Investigation of design criteria for energy efficient office buildings in Italy

Dissertation

submitted to and approved by the

Department of Architecture, Civil Engineering and Environmental Sciences
University of Braunschweig – Institute of Technology

and the

Department of Civil and Environmental Engineering
University of Florence

in candidacy for the degree of a

Doktor-Ingenieur (Dr.-Ing.) /

Dottore di Ricerca in Processes, Materials and Constructions in Civil and Environmental Engineering and for the Protection of the Historic-Monumental Heritage*)

by

Serena Miceli
born 28.06.1985
from Fiesole (FI), Italy

Submitted on	16/03/2015
Oral examination on	11/05/2015
Professorial advisors	Prof. Arch. Frida Bazzocchi
	Univ. Prof. Dr.-Ing. Manfred Norbert Fisch
	Prof. Ing. Vincenzo Di Naso

2016

*) Either the German or the Italian form of the title may be used.

ACKNOWLEDGMENTS

Very special thanks to my Italian supervisors Prof. Arch. F. Bazzocchi and Dr. Ing. V. Di Naso and also to Prof. Ing. F. Nuti for their support because they make me stronger during these three years with their advices and recommendations improving my personality.

The same special thanks also to my German supervisor Univ. Prof. Dr. -Ing. M. Norbert Fisch and to Dipl. -Ing. Arch. T. Wilken because they host me at the IGS (Department of Architecture, Civil Engineering and Environmental Sciences) where I met many skilled people, and for their wisdom and availability toward me. I think their support has definitely enriched me, becoming the complementary of the Italian one. This has encouraged me to apply a real multidisciplinary approach that is one of the main thesis goal.

Thanks also to all people and friends that I met during the "journey" of the PhD program because I will bring everything into "the baggage" of my experiences.

ABSTRACT (English)

The building sector is forced to an important change imposed by the European Directive 2010/31/EU that addresses issues such as Nearly Zero Energy Building (NZEB). The Directive imposes to the Member States that all new constructions have to be NZEB since the 31st December 2020, anticipating the date at the 31st December 2018 for all buildings owned and occupied by public authorities. Hence, it seems necessary a research that studies design criteria for energy efficient office buildings since they will be the first typology to face with such regulation.
The thesis identifies some design principles evaluating their influence on the energy demand of office buildings located in Italy. Specifically, the research looks at both the application of passive design strategies and the integration with renewable sources, maintaining good level of indoor comfort conditions. The aim is supporting designers during the pre-design phase through both qualitative and quantitative recommendations. This is made because, at the early stage of the design process, many choices have generally been based on both experience and intuition of the designer rather than energy performance indicators.

The thesis follows these steps:

- literature review to know definitions, architectural principles, energy design strategies, recurring technologies, regulations, etc.;
- qualitative analysis of office buildings realized in Europe (some of them are located in Italy) as case studies, in order to make on evidence design criteria and strategies specific for the typology;
- quantitative analysis to investigate the influence that some design choices have on the energy performance of the building. For five cities representative of the Italian climate, the research firstly analyzes the energy performance of three base cases; secondly, investigates some design parameters; thirdly, proposes some examples of energy efficient offices obtained applying the results of the parametric studies to one of the base cases.
  Specifically, parametric analyses have the following purposes:
  - assessment of the effects that some design choices (ex. thickness of the thermal insulation layer, Window-to-Wall Ratio, type of glazing, type of shading devices) have on the energy performance of the building in order to reduce it;
  - assessment of the effects that some design choices, related to the integration of photovoltaic modules into the building (ex. variation of the morphology of the roof), have on the electricity production;
- conclusions where results are summarized.

Some qualitative recommendations are, for example, that the main fronts with offices should be North/South oriented; the depth of the building should be contained (max. from 11m to 12m); the core atrium is a recurring strategy into low-rise buildings.
Some quantitative results are, for example, that the variation of the shape of the building influences the primary energy demand at maximum between 4% and 5%; while the variation of the type of system at maximum the 17% (if a reversible heat pump is adopted instead a condensing gas boiler with an air conditioning system).
The optimum thickness of the thermal insulation layer is determined in relation both to the reduction of heat losses and to the minimization of costs. Hence, it depends by the type of system adopted. For instance, it should be 12cm in Milano and 7cm in Palermo when the condensing gas boiler and the air

conditioning system are used; otherwise, when the reversible heat pump is adopted, the thickness should be reduced.
Medium (Solar Heat Gain Coefficient equal to 0.4) and high (Solar Heat Gain Coefficient from 0.27 to 0.24) selective glazing with high visible transmittance are recommended for West, East and South fronts when Window-to-Wall Ratio is more than 40%; otherwise basic glasses should be combined preferably with exterior shading devices. If the Window-to-Wall Ratio is more than 60% or 70%, high selective glass has to be combined with exterior blinds for South/West/East fronts, preferably for all locations.
The hybrid ventilation is strongly recommended in Italy. Specifically, natural ventilation aims at reducing cooling demand, should be adopted during both summer nights and days of the mid-seasons with the air change rate between 5 1/h to 10 1/h.
Photovoltaics integrated both into the roof and in the south-façade have high potential in Italy in order to reduce the primary energy demand. For example, in the energy efficient office building in Napoli, they cover the 95% of the primary energy demand.

The thesis defines qualitative and quantitative recommendations for the design of energy efficient office buildings located in Italy and shows how with this accurate design, pursued during the pre-design phase, it is possible to reach the low-energy goal.

ABSTRACT (Italian)

Il settore delle costruzioni è costretto ad un'importante cambiamento imposto dalla Direttiva Europea 2010/31 che affronta, tra i vari temi, quello della costruzione di edifici ad energia quasi zero (Nearly Zero Energy Buildings, NZEB). La direttiva comunitaria impone infatti agli Stati membri, che tutte le nuove costruzioni devono essere NZEB entro il 31 dicembre 2020, anticipando la data al 31 Dicembre 2018 per tutti gli edifici occupati e di proprietà della pubblica amministrazione.
Pertanto, appare necessario una ricerca che studia i criteri di progettazione per nuovi edifici per uffici ad alta efficienza energetica in quanto saranno la prima tipologia ad interfacciarsi con la normativa comunitaria.

La tesi presente individua alcuni criteri di progettazione per edifici ad uso ufficio situati in Italia valutandone l'influenza sulla performance energetica della costruzione. In particolare, la ricerca esamina sia l'applicazione di strategie di progettazione passiva che l'integrazione con le fonti rinnovabili, mantenendo un adeguato livello di comfort interno. L'obiettivo è quello di supportare i progettisti durante le prime fasi della progettazione attraverso raccomandazioni di tipo sia qualitativo che quantitativo. Questo appare necessario poiché, durante le prime fasi del processo di progettazione, molte scelte sono generalmente fatte sulla base dell'esperienza e dell'intuizione del progettista, piuttosto che su indicatori di prestazione energetica.

La tesi si è sviluppata secondo i seguenti passaggi:

- analisi dello stato dell'arte al fine di definire: terminologia, principi architettonici, strategie progettuali, tecnologie ricorrenti, normativa, ecc.;
- analisi qualitative di edifici per uffici realizzati in Europa (alcuni dei quali si trovano in Italia) presi come casi studio, al fine di mettere in evidenza criteri di progettazione e strategie ricorrenti specifiche per la tipologia in esame;
- analisi quantitative al fine di indagare l'influenza di alcune scelte progettuali sulla performance energetica dell'edificio. Considerate cinque città rappresentative del clima italiano, la ricerca in primo luogo analizza la performance energetica di tre casi base; in secondo luogo, investiga alcuni parametri progettuali; in terzo luogo, propone alcuni esempi di uffici ad alta performance energetica ottenuti grazie all'applicazione dei risultati degli studi parametrici su uno dei casi base.
  In particolare, l'analisi parametrica ha i seguenti obiettivi:
  - valutazione degli effetti di alcune scelte progettuali sulla performance energetica dell'edificio (es. spessore ottimale dell'isolante termico, rapporto trasparente/opaco, tipo di vetro, tipo di sistema di schermatura) al fine di ridurla;
  - valutazione degli effetti di alcune scelte progettuali, relative l'integrazione di moduli fotovoltaici nella costruzione, sulla produzione di energia elettrica (es. variazione della morfologia del tetto);
- conclusioni dove i principali risultati sono riassunti.

Alcuni risultati in termini di raccomandazioni di tipo qualitativo sono, per esempio: i fronti principali per gli uffici devono avere un'esposizione Nord/Sud; la profondità del corpo di fabbrica deve essere contenuta (max. tra 11m e 12m); la corte centrale è una delle strategie più ricorrenti negli edifici bassi a pianta larga.
Alcuni risultati in termini di raccomandazioni quantitative sono, per esempio, che la variazione della forma dell'edificio influenza la performance energetica in termini di energia primaria al massimo tra il 4% e il 5%; mentre la variazione del tipo di impianto ha un'influenza al massimo del 17% (se viene

adottata una pompa di calore reversibile al posto di un impianto composto da una caldaia a gas e da un impianto ad aria per la climatizzazione).

Lo spessore ottimale dell'isolante termico è determinato in relazione sia al contenimento delle dispersioni di calore sia alla minimizzazione dei costi; pertanto dipende dal tipo di impianto adottato. Ad esempio, quando si utilizza una caldaia a gas ed un impianto ad aria per la climatizzazione, lo spessore ottimale dell'isolante è circa 12cm a Milano e 7cm a Palermo. Tali spessori possono essere ridotti se invece viene adottata una pompa di calore reversibile.

Si raccomanda, per gli orientamenti Est, Ovest e Sud e per valori del Window-to-Wall Ratio maggiori del 40%, vetri mediamente (coefficiente di guadagno di luce solare circa 0.4) o altamente (coefficiente di guadagno di luce solare tra 0.27 e 0.24) selettivi con un elevato valore del coefficiente di trasmissione di luce nel visibile. Alternativamente, vetri meno performanti possono essere combinati con sistemi di schermatura preferibilmente esterni.

Se il Window-to-Wall Ratio, invece, ha valori maggiori del 60% o 70%, si raccomandano vetri altamente selettivi combinati con sistemi di schermatura esterni per gli orientamenti Sud, Ovest ed Est per tutte le località.

L'utilizzo della ventilazione ibrida, ai fini del raffrescamento degli spazi interni, è fortemente raccomandata in Italia sfruttando la ventilazione naturale sia durante le notti estive sia nelle ore diurne delle mezze stagioni con ricambi d'aria compresi tra 5 1/h e 10 1/h.

L'utilizzo di impianti fotovoltaici integrati sia sul tetto che sulla facciata Sud ha un grande potenziale in Italia nel ridurre l'energia primaria; ad esempio, nell'edificio low-energy proposto per la città di Napoli, l'impianto fotovoltaico copre il 95% della richiesta di energia primaria della costruzione.

La tesi presente definisce raccomandazioni di tipo sia qualitativo sia quantitativo per la progettazione di edifici per uffici energeticamente efficienti in Italia e mostra come, attraverso un'attenta progettazione da applicare fin dalle prime fasi del processo di ideazione, sia possibile raggiungere l'obiettivo low-energy.

ABSTRACT (German)

Die Änderung der Europäischen Richtlinie 2010/31/EU hat einen erheblichen Einfluss auf die Baubranche. Die Richtlinie fordert für alle Mitgliedstaaten, dass ab dem 31. Dezember 2020 (bzw. für öffentliche Gebäude ab dem 31. Dezember 2018) alle Neubauten als Niedrigstenergiehäuser errichtet werden. Es scheint daher notwendig, die verschiedenen Kriterien, die den Energiebedarf beeinflussen, genauer zu untersuchen. Die vorliegende Doktorarbeit identifiziert diese Kriterien und bewertet sie hinsichtlich des Einflusses auf den Energieverbrauch von Bürogebäuden in Italien. Dazu werden unter der Sicherstellung der thermischen Behaglichkeit passive bauliche Maßnahmen genauso betrachtet wie die Nutzung von erneuerbaren Energien.
Ziel ist, den Gebäudeentwicklern bereits in der Entwurfsphase mit qualitativen und quantitativen Empfehlungen zu unterstützen und den Fokus auch auf die Energieperformance der Gebäude zu richten.

Die vorliegende Doktorarbeit gliedert sich in folgende Punkte:

- Literaturrecherche zur Grundlagendefinitionen, architektonische Prinzipien, Energiekonzeptionen, Vorschriften, etc.;
- qualitative Analyse von Bürogebäuden in Europa (einige von ihnen befinden sich in Italien) als Fallstudien, um gebäudespezifische Kriterien und Strategien zu entwickeln;
- quantitative Analyse, um den Einfluss von verschiedenen Kriterien auf die Energieeffizienz des Gebäudes zu untersuchen. Für fünf repräsentative Städte in Italien werden dazu drei Fälle untersucht:
  1. Analyse und Untersuchung der Energie Performance für drei "Referenz Bürogebäude";
  2. Recherche und Prüfung von Design Parameter;
  3. Empfehlung zur Gestaltung von energieeffizienten Bürogebäuden auf Grundlage der Ergebnisse der vorliegenden Arbeit, beispielhaft für eins der drei "Referenz Bürogebäude".

  Die Parameterstudie hat folgende Ziele:
  - Bewertung des Einflusses bestimmter Kriterien auf den Energieverbrauch (z.B. Dämmstärke, Fensterflächenanteil, Art der Verglasung, Art der Verschattung;
  - Bewertung des Einflusses bestimmter Kriterien auf die Integrierbarkeit von PV Modulen im Gebäude auf den Stromertrag;
- Zusammenfassung und Schlussfolgerung.

Einige qualitative Empfehlungen sind beispielsweise, dass die Hauptfronten der Büros nach Nord / Süd ausgerichtet sein sollten; die Tiefe des Gebäudes sollte bei maximal 11m bis 12m liegen; das Atrium ist eine wiederkehrende Strategie in flachen Gebäuden.
Einige quantitative Ergebnisse sind beispielsweise, dass die Variation der Form des Gebäudes den Primärenergiebedarf zwischen 4% und 5% beeinflusst; während eine Veränderung der Gebäudetechnik bis zu 17% einsparen kann (wenn statt eines Gas-Brennwertkessels mit einer Klimaanlage eine reversible Wärmepumpe genutzt wird).
Die optimale Dämmstärke wird sowohl in Abhängigkeit der Wärmeverluste als auch durch die Kosten bestimmt. Auch die Systemtechnik spielt eine Rolle. In Milano beispielsweise sollten 12cm Dämmung während in Palermo nur 7cm ausreichend sind, sofern der Gas Brennwertkessel mit der Klimaanlage genutzt wird. Unter Nutzung der reversiblen Wärmepumpe sollte die Dämmstärke reduziert werden.

Bei einem Fensterflächenanteil von über 40% wird für die West, Ost und Südfassade eine mittlere (g-Wert 0.4) oder hoch selektiv beschichtete Verglasung (g-Wert 0.27 bis 0.24) empfohlen, alternativ sollte eine Standardverglasung immer mit außenliegendem Sonnenschutz kombiniert werden. Für einen Fensterflächenanteil von mehr als 60% (bzw. 70%) wird hoch selektive Verglasung mit externer Verschattung für alle Orientierungen empfohlen.
Das Lüftungskonzept sollte aus einer Kombination aus mechanischer und natürlicher Lüftung bestehen. Insbesondere die natürliche Lüftung trägt zur Reduzierung des Kühlbedarf bei. Dies gilt für Sommermonate genauso wie für die Übergangszeiten. Der Luftwechsel für die Nachtlüftung sollte zwischen 5 1/h und 10 1/h liegen.
Die Nutzung von PV Elementen sowohl in der Dachfläche als auch der Süd Fassade können in Italien im erheblichen Masse zur Primärenergieeinsparung beitragen. Beispielsweise deckt die Anlage eines energieeffizienten Bürogebäudes in Napoli 95% des Primärenergiebedarfs.

Die Doktorarbeit nennt qualitative und quantitative Empfehlungen zur Gestaltung von energieeffizienten Bürogebäudes in Italien, die schon während der Entwurfsphase angewendet werden sollten und so helfen, die ehrgeizigen Ziele der Energieeinsparung zu erreichen.

