thus, a total energy saving was achieved. About the exhibition spaces, here the problem is more complicated; in particular, the greater question regards the volumetric airflow control system.

The Museum Ritter experience provides some suggestions and advices for future designs and planning. In particular, the lack of separation among the several spaces induced several problems, regarding the lighting requests and regulations, the artwork preservation and perturbations in the thermal-hygrometric conditions.

Also the combined use of artificial lighting and daylight, even if it offers elevated potentialities, requires more effective control systems. In the Museum Ritter, the solar shadings of the roof structures offer good performances in the management of the solar radiation (*and connected overheating*) in summertime, even if, also in this case, a better control has to be thought, in order to guarantee the best compromise between daylight and heat gains.

As regards the heating need, the heat storage boilers caused elevated energy losses. In the future, a different control and workings can be planned, so that one or more wood pellet boilers balance the basic thermal load, while the other boilers cover the medium and high peak loads.

About the cooling, when the choice is oriented towards an absorption chiller, especially when coupled with a solar cooling system, it is important a well-adapted choice of the refrigerator kind. In particular, it could be useful selecting a chiller characterized by a low electrical consumption, even if this would induce a worse COP; this because, considering the conversion in primary energy, the electrical requests has a great weight.

Finally, as regards the ventilation, also in this case the great communicability inside the Museum Ritter causes a bad control of the airflow supplied into the single room; in fact, because of the connections (no doors) with the other spaces, the environmental control, under several points of views (*perfect climatic control, desired air-change per hours, lighting control…)* becomes very difficult. Therefore, the closure of the spaces can be a good strategy.

Also about the supplied airflow, the Museum Ritter control system results too complex, coupling a temperature-based strategy with the demand ventilation, variable in function of the $CO_2$ levels inside the spaces.

Moreover, also the idea of the solar system requires a perfect planning and execution; in fact, the complexity of the system, if not correctly managed, could induce higher energy requests instead of savings.

Globally, even if the higher energy demand is due to the exhibition rooms, also in the chocolate side, the continue modifications and alterations with respect to the original design induced some defects also in the technical service workings. Anyway, the following and future monitoring, after the last optimization actions, will give more exhaustively information about the performances presently achieved.

At the present moment, according to the FBTA (University of Karlsruhe) investigations, the primary energy saving potential is around 30% compared to the present value, without recurring to other technological equipments.

*ACKNOWLEDGMENTS*

*The Chapter 4 of this Thesis has been elaborated joining 2 different experiences, with reference to the knowledge and studies carried out, during the last years, by the research units headed by the professors Pietro Mazzei (DETEC - University of Naples) and Andreas Wagner (FBTA - University of Karlsruhe). The topic concerns the environmental air-conditioning and the energy efficiency strategies applied to Museum applications, analysed under several points of view, with numerical studies and concrete experiences. This study could not be realized without the contribution of the cited professors.*

*Furthermore, the help, the work and the knowledge of the professor Francesco Minichiello and of the FBTA engineer Thomas Knapp have been indispensable. In particular, the theoretical studies, above-reported, have been carried out with the indispensable support of Francesco, while, with reference to the last part of the Chapter (the Museum Ritter experience), Thomas gave me not only all the necessary documentation but, above all, continuous, punctual and exhaustive explanations.*

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## CONCLUSIONS: THE CARRIED OUT STUDY AND THE MAIN ACHIEVED RESULTS

The Thesis presented the main methodologies, targets and results carried out during the Doctorate studying period spent by Fabrizio Ascione at the DETEC (*Department of Energetics, Applied Thermo-fluidodynamics and Environmental Conditioning of the University of Naples Federico II*).

The main targets of the research activities have been oriented towards the optimization of the various components of the building-plant system, in order to reduce the energetic requests of the civil sector of the Italian buildings. The topic of the reduction of the carbon dioxide emissions is closely connected to the energy savings, with beneficial consequences also on the climatic changes. This because, with respect to the overall energy demand, the building sector is the greatest user, with a specific request equal to around the 40% of the total energy consuption, both with reference to the Italy and to the all European countries.