TABLE OF CONTENTS

LIST OF ABBREVIATION

AEDG	Advanced Energy Design Guide
ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating and Air- Conditioning Engineers
BIPV	Building Integrated Photovoltaic System
BREEAM	Building Research Establishment Environmental Assessment Method
CHP	Combined Heat and Power Generation
CISBE	Chartered Institution of Building Services Engineers
COP	Coefficient of Performance
DGNB	Deutsche Gesellschaft für Nachhaltiges Bauen
EnOB	Research for Energy Optimized Building
HVAC	Heating, Ventilation and Air Conditioning
IAQ	Indoor Air Quality
IWEC	International Weather for Energy Calculations
LEED	Leadership in Energy and Environmental Design
MV	Mechanical Ventilation
NC	Night Cooling
NV	Natural Ventilation
NZEB	Nearly Zero Energy Building
PMV	Predicted Mean Vote
PV	Photovoltaic modules
RH	Relative Humidity
SHGC	Solar Heat Gain Coefficient
SPF	Seasonal Performance Factor
VT	Visible Transmittance
WWR	Window-to-Wall Ratio

LIST OF NOMENCLATURE

α	Inclination of solar rays [°]
β	Angle of PV [°]
γ	Inclination of the roof [°]
δ_M	Thickness of thermal insulation layer [cm]
ΔT_h	Difference between indoor and outdoor air temperature in heating period [K]
η	Efficiency of system
θ	Angle of façade [°]
λ_M	Heat conductivity of insulation material [W/mK]
ACH	Air change rate [1/h]
a,b,c,d	Dimensions of the floor plan [m]
A_{PV}	Area of PV modules [m^2]
A_{fp}	Gross area of the floor plan [m^2]
A_T	Total Gross Area of the building [m^2]
A_{wall}	Area of the external wall [m^2]
CDD	Cooling Degree Days [K·d/a]
C_i	Investment for thermal insulation layer [€]
C_L	Labor cost [€/m^3]
C_M	Price of insulation material [€/m^3]
C_{tc}	Energy costs of space cooling to cover heat transmission of opaque external wall [€]
C_{th}	Energy costs of space heating to cover heat transmission of opaque external wall [€]
C_{fc}	Fuel price of space cooling [€/kWh]
C_{fh}	Fuel price of space heating [€/kWh]
HDD	Heating Degree Days [K·d/a]
H	Hourly perceived temperature [°C]
H_{med}	Daily perceived temperature [°C]
H_{tot}	Total height of the building [m]
L	PV length [m]
L_1	PV projection on horizontal plane [m]
L_2	PV projection on vertical plane [m]
Q_P	Primary Energy Demand [kWh/m^2a]
Q_f	Final Energy Demand [kWh/m^2a]
Q_{th}	Heat transmission losses of opaque external wall during the heating period [kWh/a]
Q_{tc}	Heat transmission gains of opaque external wall during the cooling period [kWh/a]
Q_u	Useful Energy Demand [kWh/m^2a]
N	Life time of thermal insulation [a]
N_L	Number of stories of the building
N_w	Number of workers
R_{wo}	Thermal resistance of the external wall except thermal insulation layer [m^2K/W]
t_h	Heating period [h]
T	Hourly temperature [°C]
U	Thermal transmittance [W/m^2K]
V	Gross volume of the building [m^3]

V_c	Summer Severity Climatic Index
X_{min}	Minimum distance between PV [m]

LIST OF FIGURES

LIST OF TABLES

LIST OF EQUATIONS

1. FIELD OF INTEREST, AIM AND METHODOLOGY

CONTENTS

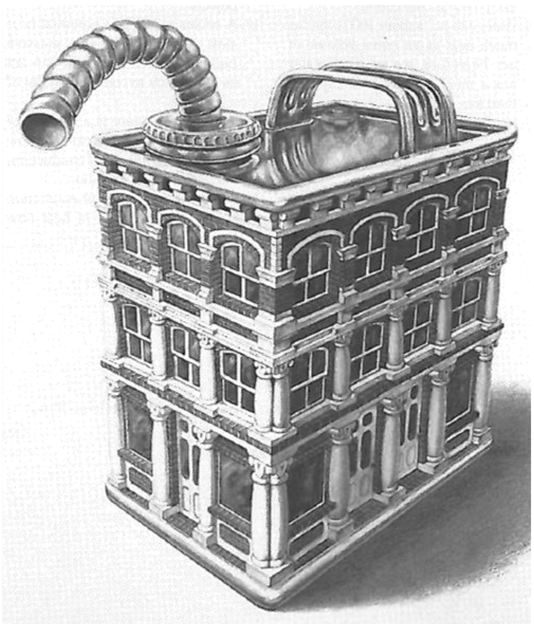


Figure 1.1: Poster by National Trust for Historic Preservation (1980), Page 49 **[1]**

INTRODUCTION

The most important issues discussed in the international scene are climate changing, rapid urbanization and the consequent reduction of urban space, new forms of communication and work, the growing global mobility, the use of renewable energy, etc.

In this scenario, smart buildings constitute a recurring theme and they represent a new challenge for architects and engineers. In fact, such buildings entail also innovative materials with low environmental impact, produce and distribute energy, monitor their consumptions and use ICT technologies to reduce wastes. [2]

The problem of global warming and of energy indeed has forced new challenges in the programming efficiency and durability of the building and urgent measures have to be considered for the building sector, responsible of the "*40% of global energy consumption in the Union*" [3].

The present research starts from the belief that the design choices during the pre-design phase affect considerably the result and they generally not enclose energy performance indicators such as CO_2, primary energy index, etc. This in the past had contributed to create a gap between the experts of the building physics and the designers. Hence, pursuing a multidisciplinary approach, the building becomes a complex organism to design on its entirety since the early phase considering its energy performance.

The extensive bibliography on this subject often appears either especially related to the housing typology or focused on single aspects or with reference of other countries with different climate conditions.

Therefore, it appears necessary to make an analysis of some design strategies and techniques for new offices in Italy towards the "Zero Energy" or the "EnergyPLUS" goals even if new buildings in our territory are just a low percentage (1.3% of the total existing heritage) [4].

Specifically, the research refers to the administration buildings since they represent the first typology to face with the European Directive. In addition, they are:

- more complex than residential buildings for typological characters;
- "energy-hungry" blocks;
- the place where people spend most of their time with a consequent importance on the maintenance of high-level of comfort.

The research investigates some design criteria especially in relation to passive and active design strategies giving qualitative and quantitative recommendations. The aim is the creation of guidelines useful for designers in order to support their decision-making process.

1.1 FIELD OF INTEREST

1.1.1 GOAL "20-20-20"

The EU Directive 2010/31/EU, which takes up and develops the principles of the previous 2002/91/CE, represents a new challenge for the Union countries that have to pursue a sustainable development. It presents important aims to achieve by 2020 in order to comply with the Kyoto Protocol, to meet the long-term commitment, to keep the global temperature rise below 2°C and to reduce the global emissions of greenhouse gases.

The objectives are:

- **reduction of greenhouse gas emissions by 20%;**
- **reduction of primary energy consumption by 20%;**
- **introduction of 20% of energy from renewable sources.**

The so-called "*20/20/20*" introduces:

- the **adoption of a methodology for calculating the energy performance of buildings**. Each Member State can establish the minimum energy performance requirements for both new buildings and existing ones. The requirements will be reviewed at regular intervals not exceeding 5 years and they have to reflect technical progress in the construction industry. There will assess the technical feasibility and the possibility of achieving optimal levels of costs (**Art.3, Art.4 and Art.5**);
- the application of **minimum requirements on the energy performance** for new buildings and for the renovation of the existing ones (**Art.6 and Art.7**);
- the definition of "**Nearly Zero Energy Building**" as a building with "*a very high energy performance*" where the energy demand is zero or net zero, partially covered by the integration with renewable sources. Since the 31st December 2018 all new buildings, occupied by public authorities and also their properties, should be nearly zero energy. The requirement will extend to all the new buildings since 31st December 2020 (**Art.2 and Art.9**);
- the release of an **energy performance certificate**, which shall contain the energy performance of the building, reference values (such as minimum energy performance requirements) and recommendations for the cost-optimal or cost-effective improvement. The certificate must be issued in the event of a new building, sale, or lease of a single unit or an entire building. In addition, it will be issued also for buildings with a total useful floor area over 500m^2 occupied by public authority (this value drop to 250m^2 since 9th July 2015). Commercial media advertisements will show the performance indicator (**Art.11 and Art.12**);
- **regular inspections** for heating systems (with an effective rated output>20kW) and air-conditioning systems (with an effective rated output>12kW), and the redaction of a report to give to the owners (**Art.14, Art.15 and Art.16**);
- the establishment of an **independent control system** of the inspection reports and of the energy certificates.

The documents are random selected and there will be considered a statistically significant percentage. The assessment will be based on checking the validity of the data used and of the results (**Art.18**).

The legislation "*20-20-20*", addressing issues such as high-performance buildings, renewable sources, energy performance certificates, systems inspections and emphasizing the importance of summer cooling on the energy balance of the building, forces Europe to move toward higher sensitivity to the environment.
Therefore, the growing of the complexity of the building and the importance of analysis for the preliminarily prediction of the energy behavior, force to eradicate all those "bad habit" that had led in the past to a preliminary design phase where, either the performance level or the strategies to reach it, were not clear.
On contrary, the new Directive requires careful planning, multidisciplinary approach and high definition level since the early stage, without leaving aspects to define during the construction phase (Figure 1.2).

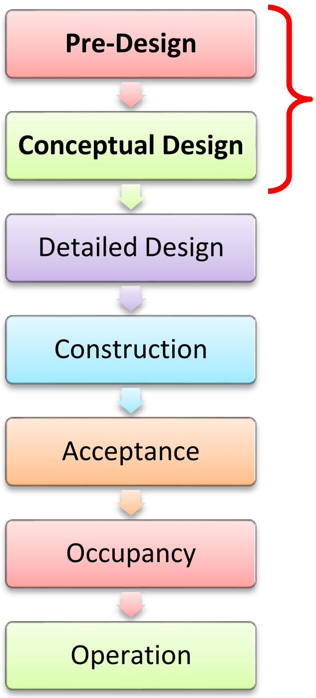


Figure 1.2: Stages of the design process

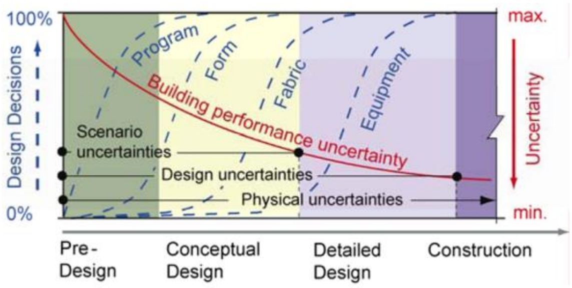


Figure 1.3: Traditional decision making process in building design adopted by Torcellini and Ellis (2006) **[5]**

1.1.2 THE DECISION MAKING PROCESS

The decision-making process has a great impact on the design of a building (Figure 1.3). Therefore, wrong choices can affect considerably the results and this appears important looking at the prediction of the energy performance since the early phase. Usually, in fact, early design decisions are based on intuition and experience rather than quantitative performance indicators such as costs, thermal comfort, CO_2 emissions, etc. [5]. In addition, qualitative and quantitative suggestions are generally contents of different disciplines: the architecture and the building physic.
However, how is possible to make a relation between them? The present research tries to reduce the gap of these two worlds merging qualitative and quantitative recommendations for the pre-design stage.

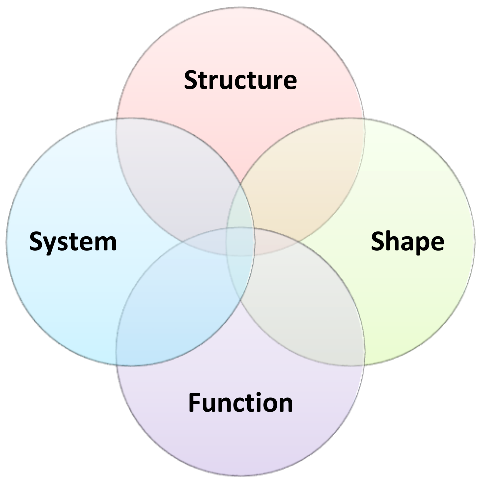


Figure 1.4: Main aspects of the design of the building

1.1.2.1 INTEGRATED DESIGN

It becomes fundamental considering the building as a complex organism where different disciplines combine and where various professionals meet.
The design process is in fact, a circular and iterative method and designers pass from a linear approach, typical of the past, to a non-linear one, where shape, function, structure and systems merge as Figure 1.4 [6].
The multidisciplinary approach is both the essence of the sustainable design and the core of this research. Working together to reach the optimal product (even if this can be translated into an articulated, long and more expensive design phase) is at the end a real opportunity to achieve a good balance between economic, environmental, social and human benefits (especially there is a cost reduction in terms of materials, energy and operation).
This integrated approach, typically adopted by huge companies into big projects, has to be borrow also for medium-small size projects.
Hence, sustainable design means applying an integrated design to minimize the energy demand of the building through architectural and structural measures, increasing the efficiency of systems and using renewable energies.
For this reason, it is important to work at three different levels (Figure 1.5 and Figure 1.6), at the same time, which are [1]:

1. **BASIC BUILDING DESIGN**
   It pursues the typical objectives of the traditional design of buildings and aims to minimize heat losses during winter, to reduce overheating in summer, to maximize daylighting and natural ventilation without sacrificing the building aesthetic. The proper decisions at this point can greatly reduce the size of mechanical systems.

2. **PASSIVE SYSTEM DESIGN**
   Exploitation of natural energies (solar radiation, winds and soil) as sources for the application of passive strategies as passive heating, passive cooling and daylighting (Paragraph 2.4). At this level, it is possible to improve the performance of the building, trying to face the unresolved problems of the first tier.

3. **MECHANICAL SYSTEM DESIGN**
   It consists into the design of mechanical equipment trying to handle the remaining loads of the previous two tiers.

Especially in the past, between these three levels, there was a hierarchy and an unbalance until the deleting of one of the tier (ex. PassivHaus). Despite, to reach the NZEB or EnergyPLUS goal, it appears indissoluble considering the integration **building-plant system**.
The integrated design must be, therefore, flexible and proceeds "**step by step**" with a preliminary moment where the programming of the process is made [7, 8].

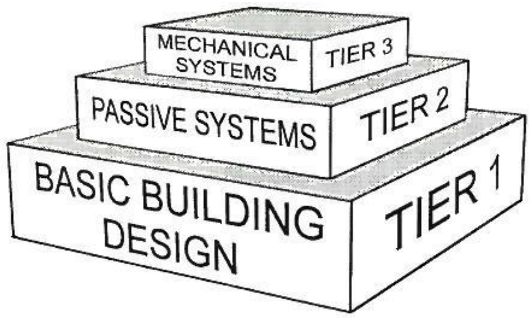


Figure 1.5: The three-tier design approach, Page 8 **[1]**

	Heating	Cooling	Lighting
Tier 1 Basic Building Design	*Conservation* 1. Surface-to-volume ratio 2. Insulation 3. Infiltration	*Heat avoidance* 1. Shading 2. Exterior colors 3. Insulation	*Daylight* 1. Windows 2. Glazing type 3. Interior finishes
Tier 2 Natural Energies and Passive Techniques	*Passive solar* 1. Direct gain 2. Trombe wall 3. Sunspace	*Passive cooling* 1. Evaporative cooling 2. Convective cooling 3. Radiant cooling	*Daylighting* 1. Skylights 2. Clerestories 3. Light shelves
Tier 3 Mechanical and Electrical Equipment	*Heating equipment* 1. Furnace 2. Ducts 3. Fuels	*Cooling equipment* 1. Refrigeration machine 2. Ducts 3. Diffusers	*Electric light* 1. Lamps 2. Fixtures 3. Location of fixtures

Figure 1.6: The three-tier design approach, Page 8 **[1]**

Specifically, the steps are briefly summarized as following (Figure 1.7):

1. **SITE ANALYSIS**
   The mutual influence between site and buildings is an important aspect to evaluate. Hence, it is essential to analyze the location in terms of (Figure 1.8):
- geographical localization (latitude, longitude and altitude);
- climate and microclimate characterization (ex. temperature, solar radiation, humidity, rainfall, wind directions);
- area characterization (geo-morphological, architectural and socio-cultural characteristics).

   In such way, since the early stage of design, are defined the elements of the location to preserve, to exploit or to avoid.
   Moreover, it is possible to delineate the potentiality of the location in terms of availability of sources (ex. wind, soil, sun, rain and water surfaces, planted surfaces) in order to choose the most cost-efficient and convenient approach.

2. **DESIGN OF THE BUILDING COMPLEX**
   The design works not on a building scale, but it considers the area where it will be located. Hence, two main macro-categories are considered (Figure 1.9):
- the quality of the outdoor environment in terms of: comfort conditions (ex. visual, thermo-hygrometric and acoustic comfort); environmental impact (ex. pollution) and integration with the context (ex. relation building-urban pattern);
- the area layout in terms of: organization of the exterior spaces and orientation of the buildings.

3. **BUILDING DESIGN**
   Starting from the definition of the indoor environmental quality (in terms of: indoor comfort conditions, IAQ and functionality of spaces), two building systems are analyzed (Figure 1.9):
- the environmental system: orientation and the shape of the building including also the distribution of interior spaces;

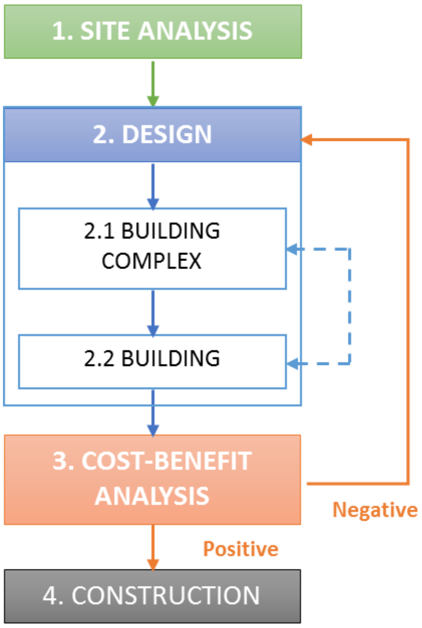


Figure 1.7: Sustainable design chart, Page 368 **[8]**

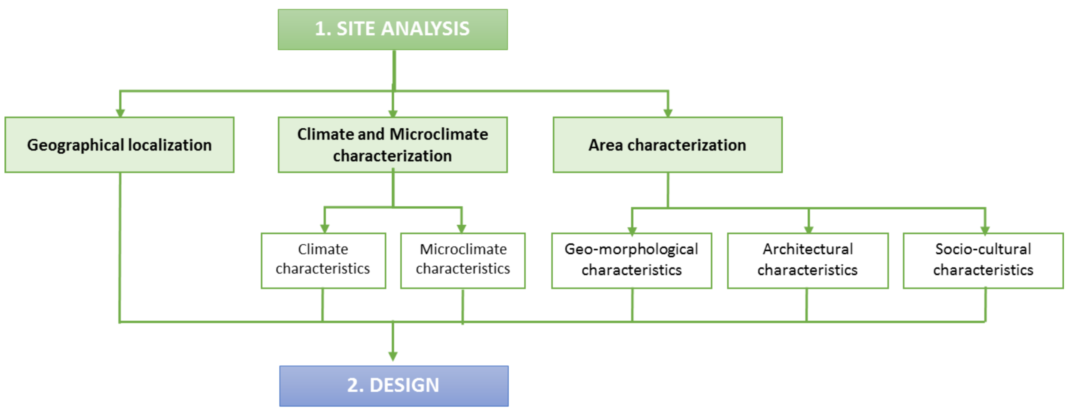


Figure 1.8: Site analysis chart, Page 368 **[8]**

- the technological system that is composed by a series of sub-systems (ex. envelope, structures, furniture, systems). At this step, both passive (ex. buffer zones, size of windows, night cooling) and active strategies (ex. solar collectors) aiming to the energy reduction/supply, characterize the decision making process.

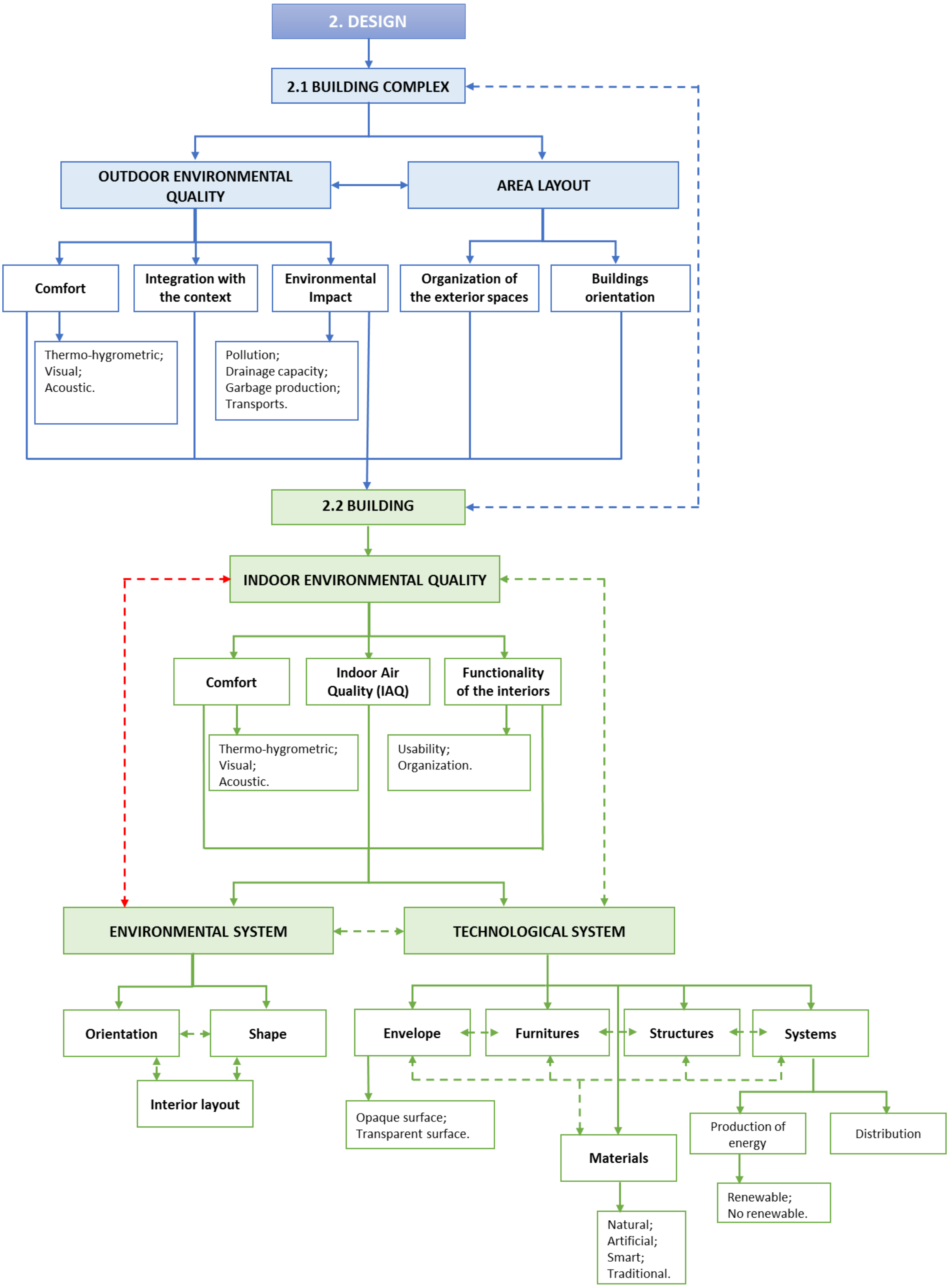


Figure 1.9: Chart of building complex and building design, Page 370 **[8]**

1.1.3 OFFICE BUILDING TYPOLOGY

Offices are a wide variety of buildings ranging from tall skyscrapers that house huge companies, to small buildings scattered in different urban areas until the single room in the apartment (home-office).
Excluding the last category that appears closely linked to the residential sphere, office buildings differ considerably (Table 1.1) according to the integration in the urban scale, the type of activity that takes place, the relation with the public, the level of technology required for the completion of the task [9].
In this multitude, it appears difficult to give recommendations valid for all of these cases. If we look at the building features, it is possible to find recurring characters sharing the office typology[1] in two macro-categories:

1. **<u>LOW-RISE BUILDINGS WITH A WIDE FLOOR PLAN:</u>** they have a predominant horizontal development rather than in elevation. Levels are less than 10 (Figure 1.10)[2];

2. **<u>HIGH-RISE BUILDINGS WITH A NARROW FLOOR PLAN:</u>** They have a vertical development with a small footprint. Levels are more than 10 (Figure 1.11)[3].

The two categories differ for different declination of the types[4] and the detailed description is presented in Chapter 3. Specifically, the topic of the present research is the analysis of design criteria for high-rise and low-rise office buildings in relation to the factors of the building type (Figure 1.12) [6].

CLASSIFICATION of OFFICE BUILDINGS	
MAIN	**SUB -**
URBAN	City center
	Administration district
	Suburb area
	Commercial and Industrial area
	Decentralized position on territory
FORMAL TYPOLOGICAL	Block
	Tower
	Linear
	Slab
	Net
CLIENT/USER	Huge organization (public or private)
	Medium organization supporting the production (ex. marketing, etc.)
	Medium organization for services
	Small organization
	Consortium
	Income cooperative
DIMENSIONAL	Centralize
	Decentralize and diffuse
	Mobile office
	Office among third party
	Lease office
	Home office

Table 1.1: Main classifications of office buildings **[9]**

Figure 1.10: Examples of low-rise office buildings

Figure 1.11: Examples of high-rise office buildings

[1] "Typology" indicates the study of types. For examples: hospitals, hotels, schools, offices, etc. are different building typologies.
[2] Figure 1.10: Federal Environmental Agency (Dessau, DE); iGuzzini (Recanati, IT); Pollmeier GmbH (Creuzburg, DE); Gotz Headquarters (Wurzburg, DE).
[3] Figure 1.11: Mary Axe (London, UK); GSW (Berlin, DE); Ropemaker (London, UK).
[4] "Type" indicates the result of a critical process, which underlines recurring elements into the variety of buildings. It tries to reduce the multitude of the solutions and it gives a schematization of one aspect.

Specifically, the thesis looks at:

- **PASSIVE DESIGN STRATEGIES** as a way to reduce the useful energy demand of the building;
- **INTEGRATION WITH RENEWABLE SOURCES (use of photovoltaics)** as one possibility to produce energy and cover the remaining electricity needs of the building;
- **INDOOR COMFORT CONDITIONS** as internal requirements to preserve for the exploitation of the specific function.

Moreover, the present research refers to the administration category excluding home-office, banks and professional studios since they are "particular offices" which require specific attention.

1.1.3.1 OFFICE BUILDING DESIGN

The design of office buildings can follow different criteria and it is traditionally related to the organization of the floor plan type.
The internal layout has always based on social and organizational concepts. The cell-space, the open-space and the combi-space[5] are, in fact, the results of historical and technological development: from the cell type, typical of a hierarchical organization of roles until the functional, dynamic and smart combi-space [10, 11]. In addition, the technological progress has influenced the way of work and the way to "live" the office. New models of “virtual work” have led to a dematerialization of the workspace (the A4 paper format is replaced by the email) allowing a spatial freedom concept where workers can perform their job wherever they are (Figure 1.13 and Figure 1.14) [12].
Beside these concepts, new aims for administration buildings are the reduction of construction costs, the decrease of the operation costs and the increasing of the productivity (ergonomic design, Figure 1.15).

[5] Combi-space: “combination office” represents a combination of cell and open-office.

This leads both to an analysis of strategies to reduce consumptions and to a study of the maintenance of the indoor comfort conditions.

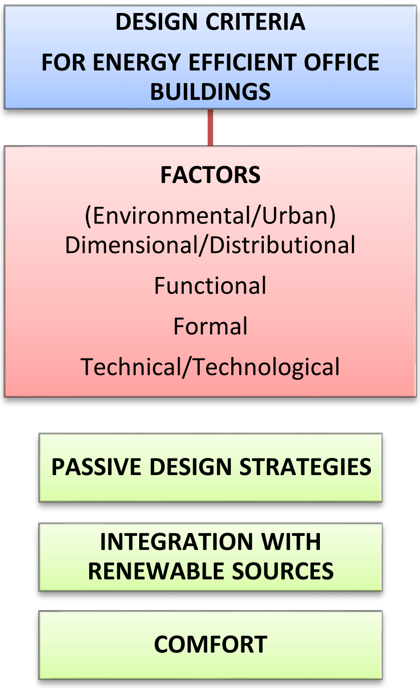


Figure 1.12: Research topic

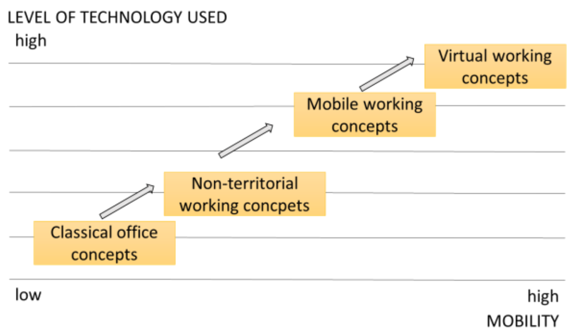


Figure 1.13: Development trends in smart working environments, Page 87 **[11]**

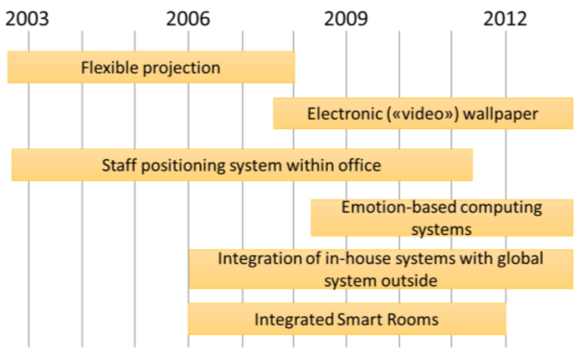


Figure 1.14: Development of forms of mobile working by means of technology, Page 89 **[11]**

The literature in this field is varied and wide both on issues such as office buildings and sustainable design.

However, many works either focus on single aspect or follow a general approach. In addition, the literature sometimes reflects the gap between the spheres of the architecture and the building physic, giving alternatively or qualitative or quantitative recommendations. Moreover, many recommendations given by guidebook, manuals, etc. are generally not related to the Italian climate. Hence, appears necessary, through a unitary approach, to define, for the specific typology, some recommendations valid in our territory.

1.1.3.2 OFFICE COMFORT

The office is the place where a good comfort guarantees not also the well-being of a person, but occurs to the work success: in fact, it influences the performance of the worker.

This is the reason why many studies focuses on the human and his relation with the workspace (Figure 1.15)[6].

Even if the technological progress and the way of working changing continuously (until a dematerialization of the traditional desk, replaced by smart-phone and tablet usable everywhere), the office remains the place where many people, materials and communications polarize and circulate.

The present thesis does not face topics as interior design in relation the well-being of the user, despite it guarantees adequate interior comfort conditions varying some architectural parameters.

Generally, the comfort faces with two aspects:

- maintenance of the well-being of the human;
- environmental problem.

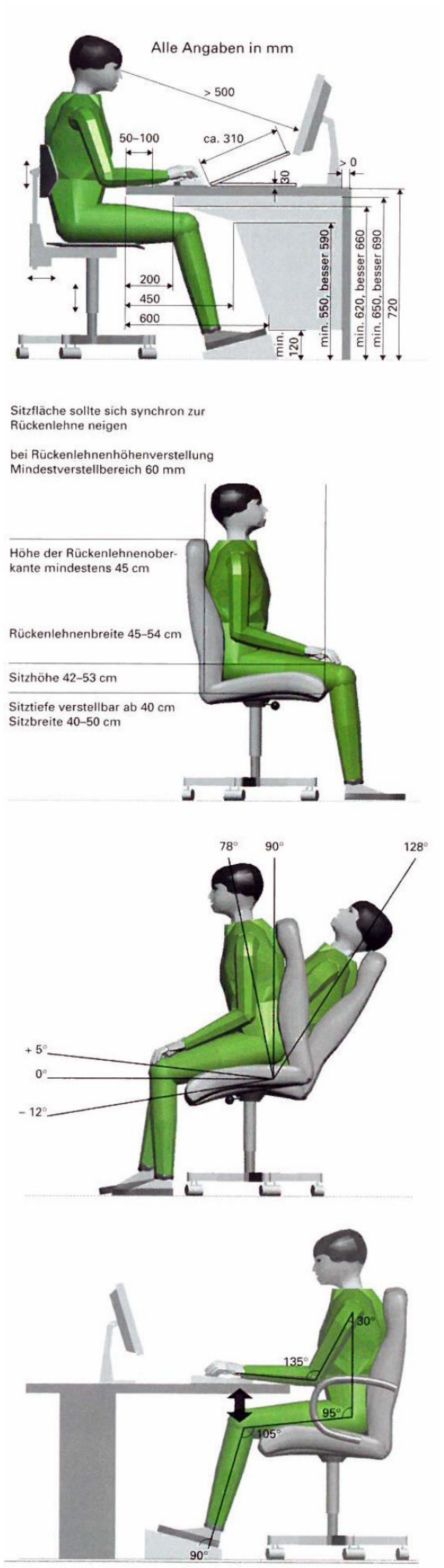


Figure 1.15: Ergonomics study of a person sitting on a desk, Page 214 **[13]**

[6] The ergonomics is the study of the interaction between the human and the environment. It was born during the Second World War when the man started to become a resource. To optimize the use of resources, the need of an efficient workforce led to a multidisciplinary study of the relation man/workspace to minimize accidents such as errors due to a lack of training for use of increasingly complex machines.

In the past, the imbalance of the two features has been occurred.
Specifically, the predominance of the first aspect, with the application of strict standards to maintain, has created oversized mechanical systems with high consumes. On contrary, the centralization on the second aspect has been accompanied by a drastically reduction (or abolition as in "PassivHaus") of mechanical systems (that is not applicable for the office typology). The risk in this case, is the creation of a building as a "prison" where users could not interact with the block in order to not influence the energy behavior of the building and vainly the designer plans.
Actually, it is fundamental to guarantee an equilibrium between the two parts and in particular for non-residential buildings.
Therefore, it is important that users have a control on the indoor temperature, on light, shadowing devices and openings. This means that the real energy building behavior is different from the predicted one and it is dependent by the user needs and his level of culture. Despite the designer could not decide to eliminate the possibility of the user choice.
For example, the natural ventilation through windows is an important aspect that affects considerably the psychological condition and the comfort of workers. Realizing an openable window reduces the electricity need, creates a transparent interface with the outside and allows the user to make a decision on his indoor comfort. On contrary, at the same time, it influences "uncontrollable" the behavior of the airflow into the building.
The problem mentioned above, for example, can be solved with a differentiated study of openings: some windows can be opened directly by users; others can be controlled automatically.

Tables from 1.2 to 1.4 summarize some requirements that the administration building should satisfy to guarantee good indoor comfort conditions for users [14].

	THERMAL COMFORT
Description	It depends on: ▪ type of clothing; ▪ time spent within a room; ▪ age, health and level of education; ▪ type of activity.
	OPERATIVE TEMPERATURE [7]
Requirements	**Indoor:** Winter: 21-22°C Summer: 25-26°C Manager rooms: 2.5°C lower **Open atrium:** Winter: 5-10 K more than outside Summer: 10 K less than outside
	SURFACE TEMPERATURE[8]
Requirements	**Floor surfaces** Circulation area: Min 12°C – Max 32°C Steadily populated areas with longer contact duration: Min 21°C – Max 29°C **Ceiling surfaces** Min 14°C – Max 28°C/Max 35°C **Wall surfaces** Min 15°C – Max 45°C/Max 65°C Maximum temperature difference between head and foot region 2K; Maintenance of a low difference between surface temperatures.
	INDOOR HUMIDITY
Requirements	The range lies between 30÷70%; Absorbent materials should be disposed in the places where humidity is to much high.
	VENTILATION and AIR QUALITY
Description	Exchange rate depends on: ▪ occupancy; ▪ type of ventilation strategy used; ▪ maintenance of system (dusts).
Requirements	Avoid local wind current; Prefer natural ventilation through an appropriate window design; Using free-emission materials; Air Change Rate (ACR) = 11 l/s·per[9]

Table 1.2: Summary with requirements for indoor comfort in office buildings - thermal comfort, ventilation and air quality

[7] The operative temperature inside an ambient is the result of the air temperature, the temperatures of all the surfaces surroundings and of the direct solar radiation. For an open atrium, which became a filter between inside and outside, the user has to feel a different temperature.
[8] Page 29 [14]
[9] $11 \cdot 10^{-3}$ m^3/s·per [20]

VISUAL COMFORT	
Description	The quality depends on: ▪ room shape; ▪ obstructions; ▪ technology of façade; ▪ reflections. Maximization of daylighting and glare protection.
Natural lighting requirements	**DAYLIGHTING FACTOR**[10]
	2% generic activity; 4% computer work. [11]
	ILLUMINANCE
	Uniformity of illuminance; *Grade of illuminance*[12]*:* 150 lux corridor, garage, toilets 500 lux light office work 1000 lux graphic work, huge space
	COLOUR
	Color rendering index: Ra=80-90 Color Temperature: 4000÷4500°K
Artificial lighting requirements	Contemporary presence of natural and artificial lighting for office spaces especially when the depth of the room is >6m; In order to do not create excessive contrasts between natural and artificial lighting, the artificial one has to be: If single window: 750 lux If continuous glass surfaces: 1000 lux
	Ceiling system for a uniform luminance of spaces, with orientation not dependent by the workstation and by the façade design; Integration of the ceiling lighting system with a punctual one for each workstation (lamp for every desk).