Starting by the Energy Performance of Buildings Directive - 2002/91/EC - and the related Italian rules (Legislative Decree 192/2005, Presidential Decree 59/2009 and Ministerial Decree 26.06.2009), the first part of the Thesis analysed calculation procedures and methodologies, such as established by the CEN (European Committee for Standardization). Then, in a second part, the document investigates the energy efficiency of the Italian and European building stocks, identifying critical aspects, performances and solutions useful in order to improve the energy uses. All the carried out studies, with reference to dwellings and social housing, office buildings and museums, evaluate the energy performances both of the building envelopes and of the active systems here installed, as regards the main energy uses due to the heating, ventilation and air-conditioning of the indoor spaces. Furthermore, the studies have been coupled to technical-economical evaluations, in order to purpose useful solutions under both the energy and economic points of view.

As above mentioned, three different kinds of building typologies have been considered. In particular, the selected uses of the architectures (*i.e. residential, office and museum buildings*) have been chosen because these are well expressive of the various peculiarities characterizing the building stock. This notation underlines, immediately, a first limit of the Italian present legislation, quite indifferent, as regards the mandatory requirements regarding the energy performances, to the several and different building destinations.

The residential buildings represent the higher part of the European and Italian architectures, requiring around the 70% of the civil sector energy needs and, considering the whole European Union, around the 27% of the total energy demand. This kind of buildings has been mainly built in the period 1950 – 1980, consequently to the great demographic expansions of the European cities, with poor attention to the environmental sustainability. Therefore no concepts of energy efficiency have been adopted (*e.g. as regards the envelope thermal insulation or about the heating system efficiency*).

Even if quantitatively less significant, the office buildings are characterized by peculiarities, above all as regards the summer energy requests, very critical under the energy efficiency point of view. In particular, the offices usually present boundary conditions very specific, above all as regards the high crowding, the great glazed surfaces, the significant installed equipments, with summer conditions quite critical, both with reference to the full air-conditioned buildings (*i.e. → high cooling requests*) and to naturally ventilated ones (*i.e. → absolutely unsatisfactory indoor temperatures*). Finally, the last investigated subject regards the Museums, characterized by operative conditions quite critical, in particular because of the continuous use of the HVAC systems (24/day during the whole year) and the very strict microclimatic necessities. In particular, for this kind of building, rigorous managements and limitations of the usual thermal-hygrometric fluctuations, commonly admitted in other kinds of building use, are required. Moreover, also a strict control of the latent loads, above all in summertime, becomes mandatory for this application, being the relative humidity the environmental parameter mainly responsible of the artwork conservation.

With reference to anyone of the above-cited building uses, in the followings the main studies and results are synthetically reported.

RESIDENTIAL BUILDINGS: THERMOPHYSICAL PROPERTIES OF THE BUILDING ENVELOPE. The analyses estimate the effects of the new technical standards and laws today into force, both as regards the energy effectiveness of the new dispositions and prescriptions, and relatively to the evaluation of the appropriateness of the established calculation methodologies. In particular, the main carried out studies concern:

- new dispositions related to the energy request limitations in winter and summer times;
- energy indicators and connected admitted limits such as established by the legislator;
- effectiveness of imposed high thermal capacity of the building envelope structures;
- poor attention to the techniques for the thermal mass discharging;
- omission of indications as regards the external coating of the building envelope.
- coexistence of different renewable energy sources in buildings.

The main obtained results evidence a not complete effectiveness of the limits set up by the Italian legislator, above all as regards the energy requirement of the buildings during the summer season. In particular, the Italian laws fixed limits to the building cooling needs, adopting only two different values ($EP_{e,invol}$ < *40 or 30 kWh/m*$^2$*year*), differentiated on the basis of the winter degrees-day of the geographic location, thus without any consideration of the real summer climate and without diversifying the achievable performances with respect to the building surface-to-volume ratio. This last geometrical characteristic of the building (*well considered in wintertime for the evaluation of appropriate limits to the thermal dispersions*) is not taken into account in summer, while, just during the warm season, its role becomes predominant, being the thermal performances of a building strongly connected to the amount of sun-exposed surface. An alternative criterion, accompanied by a numerical validation, has been proposed for a better evaluation of the minimum performances, considering quantity (*amount*) and quality (*exposure*) of the surface-to-volume ratio. Furthermore, the method proposed for the evaluation of the $EP_{e,invol}$ maximum admitted value also considers the real summer climates, accurately evaluating the external temperatures and solar radiation.