Table 1.3: Summary with requirements for indoor comfort in office buildings - visual comfort

ACOUSTIC COMFORT	
Description	It depends on: ▪ type of activity; ▪ occupancy; ▪ room shape; ▪ room materials.
Requirements	Limiting outside noise (permanent noise level/short term); Daily exposure level limit: 85dBA; Sound can be absorbed by: - dissipative absorbers = porous (it depends by the thickness of the material) - membrane absorbers = panel (ex. suspended ceilings, raised floors, etc.) - cavity absorbers.

Table 1.4: Summary with requirements for indoor comfort in office buildings - acoustic comfort

Figure 1.16: Room with direct illumination (above) and room with indirect illumination (below), Page 36 **[14]**

[10] The average daylight factor is a dimensionless parameter that describes the quality of light inside a space. It does not depend on the level of illuminance outside, but it derives from the geometric relation between a point considered within the room on a work-plane and the overcast sky.

[11] Page 79, [17]

[12] [19]

1.2 AIM

The aim of the research is the definition of design criteria (giving qualitative and quantitative recommendations) useful for the pre-design phase for new Italian office buildings.[13]

This appears overriding because, as explained above, this typology:

- is the first to face with the requirements of the Directive 2010/31/UE (31st December 2018);
- is more complex than the residential one for typological aspects (Figure 1.17);
- has high primary energy demand (Figure 1.18);
- has to guarantee high comfort conditions for the work success.

Electricity demand is predominant and is accounted mainly by cooling, lighting and specific needs of the worker as computers, printers, etc. (Figure 1.19).

The research explains the influence of some design parameters on the energy demand of the building investigating some passive and active strategies to reach energy efficient buildings in Italy pursuing an integrated approach.

All recommendations are presented in the form of advices accompanied by graphics, equations, schemes, ranges, percentage, etc. in order to support a "conscious design process".[14]

The reduction of the useful energy demand through the application of some passive strategies is the first step (envelope optimization and ventilation strategies); while the production of energy through the integration with PV systems characterize the second one.

This occurs for three different office types (Case A, B and C) and five Italian cities (Milano, Firenze, Roma, Napoli and Palermo).

Figure 1.17: The City, London (UK) **[15]**

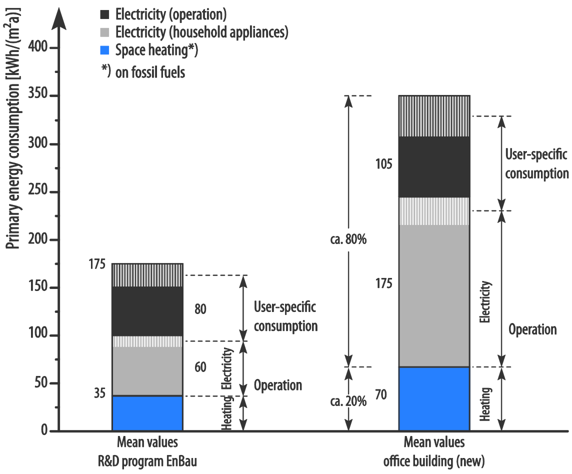


Figure 1.18: Distribution of primary energy consumption in office buildings in Germany, Page 21 **[16]**

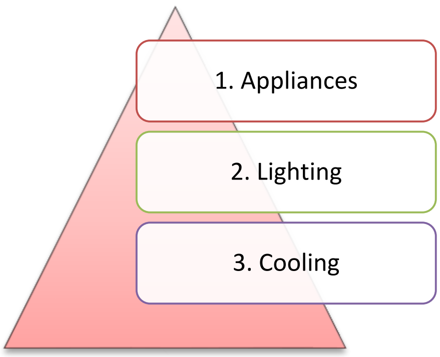


Figure 1.19: Main electricity needs in office buildings

[13] The energy certification is applied to all the buildings listed in Art.3 of the D.P.R. 26 August 1993, n.412. Specifically: *"E.2 Edifici adibiti a uffici e assimilabili: pubblici o privati, indipendenti o contigui a costruzioni adibite anche ad attività industriali o artigianali, purché siano da tali costruzioni scorporabili agli effetti dell'isolamento termico"* [18].

[14] Sustainable design implies "conscious design".

1.3 METHODOLOGY

Protocol "ITACA" for offices, "AEDG" by ASHRAE (Paragraph 2.3) and many manuals on sustainable design are the references that give a logic frame to the present work (Table 1.5).
After the literature review, existing office buildings located in Europe are studied as example of sustainable architecture and their analyses are summarized in schematic sheets. At the end of the phase, design criteria (qualitative recommendations) for both low-rise and high-rise office buildings are listed (Chapter 3).
At a later stage (Chapter 4), the energy performance of three Base Cases is defined changing climate (five cities) and system type (two types of system). The models, at this step, have same features, they reflect the division into high-rise and low-rise types and they differ only for the shape.
Thus, the influence of some passive and active strategies (parametric studies) on the energy performance is tested (Chapter 5). This is made to validate the effectiveness of some design choices for the Italian territory. Specifically, for the first tranche of simulations, the minimization of the useful energy demand of the building is the aim (parameters linked to passive strategies as windows sizing, night cooling, etc.); while for the second part, the production of the electricity is the goal (parameters connected to BIPV).
At the end, some examples of energy efficient office buildings in Italy are presented applying the results of the previous parametric studies to one base case in order to evaluate their effectiveness.

LITERATURE REVIEW

- Analysis of procedures, parameters and elements for the design of sustainable buildings (ex. climate, orientation, user needs, passive strategies, etc.);
- Study of the typological characters for office buildings (ex. morphology, organization, internal layout, constructive aspects, etc.).

ANALYSIS OF BUILDINGS LOCATED IN EUROPE

- Analysis of the examples (buildings located in Europe) trough a rational schematization (study of both the building context and the building features);
- Output: Design strategies for office buildings (qualitative recommendations).

ENERGY PERFORMANCE OF THREE BASE CASES

- Climate characterization by location (5 cities);
- Definition of Base Cases (A, B, C);
- Parameters: location, shape, type of system;
- Output: energy performance of Base Cases.

PARAMETRIC STUDIES AND STRATEGIES FOR RENEWABLE ENERGY SUPPLY

- Reduction of the useful energy demand of the building thorugh the application of some passive strategies;
- Parameters: location, orientation, thickness of the insulation layer, Window-to-Wall Ratio, glazing type, shading devices type, air change rate;
- Output: design strategies (quantitative recommendations);

- Production of energy through photovoltaics;
- Parameters: location, shape of the building, geometry of the roof, geometry of the facade;
- Output: design strategies (quantitative recommendations).

DEFINITION OF DESIGN CRITERIA FOR ENERGY EFFICIENT ITALIAN OFFICE BUILDINGS

- Five examples of energy efficient offices, one for each city;
- Summary of qualitative and quantitative recommendations.

Table 1.5: Research steps

REFERENCES

1. **LECHNER, N.** *Heating, Cooling, Lighting. Design Methods for Architects.* New York, 2nd Edition, John Wiley & Sons Inc., 2001.

2. **KRAUBITZ, T.** *Smart buildings.* Berlin, Symposium "Adaptiv buildings envelopes: from strategy to form", 18 June 2011.

3. **DIRECTIVE 2010/31/UE** *of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings, Official journal of the European Union*, 53, 2010.

4. **CELLURA, M.** *Determinazione dei fabbisogni e dei consumi energetici dei sistemi edificio-impianto, in particolare nella stagione estiva e per uso terziario e abitativo e loro razionalizzazione interazione condizionamento e illuminazione.* Attività IEA della Task 40 "Net Zero Energy Buildings", ENEA, September 2010.

5. **STRUCK, C., HENSEN, J. and KOTEK, P.** *On Supporting design decisions in conceptual design addressing specification uncertainties using perfomance simulation tools.* Journal of building Physics, Vol. 33, 2009.

6. **NUTI, F.** *Edilizia. Progetto, costruzione, produzione.* Firenze, Edizioni Polistampa, 2010.

7. **DANIELS, K.** *Advanced Building Systems. A technical Guide for Architects and Engineers.* Basel Boston Berlin, Birkhauser, 2003.

8. **VALORI, A.** *Metodi e tecniche di progetto per edifici residenziali sostenibili.* Firenze, PhD thesis, Department of Civil and Environmental Engineering, Supervisors: Prof. Arch. F. Bazzocchi, Prof. Ing. F. Nuti, Prof. Ing. G. Grazzini, Cycle XXIV, 2012.

9. **ARREDI, M.P.** *Edilizia per uffici. Progettare metodi tecniche norme realizzazioni.* Torino, UTET, 2004.

10. **CRAFTI, S.** *The Office - Designing for success.* Australia, The Images Publishing Group, 2004.

11. **SPATH, D. and KERN, P.** *Office 21.* Stuttgart, Fraunhofer-Institut fur Arbeitswirtschaft und Organisation IAO, 2003.

12. **LEARINI, P.M.** *ComfortOFFx - Metodologia innovative per la valutazione del comfort e produttività nello spazio ufficio.* Milano, PhD thesis, Dipartimento di Scienze e Tecnologia dell'ambiente costruito, Supervisors: Prof. N. Aste, Prof. P. O. Fanger, Prof. B. W. Olesen, Prof. J. Toftum, Cycle XVI, 2006.

13. **EISELE, J. and STANIEK, B.** *Bürobau Atlas.* Munchen, Grundlagen, Planung, Technologie, Arbeitsplatzqualitäten, Callwey, 2005.

14. **BAUER, M., MÖSLE, P. and SCHWARZ, M.** *Green Building. Guidebook for Sustainable Architecture.* Berlin Heidelberg, Springer-Verlag, , 2010.

15. **http://www.skyscrapercity.com.** [Online]

16. **FISCH, M. N., WILKEN, T. and STAEHR, C.** *EnergyPlus.* Leonberg, Univ. Prof. Dr. -Ing. M. Norbert Fisch, 2013, ISBN:978-3-00-041246-2.

17. **GOTTSCHALK, O.** *Progetto ufficio.* Milano, BE-MA Editrice, 1982.

18. **D.P.R. 26/08/1993, n.412.** *Regolamento recante norme per la progettazione, l'installazione, l'esercizio e la manutenzione degli impianti termici degli edifici ai fini del contenimento dei consumi di energia, in attuazione dell'art. 4, comma 4, della legge 9 gennaio 1991, n.10.*

19. **UNIEN12464-1:2004.** *Light and lighting. Part 1: Indoor workplaces.*

20. **UNI10339:1995.** *Impianti aeraulici a fini di benessere. Generalità, classificazione e requisiti.*

2. LITERATURE REVIEW AND DEFINITIONS

CONTENTS

INTRODUCTION

Chapter 2 “Literature Review and Definitions” is the presentation of the background in which the topic is inserted (Figure 2.1).
Specifically, there are presented:

1. various definitions for the identification of energy efficient buildings. Specifically, the explanation of terms as Nearly Zero Energy Buildings (NZEB) and EnergyPLUS buildings;
2. energy needs in office buildings since the reduction of them is the aim of the present research. In fact, the energy demand will be reduced through the application of some strategies described at point 4.
   In addition, various studies that propose strategies to reach the goal low-energy, are presented;
3. example of guidebook for office buildings proposed by ASHRAE, with the identification of the methodology adopted and the parameters analyzed;
4. summary of both passive and active design strategies as example of possibilities to reduce heating, cooling and lighting demands exploiting renewable sources.

Figure 2.1: Heliotrop, Designer: Rolf Disch, Freiburg (DE), 1994 - Example of the first EnergyPLUS building **[1]**

2.1 HIGH PERFORMANCE BUILDINGS: DIFFERENT DEFINITIONS

Many terms are used to indicate new generation buildings with a high energy performance as “low-energy”, “passive”, “solar-active”, “green building”, “zero-energy”, “net-zero”, “EnergyPLUS”, “CO2-neutral buildings”, etc. and various indicators should be considered as primary energy, final energy, CO_2 emissions, etc. In addition, different boundary systems and different period of duration (annual or life cycle) could be analyzed. This multitude can create confusion and disoriented people that can lost the sense of the most important thing: to build high-energy performance buildings.
For example, the terms “zero-energy” and “zero-emission” buildings are imprecise terms since they do not describe the plus or negative value of the energy balance and zero is a difficult value to reach in the reality. Despite of the word “net” provides a more accurate description of what it is required [2].
Here below there is the summary of some definitions for high performance building.

2.1.1 NEARLY ZERO ENERGY BUILDING

The European Directive 2010/31/EU defines NZEB as *“…a building that has a very high energy performance…”*[1] where energy demand is zero or net zero, partially covered by the integration with renewable sources. It represents a building with greatly reduced operational energy needs, where efficiency gains have been made such that the balance of the energy needs can be offset by renewable technologies [3].
There are four definitions of NZEB, which enclose different energy use accounting methods:

1. *Net Zero Site Energy:* it *“…produces at least as much energy as it uses in a year, when accounted for at the site.”* [3]. In such case, the site must be defined and it can enclose just the building footprint (this declination give priority to BIPV) or also the entire property.

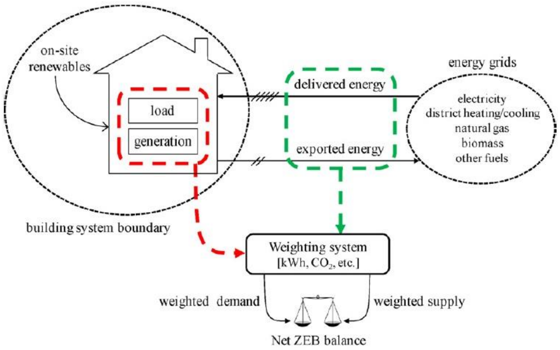


Figure 2.2: Sketch of connection between building and energy grid **[4]**

|weighted supply|−|weighted demand| ≈ 0
$$\sum_i \boldsymbol{e_i \cdot w_{e,i}} - \sum_i \boldsymbol{d_i \cdot w_{d,i}} = \boldsymbol{E - D} \geq \boldsymbol{0}$$
e = exported; d = delivered; w = weighting factor; i = energy carrier; E = weighted exported energy; D = weighted delivered energy.

Equation 2.1: NZEB balance **[4]**

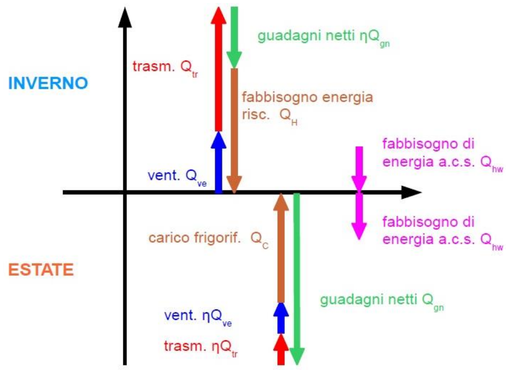


Figure 2.3: Energy balance of traditional building **[5]**

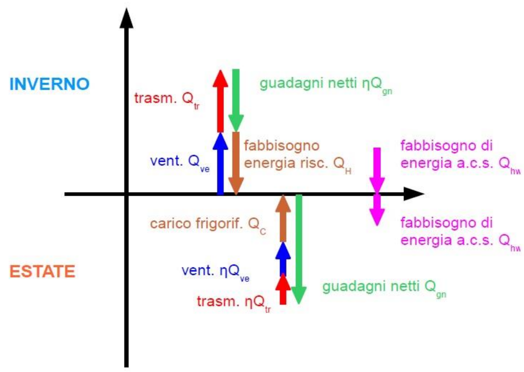


Figure 2.4: Energy balance of NZEB **[5]**

[1] European Directive 2010/31/UE, Art. 2.

2. *Net Zero Source Energy:* it *"…produces at least as much energy as it uses in a year, when accounted for at the source."* [3].
   It refers to the primary energy used to generate and deliver the energy on the site. The source NZEB depends more on how the utility is buying or producing the power rather than the energy performance of the building. For this reason, this analysis is difficult.
3. *Net Zero Energy Costs: "…the amount of money the utility pays the building owner for the energy the building exports to the grid is at least equal to the amount the owner pays the utility for the energy services and energy used over the year."* [3].
   This should be verified thanks the utility bills, but reaching zero is almost improbable because of the utility rate structures.[2]
4. *Net Zero Energy Emissions:* it *"…produces at least as much emission-free renewable energy as it uses from emission-producing sources."* [3].

About building site boundaries, there are two different ways to produce energy by using supply-side renewable energy technologies either as <u>on-site</u> (use renewable sources within the boundaries of the building site) or <u>off-site</u> (use renewable sources outside the boundaries of the building site).

About the relation between the building and the grid connection, the building can be:

- <u>Off-grid:</u> It is independent by the grid and it cannot feed its excess energy production back into the grid. This option can be very difficult to reach and it looks not possible for complex buildings;
- <u>On-grid:</u> When the energy production on site is greater than building loads, the excess is done to the grid [6, 7].

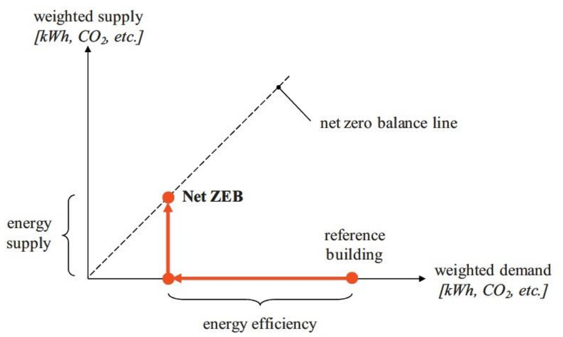


Figure 2.5: Graph representing the NZEB balance concept **[4]**

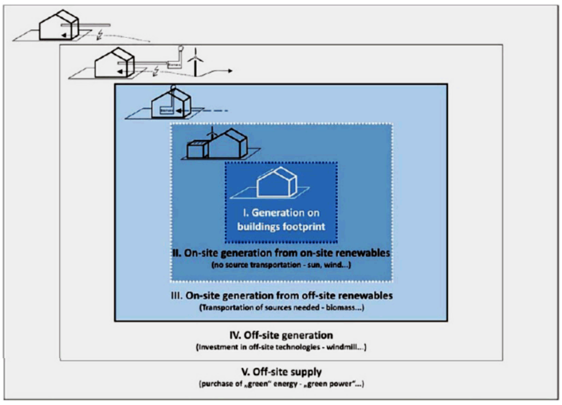


Figure 2.6: Overview of current renewable energy supply options linked to common international practice for energy calculation methodologies for NZEB **[8]**

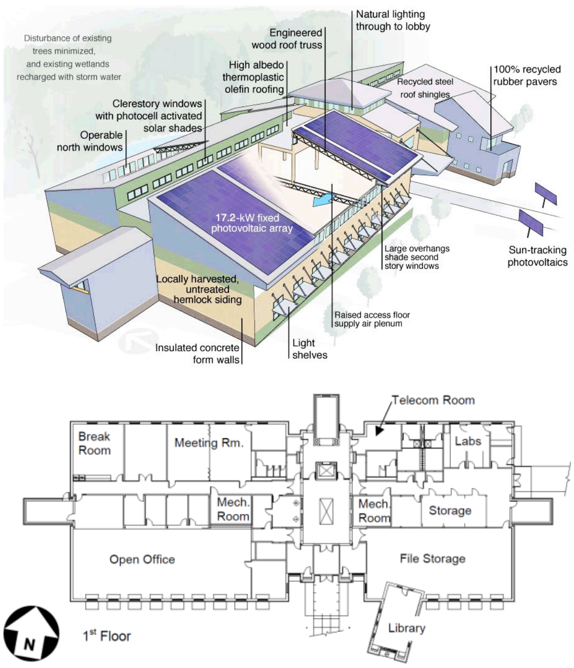


Figure 2.7: High-performance Cambria office building, Page 15 **[7]**

[2] Rate structures give credit for the energy returned to the grid, but they will not allow the number to go below zero on an annual basis.

2.1.2 ENERGYPLUS BUILDING

The EnergyPLUS[3] building produces more than how it needs (Figure 2.8) and has the following characteristics:

- 100% renewable energy;
- emission-free;
- grid connection with its surplus of energy given to the public grid;
- Primary Energy Demand (Q_P) and Annual Final Energy Demand (Q_f) are negative (Equation 2.2).

The observation period is generally annual, but it may also enclose the entire life cycle (Figure 2.9).

The EnergyPLUS building (Figure 2.10) uses different fuel resources. Specifically, coal, lignite oil and natural gas have high expenditure costs and they are avoided; while solar, hydro, wind, biomass or wood have lower expenditure costs and they are preferred.

The grid becomes a virtual energy storage where lead and extract energy and can also be extended and connected with wind and PV plants in the territory. Nevertheless, according to the complexity of the creation of such network nowadays, the production of energy on-site is preferable. In addition, the direct production/usage of energy on-site permits also the promotion of the adoption of low-emission vehicles.

Looking at the building blocks, this standard feeds with the application of passive strategies to reduce the energy demand without renouncing to the use of mechanical systems and encloses appliances as electrical consumptions to cover.

The EnergyPLUS standard can be extended to an urban scale. This could facilitate the energy goal to reach and support the future energy renovation of the existing heritage [2].

$$\textbf{ENERGYPLUS: } Q_f < 0; \;\; Q_p < 0$$

Equation 2.2: EnergyPLUS **[4]**

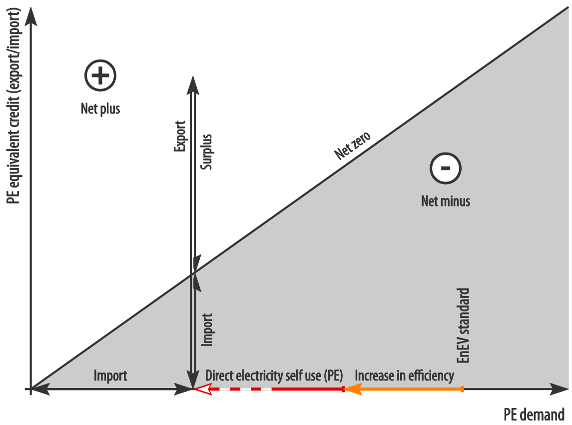


Figure 2.8: Annual PE balance, Page 29 **[2]**

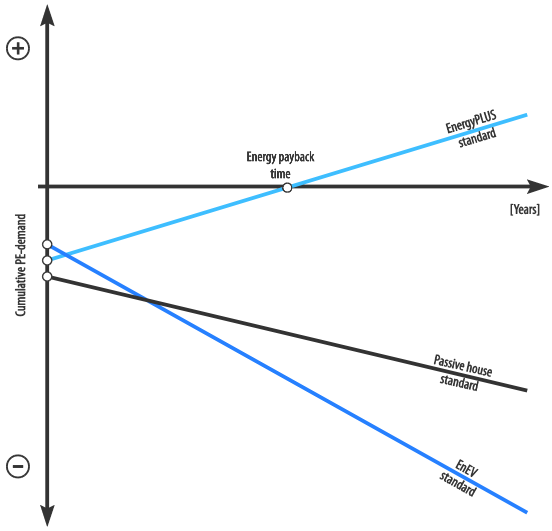


Figure 2.9: Cumulative primary energy demand over the life cycle, Page 30 **[2]**

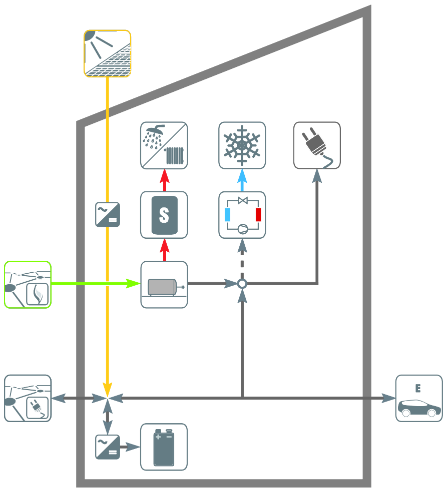


Figure 2.10: Example of concept for EnergyPLUS building - Combination of CHP and PV plant, Page 33 **[2]**

[3] The architect Rolf Disch introduced the term during the ´90s.

2.2 ENERGY CONSUMPTIONS IN OFFICE BUILDINGS

Offices are energy hungry buildings with the annual primary energy demand of around 250kWh/m^{2}a (Figure 2.13) and high electricity needs (Figure 2.11). This occurs mainly for lighting, equipment and cooling.
Specifically, it is possible to observe (from Figure 2.11 to Figure 2.13) how lighting and equipment are the most important. For example, in the city of Torino, they represent respectively the 38% singularly, with an overall value of 76% of the total energy demand [9].[4]
On the other hand, service hot water is not important as in residential houses.
For this reason, minimizing the annual primary energy demand of office buildings means, overriding, to find strategies in order to reduce and cover the electricity needs.
Different solutions can be proposed and here below some studies are briefly presented.

KNISSEL J. [10], for instance, compares the primary energy demands of a German "standard office" and an "efficient office"[5] (Figure 2.15). The high performance building encloses: high thermal insulation; low electricity need of the equipment and lighting; no adoption of active cooling; use of humidification and dissecation systems; use of heat and humidity recovery and adoption of earth tube exchanger[6]. Specifically, the energy saving is reached thank the following actions:
Heating reduction reached by:
- big thickness of the insulation layer (between 30cm and 40cm);
- triple glazing with high-insulated window frames;
- ventilation plant with efficient heat recovery and earth tube heat exchanger.

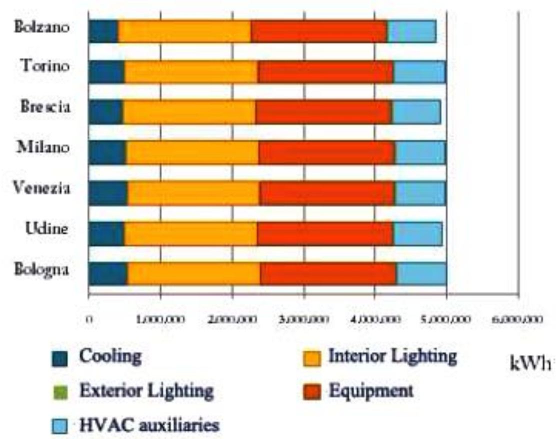


Figure 2.11: Annual electrical energy demand, Figure 8 **[9]**

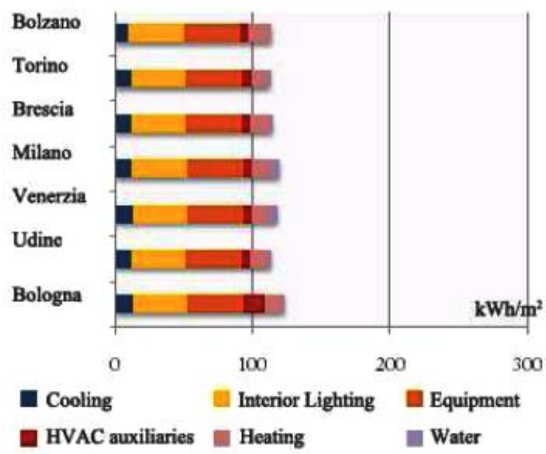


Figure 2.12: Annual final energy demand, Figure 9 **[9]**

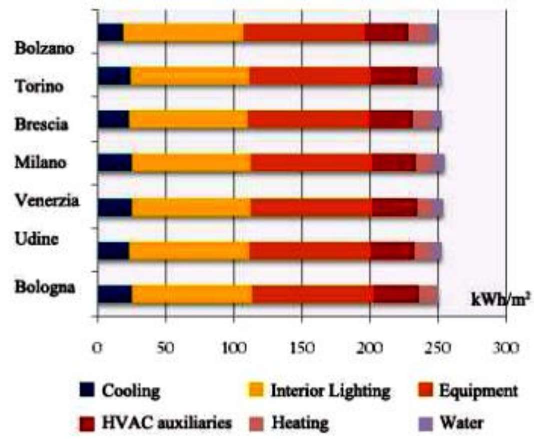


Figure 2.13: Annual primary energy demand, Figure 10 **[9]**

---

4 The group of the University of Turin simulated many office types (medium and large size). The present Paragraph shows the energy performance, for various Italian cities, of a large office building with A_{TOT}=89077m^2 and V=178146m^3.

5 The building, located in Frankfurt, is a five-story linear block with a central corridor and two strips of offices oriented with the main axes East/West (Figure 2.14).

6 For the analysis, costs are taken into account in order to verify the profitable investment.

Lighting reduction reached by:
- high efficient fluorescent lamps;
- lighting control system which switched off when exceeding;
- zoning with different light intensity (220lux ceiling lamps; 500lux desk lamps).

Office equipment reduction reached by:
- notebook instead computer;
- photocopier, etc. GED marked.

Air conditioning system reduction reached by:
- no air conditioning systems adopted.

ASHRAE 2011 [11] demonstrates how following the recommendations contained in the Advanced Energy Design Guide (AEDG), it is possible a reduction of the 50% on the annual primary energy demand (Paragraph 2.3 and Figure 2.16) comparing to the results obtained for the same building following the recommendation contained in the ANSI/ASHRAE/IESNA Standard 90.1-2004.

FISCH M.N. et al. [2] propose five ways to cover the electricity needs of the building thanks the adoption of the following strategies:

1. electricity supported mainly by photovoltaics (that primarily operates a heat pump) and a battery that can be recharged. Generally this way could not cover completely the needs during the year, in such case the electricity comes from the grid;
2. electricity supported mainly by the integration of photovoltaics and the production of hydrogen by electrolysis. This can be stored and then used either for heating or producing electricity. In this concept, it is provided also a hot water storage for the reduction of the peak loads and for a better accumulation;
3. biomass energy supply for heating and electricity production combined with a CHP powered by wood pellets;
4. combination of CHP that works during the winter period and PV plant with also a battery that can be recharged;
5. solar thermal collectors cover the heating demand feeding a water hot storage tank and if the solar radiation is not enough, a biomass gas boiler is present. PV are also adopted.

From the previous considerations, it is possible to underline that the energy-efficient office building needs: high thermal insulation layer; accurate design of the windows (ex. size, type of glass, etc.); ventilation strategy; integration with renewables especially photovoltaics to cover electricity needs.

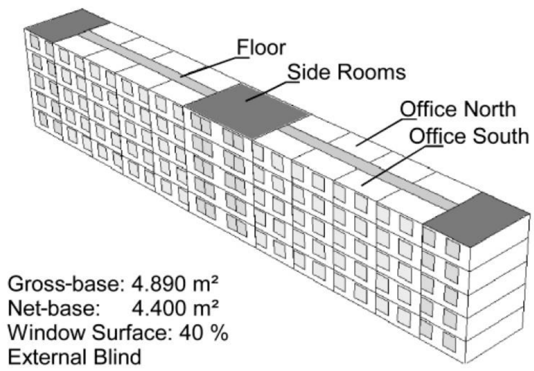


Figure 2.14: Model of the building by Knissel J. **[10]**

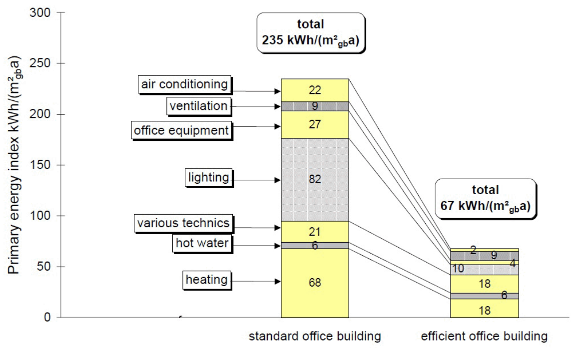


Figure 2.15: Primary energy index for the “standard” and the “efficient” office building, Page 3 **[10]**

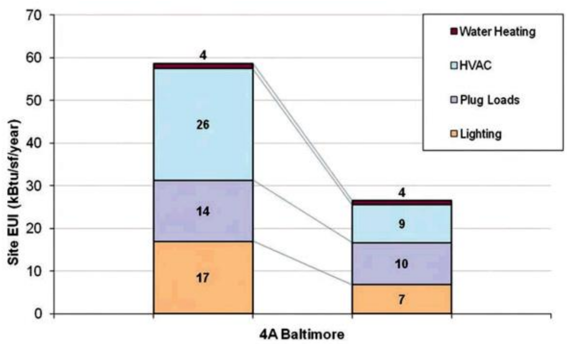


Figure 2.16: Comparison of baseline to prescriptive 50% AEDG solution showing breakdown of energy saving components, Page 22 **[11]**

2.3 EXAMPLE OF GUIDELINES: AEDG BY ASHRAE

The Advanced Energy Design Guide (AEDG) realized by ASHRAE is the most important example of guideline about high-performance offices, which contains recommendations for Small to Medium Office buildings (AEDG-SMO) up to 100000ft^2. It contains recommendations to design energy efficient office buildings, which consume less than the buildings designed following the minimum code-compliant.

The guide is not a code or a standard, but a voluntary guidance document that focuses on the primary energy demand of a building and it assumes that all the component and systems comply with the minimum design criteria of ANSI/ASHRAE/IESNA Standard 90.1-2004.

The AEDG considers the following office spaces: open plan and private offices; conference and meeting rooms; horizontal and vertical connections; lounge, recreation, lobby, active storage, restroom, mechanical and electrical spaces; etc. On contrary, it does not consider spaces as room for data center.

The methodology encloses the energy analyses of two office-building prototypes.[7] They are energy simulated on hourly base, defining two sets:

1. in the first one, the minimum code standard is applied (ANSI/ASHRAE/IESNA Standard 90.1-2004);
2. in the second set, the recommendations of the guide are adopted.

The output is the production of sheets that summarize the recommendations subdivided into macro-categories (Figure 2.17 and Figure 2.18) according to a subdivision of the USA territory in 8 primary climate zones (Figure 2.19 and Figure 2.20).

The present thesis looks at the methodology and at the parameters adopted in the guide focusing mainly on some topics as envelope, daylighting, etc.

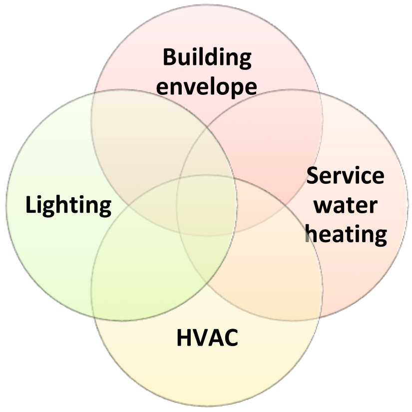


Figure 2.17: Macro categories

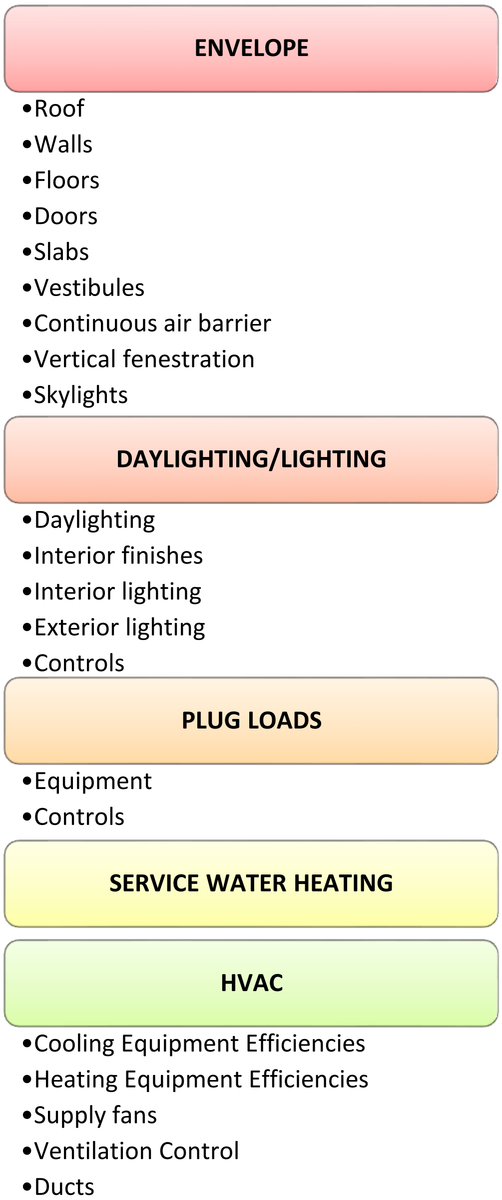


Figure 2.18: Summary of categories

[7] Zoning of the floor plates with a perimeter zone as a ring of 10-15ft and an interior zone.