Other studies investigated the effectiveness of the new legislative measures as regards the limitation of the indoor environment overheating in summertime and the reduction of the building cooling need. The carried out research underlines only a partial usefulness of the prescriptions that impose high thermal capacity (*or a low periodic thermal transmittance*) of the building envelope components. In fact, the present impositions, suitable for reducing the indoor thermal load peaks and apt to guarantee a satisfactory time lag of the thermal wave, are quite ineffective as regards the seasonal cooling energy saving. Therefore, the studies have been centred on individuation and proposition of integrative measures, in order to improve the actual legislative frame, in particular relating the building envelope thermal capacity to the building use. Furthermore, the studies evidence the usefulness of the mass activation, suggesting also several techniques, such as the nocturnal radiative cooling and nighttime ventilation. Moreover, other possible improvements have been tested and proposed, such as the variation of the radiative characteristics of the external envelope surfaces (*high solar reflective and/or high infrared emissive*) in order to reduce the summer cooling loads and the indoor thermal levels in summertime. The building facades are interested by degradation phenomena and therefore these are periodically renovated. In order to minimize the energy building needs, the analysis evaluated the different performances of various external coatings typologies for opaque vertical walls and roof structures, such as low-emissive type, metal type, brick type, and those with traditional plasters; in order to optimize the needs of the building-plant system, the evaluations have regarded also the winter period.

With reference to existing buildings, a simple innovative climatic index (*SF – Surface Factor*) has been proposed, useful to identify the energetically best external coatings as a function of the outdoor climatic characteristics. In presence of heating and cooling systems installed in the buildings, for the cities with high solar irradiation and/or low winter degrees-day, cool paints are more convenient, while the opposite results have been obtained for cold climates. Finally, the influence of the building envelope thermal inertia on the summer cooling energy requests has been evaluated, measuring the contemporary effects of the wall mass, surface radiative characteristics and indoor ventilation. For climatic zones in which the summer outdoor temperature during the night is lower than the indoor one, significant energy convenience of high thermal inertia envelopes has been obtained only when the use of massive walls is coupled to night ventilation. As regards the diurnal ventilation, it is strongly penalizing if used in presence of massive walls, making inefficacious the benefits due to the building thermal inertia.

Moreover, also other several critical aspects, regarding the Italian new energy laws referred to the building energy efficiency, have been investigated, both with reference to the legal and procedural aspects. In particular, the role played by the glazed surface in wintertime (*not penalizing, as regards the energy balance, if well-exposed*) and the compatibility of different renewable sources (*critical with reference to the intensive suburban housing*) have been analysed.

The achieved results, sometimes well-correspondent to the knowledge of the specific technical literature, sometimes quite significant about the underlining of some deficiencies and defects of the Italian context, have been reported in order to stimulate new investigations and reflections in the national technical community.

OFFICE BUILINGS: PASSIVE COOLING TECHNIQUES FOR THE COOLING LOAD REDUCTION. The service sector requires energy needs, with reference to the necessary energy uses (heating, lighting, ventilating and, above all, air-conditioning), not sustainable. In particular, the usual elevated radiative loads, the high endogenous thermal gains (due to the high specific crowding and high density of installed electrical equipments) induce energy demand particularly elevated in order to cool the indoor space. On the other hand, with reference to naturally ventilated buildings, these peculiar characteristics determine critical conditions as regards the indoor thermal levels. The peculiarities of the office buildings, thus, require specific solutions, by means of a design approach completely different with respect to methods and solutions well apt with reference to residential applications. Therefore, an important part of the studies reported into the Thesis (*carried out also in collaboration also with the institute FBTA - Institute of Building Physic and Building services - of the University of Karlsruhe*) has investigated the potential of several passive cooling strategies. In particular, with reference to simulated office buildings, designed according to the most recent German and Italian standards and energy regulations, the achievable energy performances have been investigated. The analyses showed that, with reference to European climates, while the present legal prescriptions result very well suitable in order to reduce the winter heating energy requests, the imposed verifications are instead very low effective as regards the summer period performances.

In particular, buildings that full respect the present regulations about the summer energy performances (*limited sun exposed transparent surfaces, correct exposure of these, adoption of quite low solar transmittance glazing, high mass of the building envelope, elevated time lag effect, low attenuation factor*) do not results apt in order to reduce the cooling energy demand.

Therefore, several passive cooling strategies have been defined, optimized and analyzed. In particular, the different solutions are based on different heat transfer phenomena: movable insulation of the roof and of the vertical walls (*envelope radiative cooling acting from the external side of the building*), nightime natural ventilation (*envelope convective cooling, acting from the internal side of the building*), earth-to-air heat exchanger (*indoor space convective cooling during the diurnal hours*). All the passive cooling solutions have been implemented in simulated office buildings, carefully considering the different thermal zones, being floor and exposure strongly influent on the achievable performances. A first analysis, with reference to specific thermal zones of the buildings and for various climatic regions, identified the best adoptable solutions; then a second study coupled the best passive cooling techniques, in order to optimize the building energy performances. With reference to Mediterranean climates, the various passive cooling strategies evidenced important reductions of the cooling loads, even if these could be limited but not nullified. On the other hand, the climates of the central and north Europe determine a great potential of the passive solutions, which provide, when well-designed, satisfactory thermal comfort also in naturally ventilated buildings, according to the adaptive comfort criteria.

Thus, as regards the service sector buildings, the Thesis purposes investigation methods and technical effective solutions for the reduction of the summer cooling energy requests in full air-conditioned offices and as regards the improvement of the indoor thermal conditions in naturally ventilated buildings. In particular, in all the considered European climatic regions, the studied evidenced a good potential of the ground cooling by means of buried ventilation pipes, so that a deepening has been carried with reference to the Italian climate. With reference to three climates expressive of different Italian weathers (*Naples, Rome and Milan*), the energy performances of an earth-to-air heat exchanger have been deeply evaluated both in summer and winter. In particular, a large parametric analysis, regarding the influence of different kind of soils and ground, the flow characteristics inside the tube, the airflow rate, the length and depth of the buried pipes, the control strategy has been realized. The results showed that wet/humid soil ensures best performances, while the pipe material does not represent a strongly incident parameter, since the tube thermal resistance is always low. As regards the tube length, the improvement achievable adopting very long tubes is not relevant., while the costs (ground moving and pipes) could be much higher. As regards the tube depth, a time temperature profile with a phase constant around six months is better than a quite constant value throughout the whole year, even if a good compromise between costs and thermal recovery is achieved with a profoundness around 3 meters. Fixing the airflow rate, low air speeds are preferable, because the pressure losses are reduced and the thermal exchange surface is maximized. In summertime, an increase of the air-changes determines better performances, while in winter, the best solution consists in providing the minimum outdoor airflow necessary to guarantee a satisfactory indoor air quality. The extra-cost due to the adoption of intake fan instead of exhaust one (*being lower, in this second case, the supply air temperature*) is not relevant. Despite very significant coefficient of performances, the economic analyses denounce the necessity of a rigorous design, in order to reduce the systems costs, above all those related to the ground moving and to the tube material.

MUSEUM BUILDINGS: ENERGY SAVINGS AND TIME AND SPATIAL STABILITY OF THE INDOOR MICROCLIMATE, ADOPTING INNOVATIVE HVAC SOLUTIONS. With reference to the museum environment, for this kind of application the energy efficiency has to be coupled to a necessary strict control of the indoor microclimate. The time and spatial stability of the values assumed by microclimatic parameters should be assured first of all for the environmental protections of the cultural artworks and, secondarily, for the thermal and hygrometric comfort of the occupants. Thus, the particular boundary conditions impose a very arduous design, also considering that, often, the same buildings are characterized by an artistic value and it imposes a lot limitations, both as regards the envelope and regarding the active systems here installed.