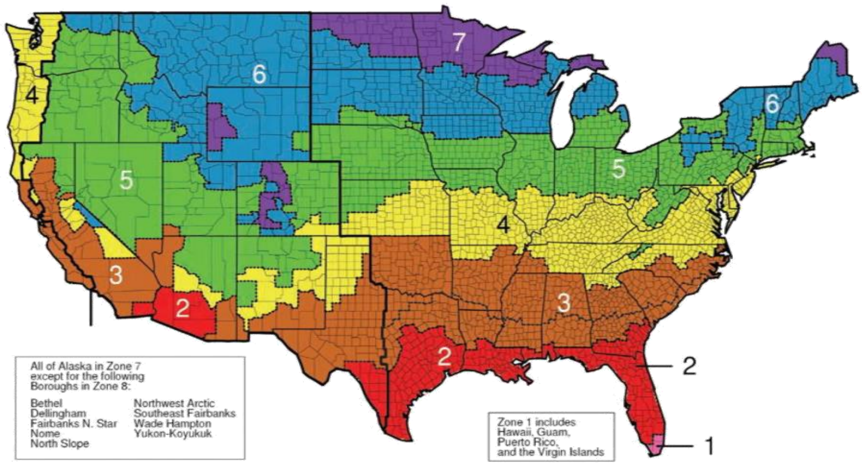


Figure 2.19: USA map showing climate zones, Page 79 [11]

Climate	Hot	Mild	Cold	Very Cold	Extremely cold
Marine		San Francisco (CA) Seattle (WA)			
Humid	Miami (FL) Houston (TX) Atlanta (GA)	Baltimore (MD) Madison (IL) New York (NY)	Adams (CO) Chicago (IL) Minneapolis (MI)		
Dry	Los Angeles (CA) Las Vegas (NV) Phoenix (AZ)	Albuquerque (NM)	Delta (MI) Denver (CO) Helena (MT)	Baraga (MI) Duluth (MN) Grand (CO)	Bethel (CA) Dillingham(CA) Fairbanks

Figure 2.20: Cities characterized by climate combinations

	ITEM	PARAMETER
ENVELOPE	Roof	Thermal resistance [hft²F/Btu]; Solar Reflectance Index ;
	Walls	Thermal resistance [hft²F/Btu];
	Floors	Thermal resistance [hft²F/Btu];
	Doors	Thermal transmittance [Btu/hft²F];
	Slabs	Thermal resistance [hft²F/Btu];
	Vestibules	Position;
	Continuous air barrier	-
	Vertical fenestration	Window to wall ratio [%]; Window orientation; Projection factor of the exterior sun control; Thermal transmittance [Btu/hft²F]; Solar heat gain coefficient;

Table 2.1: List of items and parameters investigated in AEDG

	ITEM	PARAMETER
DAYLIGHTING/LIGHTING	Daylighting	Light to solar gain ratio; Vertical fenestration effective aperture;
	Interior finishes	Interior surface average reflectance [%]; Open office partitions parallel to window walls;
	Interior Lighting	Lighting power density [W/ft²]; Type of ballasts; Controls;
	Exterior Lighting	Lighting power density [W/ft²]; Controls;
PLUG LOADS	Equip.	Number of laptop computers; Number of total computers; Type of equipment;
	Controls	-

2.4 PASSIVE DESIGN STRATEGIES

Passive design strategies permit to reach the indoor comfort conditions reducing the need of mechanical systems. They can help for heating, cooling, lighting and ventilating naturally the building and, if they are right applied, can reduce the need of mechanical systems without eliminating (ex. mixed mode ventilation).
They can be grouped into main macro-categories either according to the aim they are applied for (Figure 2.21) or according to the renewable source exploited (solar radiation, winds, water and soil).

2.4.1 PASSIVE SOLAR

Passive solar strategies can:
- heat/cool (thermal system)[8];
- lighting (daylighting system) [12].

Generally, they are composed by the following components [13]:
- **collector**[9] that captures and transfers the solar radiation into the indoor space (ex. window, aperture);
- **storage** of the energy thanks to materials with high inertia that have an absorber surface (ex. structural mass);
- **distribution** through the surfaces (ex. shape, size and orientation of the room);
- **control elements** (ex. overhangs, trees, blinds, sensors).

To reach performance and efficiency from passive solar strategies (Figure 2.22), it is fundamental to find a balance between size, shape and location of each subsystems.
Specifically, looking at passive heating systems, there are three different categories according to a different relation between collector and energy-storage (Figure 2.23): direct gain (without storage); indirect gain (with storage) and isolated gain (direct gain + storage).

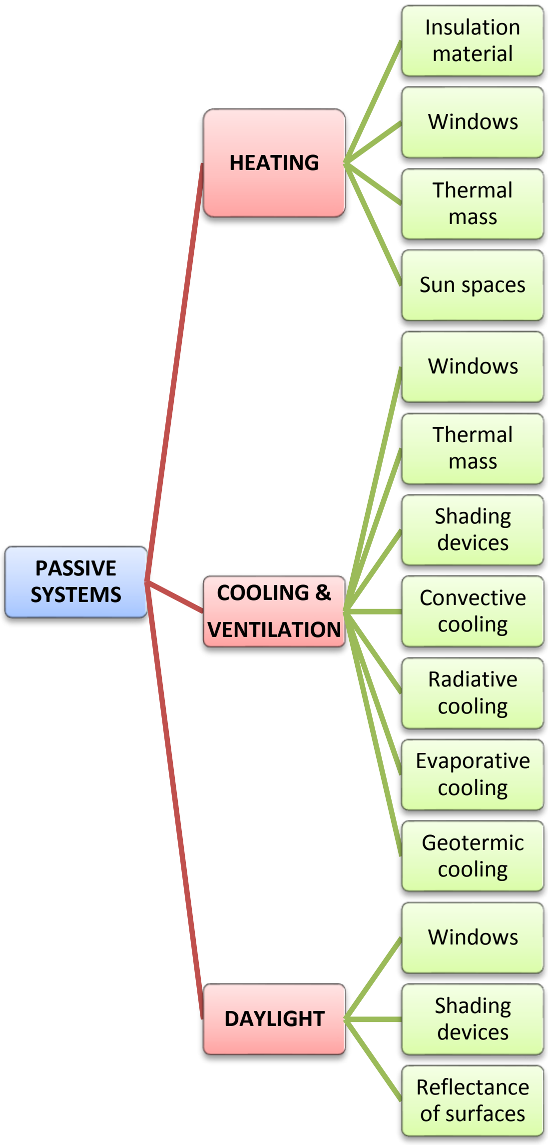


Figure 2.21: Passive strategies

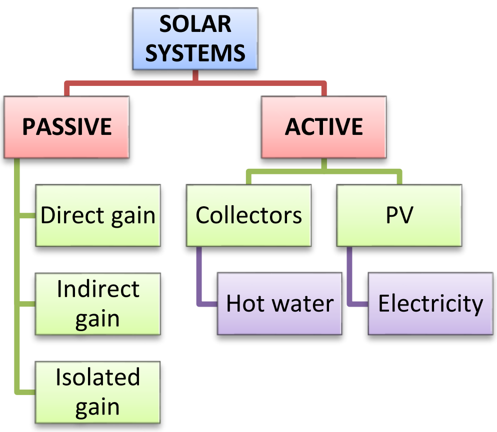


Figure 2.22: Solar strategies

[8] The natural processes used in passive solar energy are thermal energy flows associated with radiation, conduction and natural convection.

[9] The collector maximizes the solar radiation on entrance if it is south facing.

Here below, the summary of the main solar passive strategies:

1. <u>TRANSPARENT SURFACE DESIGN:</u> it requires a compromise between heat gain, heat losses, overheating and daylighting according to the climate condition. The strategy entails:

- disposition and size of windows according to the orientation and the internal layout;
- glass properties and relation with shading device systems.

Parameters: position, Window-to-Wall Ratio, glazing type and type of shading devices.

2. <u>THERMAL-MASS DESIGN:</u> it takes advantage by the reduction of the amplitude of the temperature swing. There are two types of systems: the thermal storage wall system (Trombe Walls) and the roof pond system.
The strategy entails:

- disposition and size of the thermal mass according to the orientation and the internal layout;
- material characteristics according to the climate conditions.

Parameters: position, dimensions, technologies and materials.

3. <u>BUFFER SPACE DESIGN:</u> it represents a space with intermediate thermo-hygrometric conditions between inside and outside [14]. There are many systems as sunspaces, atria, double skin façades, etc.
The design generally entails:

- orientation and position in relation to the building;
- morphology, technologies and materials;
- ventilation strategies and shading device systems;
- features of the adjacent spaces (ex. envelope composition).

Parameters: position, shape, technologies and materials.

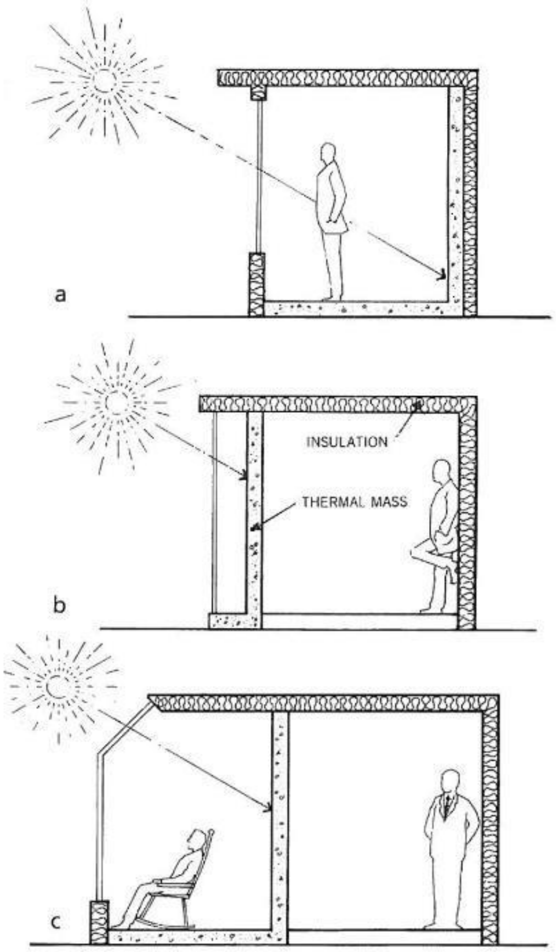


Figure 2.23: Three types of passive solar space-heating system. a) Direct gain; b) Trombe wall; c) Sun space, Page 147 **[15]**

Figure 2.24: Example of office building with passive solar heating strategies, the "hub", Atkins' office, Bristol (UK) **[16, 17]**

2.4.2 NATURAL VENTILATION AND PASSIVE COOLING

Natural ventilation[10] could be exploited for **ventilating** and **cooling** naturally the building and it contributes to:

- a sustainable building environment;
- eliminate the electrical energy for fans;
- increase the acceptance of users that prefer to have the control to their environment and do not be completely isolated from the outside.

On detail, to exploit natural ventilation, it is important focusing on (Figure 2.25 and Figure 2.26) [15]:

1. OPENINGS DESIGN: it requires a compromise with the window design aimed at the exploitation of the solar radiation. For instance, to privilege the cross ventilation, it is preferable the disposition of the openings perpendicularly to the wind direction; otherwise oblique winds can generate turbulences inside the building privileging the air motion. The strategy entails:

- disposition and size of the opening part of the window according to prevailing winds, passive solar strategies and internal layout.

2. FIN WALLS AND OVERHANGS DESIGN: fin walls and overhangs increase the velocity of the local winds changing the pressure distribution. For example, fin walls at 45°work better for winds; while overhangs of minimum 6inches[11] increase the positive pressure. The strategy entails:

- disposition, size and angle of the elements according to the wind direction.

3. FANS DESIGN: fans increase the air motion according to different aims. For instance, when is not sufficient the quantity of ventilation; to exhaust hot when air is humid and polluted; to bring in outdoor air or cool at night; etc. For all purposes, separate fans are required.

4. INTERIOR PARTITION DESIGN: interior partitions constitute the limit for the air circulation within the building, but an accurate design that entails also openings can contribute to guarantee a better air circulation.

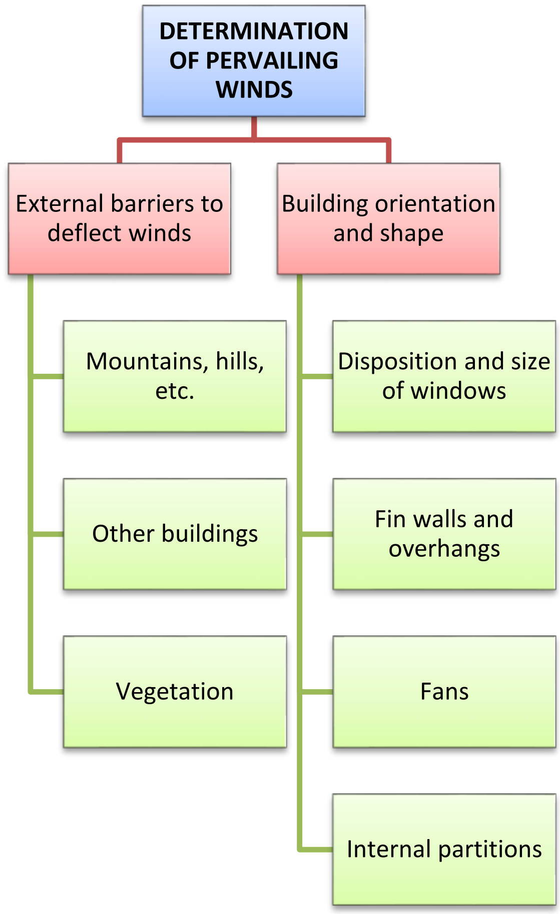


Figure 2.25: Chart of natural ventilation design

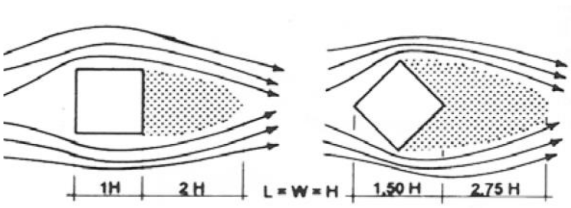


Figure 2.26: Example of natural ventilation design, Page 202 [18]

[10] There are three types of natural ventilation:
1) winds blow air through openings on the windward side of the building and suck air out from the openings on the leeward side;
2) temperature differences of air that creates air movements;
3) buoyancy caused by differences in humidity can allow a pressurized column of dense, evaporative cooled air to supply a space, and lighter, warmer, humid air to exhaust near the top [33].

[11] Page 261, [15].

Natural ventilation is perceived risky in comparison either to the application of passive solar strategies[12] or to the adoption of mechanical ventilation[13]. In fact, sophisticated analyses as CFD analyses[14] or experimental tests in wind tunnel are recommended to estimate the effectiveness of these strategies for each specific case.
In addition, natural ventilation should be not enough in hot humid climates. In such case, it is acceptable if it is combined with some form of low-energy cooling system [19].
For these reasons, mixed-mode systems offer a way of overcoming or reducing the risk. In recent years, it has been increased the adoption of such mixed systems, which are referred to as hybrid or assisted natural systems. From CISBE (2005), three types of systems (Figure 2.27) are identified: contingency, zoned and complementary[15].

According to the growth of air conditioning systems in recent years, cooling in buildings is not a peculiar of just the southern climates countries but also for the northern ones.
The consequence of the use of air conditioning systems with the growth of the electricity demand is a problem for many countries as also the effects that such systems have on the indoor air quality (ex. illness increases).
Alternatively, passive cooling strategies can be very effective [20, 15].
Here below some strategies are summarized:

1. <u>DIRECT FREE COOLING</u>: it exploits the outside lower temperatures to cool the indoor spaces. For hot and humid climate, for example, the night air is significantly cooler than the daytime air. This can be used to flush out the heat and, at the same time, the precooled mass can absorb heat during the day. This strategy entails a diversification of openings in order to decide which can be open automatically.

2. <u>INDUCED VENTILATION TECHNIQUES:</u>
<u>Solar chimney:</u> natural ventilation is induced by the thermal-buoyancy effect created thanks the structure that absorbs solar radiation during the day permitting the hot air to rise. The cooling effect can be improved thanks an appropriate window design (Figure 2.29);
<u>Wind tower:</u> it works in the opposite way as solar chimneys, in fact, hot air enters from the tower through a series of openings, gets cooler and sinks down (Figure 2.28);

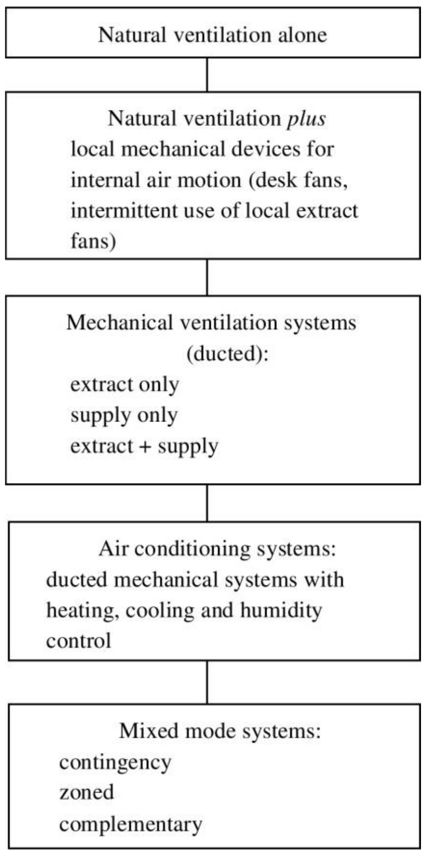


Figure 2.27: Hierarchy of ventilation systems, Page 4 [19]

[12] Sun strategies are easier to control; winds are not constant and they can be, for example, rerouted through barriers (ex. artificial or natural barriers).
[13] For example, mechanical system provides flow rates constant in both magnitude and direction that are time independent; while in natural ventilation, they are time dependent.
[14] Computational Fluid Dynamics.
[15] Contingency: natural ventilation is used but the building is designed to allow for later installation of mechanical systems;
Zoned: different systems are used in different parts of the building;
Complementary: natural and mechanical systems are installed but they operated at different times.

Air vents: the system works on the principle of cooling by induced ventilation, caused by differences of pressure. Curved roofs and air vents are used in combination to cool air in hot and dry climates, where dusty winds make wind towers impracticable. A hole in the apex of the domed or cylindrical roof with the protective cap over the vent directs the wind across it.
The opening at the top provides both ventilation and an escape path for hot air collected at the top.

3. RADIATIVE COOLING: the roof is used both as a nocturnal radiator and as a cold store.
The roof, exposed to the night sky, loses heat by long-wave radiation and by convection; while, during the day, it is externally insulated in order to minimize heat gains from the sun. Then, it absorbs the heat from the room below.
This strategy entails the choice of a surface light colored and isolated for the roof [21].

4. EVAPORATIVE COOLING: air is cooled by evaporating water based on the principle that the heat of air is used to evaporate water.
The efficiency of such strategy depends by the air humidity level (it works better in dry climate where relative humidity is <30%) and it has to be accompanied by a good ventilation system. This strategy entails:
- either the design of pools within the ambient (Figure 2.30) or the use of nebulizers (direct cooling);
- the design of a roof pond that transform the ceiling as a cooling element that cools the space by convection (indirect cooling).

Figure 2.28: Example of wind towers, University of Qatar (QA) [22]

Figure 2.29: Example of solar chimney in office building, Hydro Place, Designer: Kuwabara Payne McKenna Blumberg Architects, Manitoba (CA) **[23]**

Figure 2.30: Example of evaporative cooling in office building (atrium), Federal Environmental Agency, Dessau (DE), Chapter 3 example n.2

5. <u>GEO-COOLING (INDIRECT FREE COOLING):</u> according to the mainly constant temperature of soil (Figure 2.31), free cooling permits to cool the interior spaces thanks to the circulation of either air or water into the ground and then into the building (Figure 2.32).

For example, water that returns from the vertical loop field into the ground can be turned out into the radiant panels. With this system, in summer, the ground temperature is closed to the intake liquid temperature and the heat pump[16] could be bypassed. This strategy entails low-energy consumes for cooling and has to be supported also by a dehumidification system.

Free cooling (geothermic) and thermo-active ceiling appears a solution recommendable providing a savings potential *"between 8 and 16kWh/m^2 when compared to a traditional system using a heat pump to supply cooling"* [24].

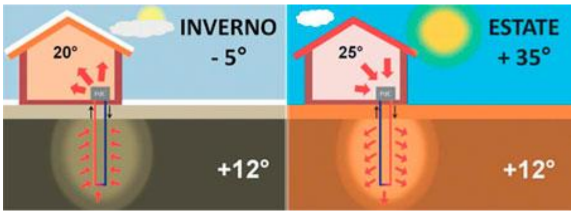


Figure 2.31: Geo-heating and cooling **[25]**

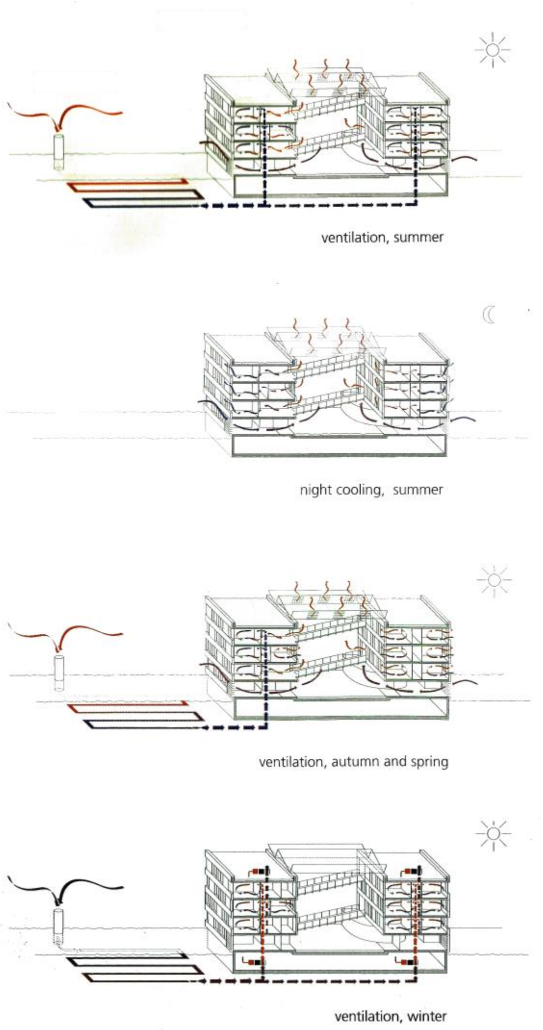


Figure 2.32: Example of geothermal heat exchanger in office building with horizontal pipes, Federal Environmental Agency, Dessau (DE), Chapter 3 example n.2 **[26]**

Passive cooling strategies have a great potential in hot and dry climates with some problems in humid regions in fact it is important to understand if a direct use of the outside air can be made (and moreover in which period and time) or otherwise, if it needs a treatment.

For the Italian climate, this appears to be a fundamental aspect.

The present thesis considers some passive strategies as the first level of the energy design and, it focuses on:

a) **passive solar strategies** (Paragraph 2.4.1), especially the point "1. Transparent surfaces design";
b) **natural ventilation and passive cooling** (Paragraph 2.4.2), the point "1.Direct free cooling" where natural ventilation is used to cool interior spaces.

[16] The earth heating/cooling can have the presence of a heat pump that works or just during the winter season or during all the year. Despite that, generally, during winter period, the liquid goes down (water: from 3° to 4°, if additivated: 0°) with a lower temperature than the ground one and comes back hotter in order to permit the heat pump to distribute hot water (from 30° to 32°). In summertime, the liquid has a higher temperature (from 25° to 30°) than ground; consequently, it gives away heat.
Geothermal heat pump can use the heat extracted from the ground for the production of sanitary water. In this case, the temperature produced is greater and the pump efficiency tends to decrease slightly. It is better to evaluate the possibility to produce service hot water in combination of solar collectors.

2.5 ACTIVE DESIGN STRATEGIES

"One of the essential characteristics of photovoltaics is its chameleon-like ability to adapt and transform as required, and therein lays its aesthetic potential" [17]

The integration of photovoltaics into the building appears fundamental to consider. Photovoltaic panels represent an important solar active strategy to apply especially for the design of new offices where the aim is the reduction of high electricity needs.

In fact, if passive design strategies can reduce the energy demand of the building, it is unimaginable to think they can be sufficient to cover the energy needs. For example, administration buildings have high consumes related also to the use of appliances and this part can be covered by the introduction of PV. For this reason, the use of PV modules has an impact on the overall process, forcing the designer to take into consideration since the early design phase.

The multidisciplinary approach reveals, for instance, the importance of a compromise between building technicians who speak of watt-peak and architects who either think in m^2 or look at the building aesthetic. [27]

In addition, Italy is a country where there is a high energy potential as shown in Figure 2.31.

A multitude of office buildings contemplates the use of PV, some symbols, for example, are [2, 27, 28, 1]:

- Heliotrope (Figure 2.1 and Figure 2.34): It is a residential and office building, erected in 1994 in Freiburg (DE) and designed by Rolf Disch. It represents the first EnergyPLUS (Plusenergiehaus) with a rotating cylinder-shape, a solar thermal plant and a wood stove for the heating supply, and $54m^2$ of dual axis sun-tracking PV awning;
- Solar Freiburg Settlement (Figure 2.35): It is a large-scale plan with a group of 59 buildings (residential, offices and commercial) in Freiburg (DE) designed by Rolf Disch in 2004. Specifically, the PV settlements produce 425000kWh/year.

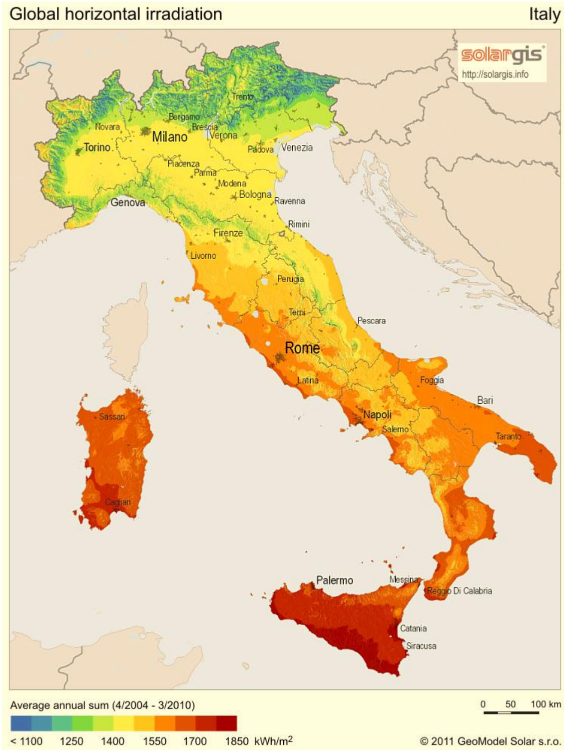


Figure 2.33: Global Horizontal irradiation in Italy **[29]**

Figure 2.34: Heliotrope [1]

Figure 2.35: Solar settlement, Freiburg (DE), 2004 [1]

[17] Page 9, [27]

2.5.1 BUILDING INTEGRATED PHOTOVOLTAIC SYSTEM

Photovoltaic systems can be overlapped or integrated into the envelope (Figure 2.36 and Figure 2.37). In the first case, PV panels constitute an "addition" and, for example, they should be adopted on existing buildings. In the second case, PV modules become a component of the envelope and can be used for new buildings (BIPV).
The photovoltaic technology is developing towards the integration into the building representing one of the most suitable growing area for the PV industry. This because infrastructure costs for PV modules are reduced with the building integration even if a complex set of issues is introduced that can greatly affect the PV performance and the viability. [30]
Anyway, in BIPV, a multidisciplinary approach is necessary since photovoltaic modules assume simultaneously the functions of electricity production and building component.
Hence, it is essential a carefully design in order to (Table 2.2):

- maximize the energy generation according to the climate and the optimal array orientation;
- dispose PV according to other elements of the envelope (ex. opaque/transparent surfaces, daylighting control, roof/façade);
- solve constructive aspects (ex. thermal insulation, connection between modules and structure, relation with the other components);
- guarantee the aesthetic effects.

On detail, there are three methods to integrate PV [31]:

1. **OVERCLADDING (cold roof or façade):** PV create the external layer and waterproofing material is placed over an opaque layer that ensures thermal insulation. In such case, the ventilation of the PV modules is important for the efficiency (Figure 2.39);
2. **ENCLOSURE (warm roof or façade):** PV are adapted on conventional glazing systems (mullion-transom or structural glazing).
   In that way, a double skin could be provided with a ventilated chamber, which improves the thermal performances with consequent optimal savings (Figure 2.38 and Figure 2.40);
3. **SHADING DEVICES:** Blinds or awnings provide the electricity production as also the shadowing of interior spaces (Figure 2.39).

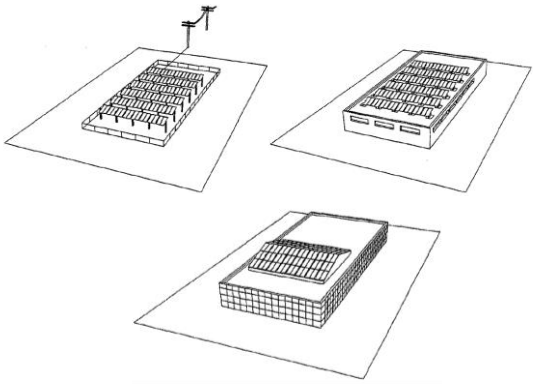


Figure 2.36: Field-mounted PV, Building-mounted PV, Building Integrated PV **[30]**

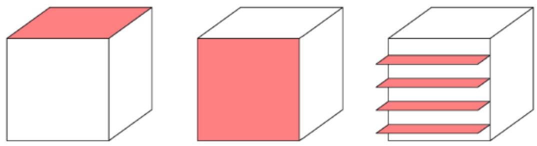


Figure 2.37: Sketches of Buildings Integrated Photovoltaics

CLIMATE PARAMETERS	Location Cloudiness Temperatures Precipitation Humidity Dust Wind loads
ARCHITECTURAL AND AESTHETIC PARAMETERS	Shape Color Transparency Orientation Tilt angle Thermal insulation Water tight Durability Structure
ENERGY PARAMETERS	Peak power Annual Yield Energy production

Table 2.2: Summary of some parameters that influence the design of PV modules

The present research analyzes the potential of the use of BIPV varying some architectural parameters (ex. building shape, roof geometry, facade geometry) according to various Italian location (Paragraph 5.5).

The goals are the following:

- underline the importance of covering high electricity needs of administration buildings trough also the use of active systems;
- show how the architectural choices affect the performance of PV, forcing to consider their installation since the pre-design phase.

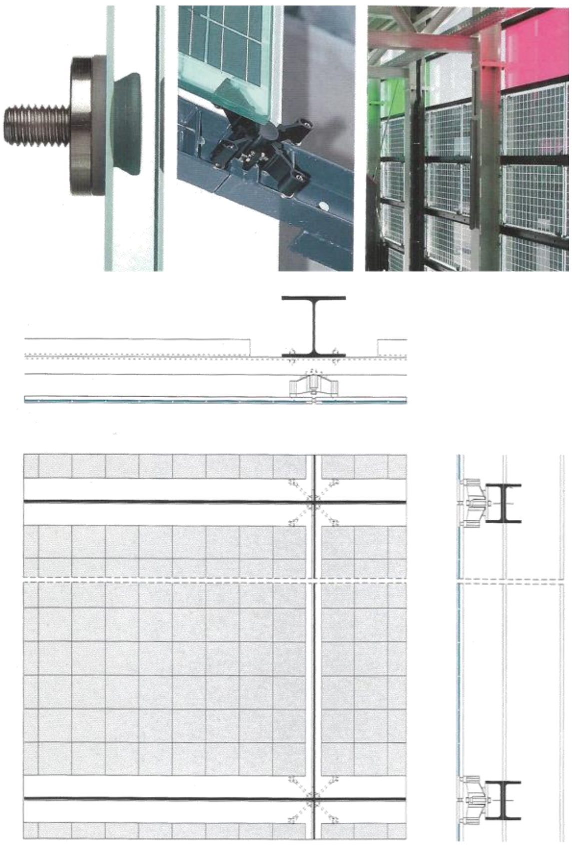


Figure 2.38: Photovoltaic modules attached to the main load-bearing system at four points using undercut plate anchors, Page 152 [27]

Figure 2.39: Example of cold façade, Buhler Electricitè Office, designer: Kurmann & Cretton SA, Monthey (CH), 2008-2011 - Renovation, Energy production of PV on South-façade = 6000 kWh/a [32]

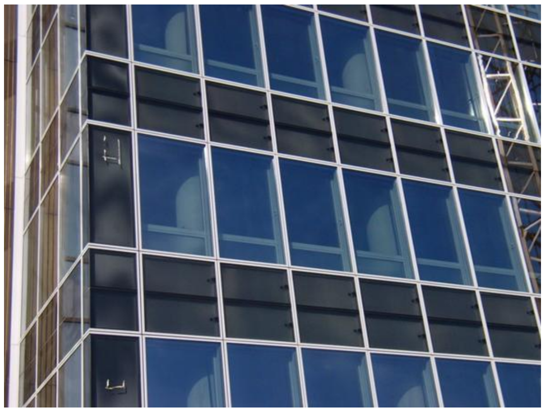


Figure 2.40: Example of warm façade, Autobrennero A22 Office, designer: Studio Associato Giovanazzi, Trento (IT), 2009 - Curtain wall with PV: thin film, 94m² [32]

Figure 2.41: Example of shading devices, FEAT headquarters, designer: Claudio Lo Riso, Lugano (CH), 1997 - Renovation, Solar shading devices with PV: monocrystalline, 26m² [32]

REFERENCES

1. **http://www.rolfdisch.de.** [Online]

2. **FISCH, M. N., WILKEN, T. and STAEHR, C.** *EnergyPlus.* Leonberg, Univ. Prof. Dr. -Ing. M. Norbert Fisch, 2013, ISBN:978-3-00-041246-2.

3. **TORCELLINI, P., PLESS, S. and DERU, M.** *Zero Energy Buildings: A Critical Look at the Definition.* Conference Paper presented at ACEEE Summer Study, 2006, NREL/CP-550-39833.

4. **SARTORI, I., NAPOLITANO, A. and VOSS, K**. *Net Zero Energy Buildings: A consisten definition framework.* Energy and Buildings, 2012.

5. **http://www.uponor.it/academy.** [Online]

6. **ABDEL-GWAD, M.** *Designing Energy Office Buildings in Hot Arid Climate.* Braunschweig, PhD thesis, Supervisors: Univ. Prof. Dr. -Ing. M. N. Fisch, Prof. P. Krusche, Der Andere Verlag, 2011.

7. **DERU, M. and TORCELLINI, P.** *Analysis of the Design and Energy Performance of the Pennsylvania Department of Environmental Protection Cambria Office Building.* NREL, 2005, NREL/TP-550-34931.