These several difficulties have been investigated, analysed and sometimes solved in the last part of this Thesis. First of all, suitable air-conditioning systems are necessary. Considering the need to control the indoor microclimatic parameters twenty-four hours per day, during all the year, the HVAC system annual energy request is usually very high: thus the design aim is the obtainment of useful energy savings and, at the same time, the requested microclimatic target conditions.

Generally, all-air systems are particularly well-adapted to the museum requirements: in fact, using this type of systems, the risk of leaks from overhead or decentralised equipments is avoided, as well the possible breaks of water/steam pipes over and within the exhibition areas. On the other hand, all-air systems could present problems related to their integration in historical buildings due to the considerable space taken up by their equipments.

The carried out studies present energy analyses of different HVAC solutions, using the dynamic energy performance simulation and comparing both the energy requests and the microclimatic control achievable adopting several air-conditioning configurations, in particular equipping a constant all-air volume system with dehumidification by adsorption (*desiccant wheel*), total energy recovery ventilator (*enthalpy wheel*), outdoor airflow rate variation, enthalpy air economizer. The use of desiccant module, enthalpy wheel and demand control ventilation provide significant annual energy cost savings with respect to a traditional air-conditioning system. The chemical dehumidification shows optimal performances in case of strict hygrometric control. In cold and dry climate zones, the use of desiccant wheel show energy savings minor than the enthalpy wheel. Important energy savings are also obtainable if larger indoor relative humidity range can be accepted for the artwork conservation. As regards the thermal-hygrometric performances, the relative humidity control is generally more critical in summer conditions; about this, the desiccant wheel guarantees, usually, the best performances. Further investigations are necessary for the demand control ventilation, because it provides the highest energy savings but appears not optimal as regards the microclimatic control.

Then, adopting a different kind of numerical analyses, the spatial uniformity of microclimatic parameters inside typological exhibition rooms has been evaluated. The flow rate and thermal-hygrometric conditions of the supply air, calculated to balance macroscopically cooling and heating thermal loads, do not guarantee the design microclimatic parameter values in each region of the exhibition spaces. Thus, the accurate designing of air diffusion systems becomes an essential practice inside the planning activity relative to the museum environment. Therefore, Computational Fluid Dynamic investigation techniques have been adopted in order to evaluate the performances of various air diffusion equipments, considering different part load conditions. In order to avoid short-circuits, when the conditioned air is supplied from the ceiling, always down-placed extraction grilles are preferable. Globally estimating indoor temperature, relative humidity and microclimatic uniformity, the air diffuser types that show the best average performances are those characterized by high induction (swirling diffuser, nozzles, slot stripes). This event is verified because such diffusers are characterized by the best capability in containing the vertical stratifications, so that they can be a very suitable solution when the inner heights are elevated. Thus, considering that relative humidity (*related to both thermal level and air moisture content*) is the most influent indoor microclimatic parameter for the conservation of the artworks, the use of high-turbulence diffusers represents a quite good design solution, even if specific studies are necessary as regards the air-velocity into the indoor environment (*i.e. air speeds lower than 0.12 m/s are preferable in the occupied region*).

Finally, during a study period spent at the University of Karlsruhe (at the above-cited FBTA Institute), the theoretical studies have been accompanied by an operative experience. In particular, considering the EnOB targets (*i.e. Energy Optimized Buildings, a research program on demonstration buildings funded by the German Government*), some studies have been carried out with reference to the innovative building of the Museum Ritter in Waldenbuch. These studies interested the design of the adopted high efficient energy solutions. In particular, solar thermal energy by means of evacuated collectors, solar cooling systems, biomass adoption, geothermal cooling, total heat recovery and, finally, the high photovoltaic electric generation do this building well expressive of the state of art of the present building science and technology.

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