8. **MARZAL, A.J**. *Zero energy buildings: A review definition and calculation methodologies.* Energy and Buildings, Vol. 43, 2011

9. **FABRIZIO, E, GUGLIELMINO, D and MONETTI**, V. *Italian benchmark building models: The office building.* Sydney, Comference Proceedings: 12th Conference of International Building Performance Simulation Association, 14-16 November 2011.

10. **KNISSEL, J.** *Energy efficient office buildings.*

11. **ASHRAE.** *Advanced Energy Design Guide for Small to Medium Office Buildings. Achieving 50% Energy Saving Toward a Net Zero Energy Building,* 2011.

12. **AIR FORCE, United States.** *Passive Solar Handbook. Introduction to Passive Solar Concepts.* Colorado USA, Vol. 1, Architectural Energy Corporation.

13. **EERE**, Information Center. *Guide to Passive Solar Home Design.* DOE/EE-0342, October 2010.

14. **OLIVETI, G. et al.** *Tecnologie solari negli edifici esistenti. Criteri di progetto e metodologie di calcolo.* Roma, EPC Editore, 2013.

15. **LECHNER, N.** *Heating, Cooling, Lighting. Design Methods for Architects.* New York, 2nd Edition, John Wiley & Sons Inc., 2001.

16. **www.atkinsglobal.com.** [Online]

17. **www.intotodesign.com/casestudy.** [Online]

18. **GROSSO, M.** *Il raffrescamento passivo degli edifici in zone a clima temperato.* Maggioli Editore, 2008.

19. **ETHERIDGE, D.** *Natural Ventilation of buildings. Theory, measurement and design.* United Kingdom, John Wiley & Sons Ltd, 2012.

20. **SANTAMOURIS, M. and ASIMAKOPOULOS, D.** *Passive cooling of Buildings.* USA and Canada, Earthscan, 2013.

21. **KAMAL, M. A.** *An Overview of Passive Cooling Techniques in Buildings: Design Concepts and Architectural Interventions.* Acta Technica Napocensis, Civil Engineering & Architecture, Vol. 55, n. 1, 2012.

22. **www.qatarsearching.com.** [Online]

23. **http://www.treehugger.com/sustainable-product-design/kpmb-design-the-best-tall-building-in-north-america-for-manitoba-hydro.html.** [Online]

24. **MURPHY, M.** A. *Savings Potential with Thermo-Active Ceilings & Free Cooling.*

Conference Proceedings: International High Performance Buildings Conference, 2010.

25. **http://www.pumaservicesrl.it/impianti-geotermici.htm.** [Online]

26. **HERZOG, T.** *Uffici sostenibili. Architetture premiate in Europa.* Bologna, Proctor Edizioni S.p.A., 2009.

27. **LULING, C.** *Energizing Architecture.* Berlin, TSB , 2009.

28. **JAMES, T. et al.** *Building-Integrated Photovoltaics in residential sector: An analysys of installed Rooftop system prices.* NREL, Techinical Report, November 2011.

29. **http://solargis.info/doc/71**. [Online]

30. **KISS, G. and KINKEAD, J.** *Optimal Building-Integrated Photovoltaic Applications.* NREL, November 1995, NREL/TP-472-20339.

31. **FUENTES, M.** *Guidelines. Integration of PV into the built environment.* UK, BRITA in PuBs - Bringing retrofit innovation to application in public buildings, EU6, October 2007.

32. **www.bipv.ch.** [Online]

33. **www.wbdg.org/resources** [Online]

3. ANALYSIS OF SOME CASE STUDIES

Contents

INTRODUCTION

Office buildings located in Europe and Italy are analyzed as examples in order to underline the main design principles for the office typology. Grouped in low-rise and high-rise buildings, they differ for diverse design and energy strategies adopted to reach the goal energy efficient.

The present chapter presents a systematic study with a critical analysis of the cases that highlights some peculiarities for the design of new offices and specifically:

- the relation between building and context;
- building description and study of the application of passive and active strategies. In addition, a particular attention to the technologies adopted is addressed.

LEED (USA)

- Sustainable site;
- Water Efficiency;
- Energy and atmosphere;
- Materials and resources;
- Indoor Environmental quality;
- Innovation in design.

BREEAM (Great Britain)

- Management;
- Health and wellbeing;
- Energy;
- Transport;
- Water;
- Materials;
- Waste;
- Pollution;
- Land Use & Ecology.

DGNB (Germany)

- Ecology (Technical and process quality);
- Economy (Technical and process quality);
- Social quality (Technical and process quality);
- Site quality.

ITACA (office buildings, Italy)

- Site quality;
- Resources consumption;
- Environmental load;
- Indoor environmental quality;
- Service quality.

Table 3.1: Structure of various protocols [1, 2]

3.1 FORMAT DESCRIPTION

The importance of the realization of technical sheets lies in verifying the application of sustainable criteria and their declination into the office typology. Looking at the ITACA protocol for offices [1] and focusing on the building features, each sheet is divided in four main sections:

- **GENERAL DATA**;
- **BOUNDARY CONDITIONS** with the explanation both of climate and location;
- **BUILDING ANALYSIS** with the description of the building, techniques and systems;
- **MONITORING OF THE PERFORMANCE** of the building (if present).

Every macro-category (Table 3.2) is divided into micro-categories to offer a complete and systematic description of each case.

In addition, strategies are grouped according to a list of goals in order to make on evidence various technical solutions that reach the same goal. Images and details aid the comprehension of both the architectural choices and the technologies adopted. At the end of each example, it is also possible to find references.

The format adopted is the same for all cases and it encloses:

- in the upper part: Name of the building/Identification of the building with a number/Date of construction/Location;
- in the lower part: Design Team/Number of the page/Client.

The buildings analyzed are offices located in Europe (four of them are in Italy) and they are grouped into low-rise with a wide floor plan and high-rise with narrow floor plan buildings.

They are selected since they constitute an example of low-energy design. Hence, most of them have been awarded either for this reason or for their architectural quality.

Table 3.3 and Table 3.4 show the list of the buildings analyzed.

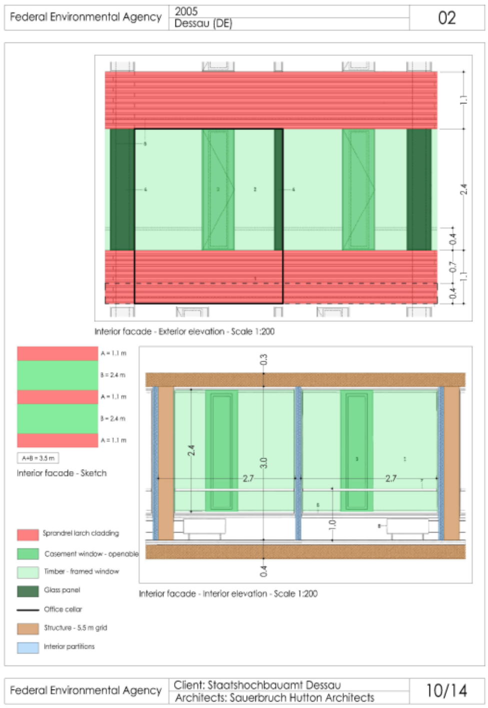


Figure 3.1: Sheet format

GENERAL DATA

- Scenario
- Building Description (General Description/Goals and key aspects/Data/Time/Awards)

BOUNDARY CONDITIONS

- Climate Data
- Site location and site quality

BUILDING ANALYSIS

- Orientation and shape
- Internal layout
- Structure and Envelope composition (Structure/Floor/Façade/Roof)
- Energy concept and Systems
- Environmental strategies

MONITORING OF THE PERFORMANCE

References

Table 3.2: Sheet description

[1] Table 3.1 [1, 2, 23]

3.2 CASE STUDIES

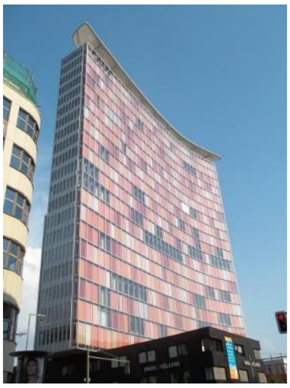
N°	*LOW-RISE BUILDINGS WITH A WIDE FLOOR PLAN*
	POLLMEIER
01	 Seelinger & Vogels Architekten/Creuzberg (DE)/2002
	FEDERAL ENVIRONMENTAL AGENCY
02	 Suerbruch-Hutton Architects/Dessau (DE)/2005
	HIGH-RISE BUILDINGS WITH A NARROW FLOOR PLAN
	GSW HAUS
05	 Suerbruch Hutton Architects/Berlin (DE)/1999
	ROPEMAKER
06	 Arup Associates/London (UK)/2009

Table 3.3: European buildings

N°	*LOW-RISE BUILDINGS WITH A WIDE FLOOR PLAN*
	IGUZZINI ILLUMINAZIONE
03	 Cucinella Architects/Milano (IT)/1999
	CENTRO LEONI
04	 V. Benati & A. Gallo Architects/Milano (IT)/2005
	HIGH-RISE BUILDINGS WITH A NARROW FLOOR PLAN
	UNIPOL TOWER
07	 Studio Open Project/Bologna (IT)/2012
	ISOZAKI TOWER
08	 Isozaki & A. Maffei Architects/Milano (IT)/In construction

Table 3.4: Italian buildings

1. Scenario

Pollmeier is Europe leading wood processing company in the hardwood sector running sawmills in Creuzburg and Aschaffenburg (DE). Hence, the idea of the client was the creation of a new building located in an industry and commercial area in Creuzburg (close Eisenach, Thuringia) that:

- gives visibility to the company;
- involves qualified people of the sectors;
- improves the quality of the zone;
- guarantees a high quality of the workplaces;
- is an energy efficient construction.

2. Building description

General Description: The building is a 3-storey office characterized by a square shape with a core atrium covered by a glass roof and an open-space organization, which receive 400 staff members.

Goals: B) Reduction of heating demand; C) Reduction of cooling demand; D) Maximization of daylighting; E) Protection from glare and sun radiation; F) Maximization of natural ventilation; G) Ecology of building materials; I) Integration with renewables; L) Optimization of operations.

Key aspects: Atrium, Daylight planning and optimized lighting, Ventilation + heat recovery, Regenerative + passive cooling, Photovoltaics, Biomass utilization, Heat pump, Optimization of operations.

Data:

Number of floors: 3
Gross Volume: 16847m³
Heated Net Floor Area: 3510 m²
Usable Floor Area: 3489m²
Storey height: 3.6 m
Workplaces: 400
Construction Costs Net construction costs relating to gross floor area. = 1034 €/m²
Cost for Technical system = 280 €/m²
Energy indices according to German regulation EnEV*: Heating energy demand = 32 kWh/m²a (according to German regulation WSchVo 95); Overall primary energy requirement = 37 kWh/m²a (according to LEE, based on heated net floor area)
Measured energy consumption data*: Thermal heat consumption = 60.6kWh/m²a (in 2003, based on heated net floor area); Total source energy = 73.4kWh/m²a; Building services and lighting = 19kWh/m²a; Working appliance/miscellaneous = 32kWh/m²a

*Data of 2003, based on heated net floor area

Time: Completion 08/2001
Inauguration 02/2002

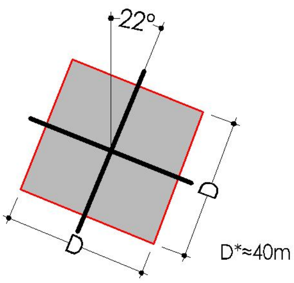
Awards: 2002 "Fassadenbaupreis" (German facade construction award)

Experts: Architecture and project management: Seelinger & Vogels Architekten
Energy concept, building services engineering, building physics, simulation: Solares Bauen GmbH
Daylight concept: Fraunhofer ISE
Monitoring and accompanying research: Zentrum für Umweltbewusstes Bauen (ZUB) e.V.

Photo [5]

Photo [5]

Masterplan - Scale 1:7500

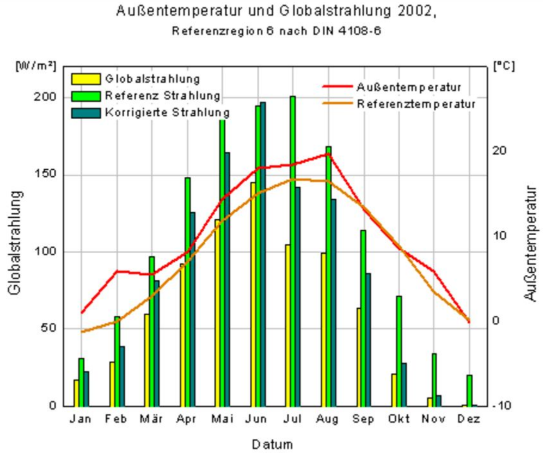


- Office building
- Industrial constructions/Warehouse
- Housing
- Main traffic stream
- Secondary traffic stream
- Car park

3. Climate data

Latitude: 51°3' *Longitude:* 10°14'

Description: Humid continental climate (Dfb) or oceanic climate (Cfb) according to Köppen classification.
Winter: Cold with light snowfall (colder months: from December to February).
Summer: Warm and occasionally humid.
Winds: Prevailing winds from West direction.



4. Site location and site quality

Site location: Pferdsdorfer Weg 6, 99831 Creuzburg (DE);

Site quality: Industrial area and countryside;

Nearby Buildings / Position and Morphology: The construction is isolated and it belongs to the Pollmeier industry area, positioning on South side. North: Street for the circulation within the Pollmeier zone; South/West: Countryside with isolated buildings; East: Car park and countryside.

Vegetation / Position and Typology: The building is surrounded by green grass and immersed in the countryside except for the North that communicates with the other buildings of the company. On North front a line of evergreen trees is located.

5. Orientation and shape

Orientation: Polar symmetry with axes rotated by an angle of 22°;
C) Reduction of cooling demand + F) Maximization of natural ventilation → Prevailing winds from West side. Hence, the building orientation contributes to increase the wake in the leeward side.
D) Maximization of daylighting → Rotation of axes to have prevailing exposition of fronts on North and South sides even if with intermediate conditions.

Shape: Square shape of the block with square core atrium.
B) Reduction of heating demand → A/V = 0.32 m²/m³ => Compact.

6. Internal layout

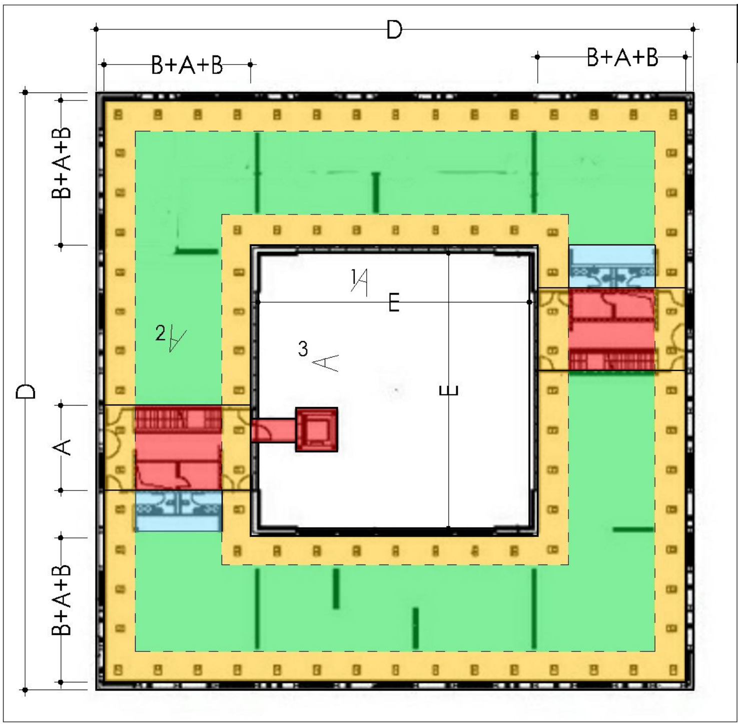
Office Spaces: Two floors dedicated. Open-space layout with offices distributed along each orientation.

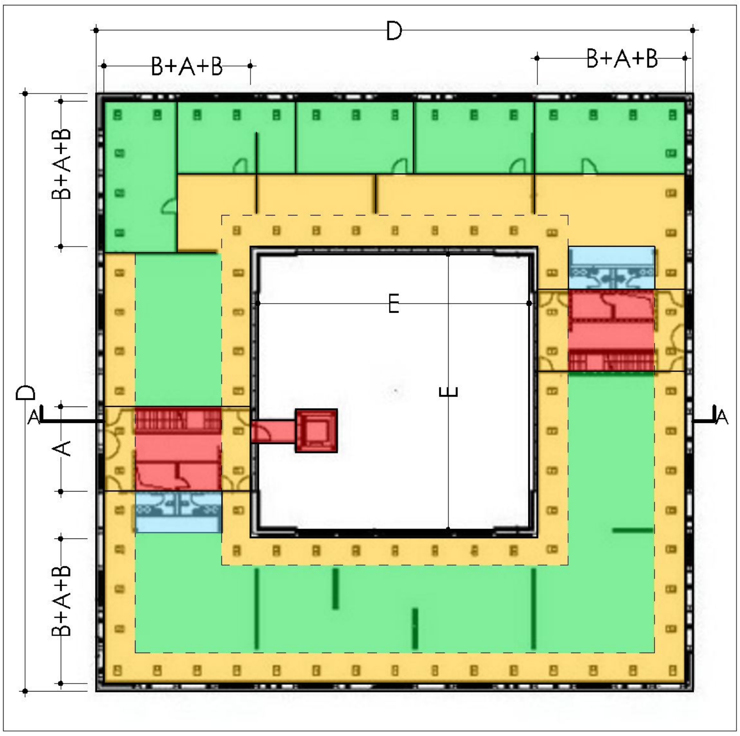
Meeting room/conference room/video conference: Ground floor.

Services (break areas, toilets, technical spaces): Ground floor accommodates bar and technical spaces. Toilets are closed to the staircase blocks on East and West positions.

Connections: Vertical connections on East and West sides and one lift positioned in the atrium. Horizontal connections at each level as double rings, one external closed to the façade, one internal closed to the atrium.

Atrium: It has a core position and it is higher than the building, covered by a transparent roof.





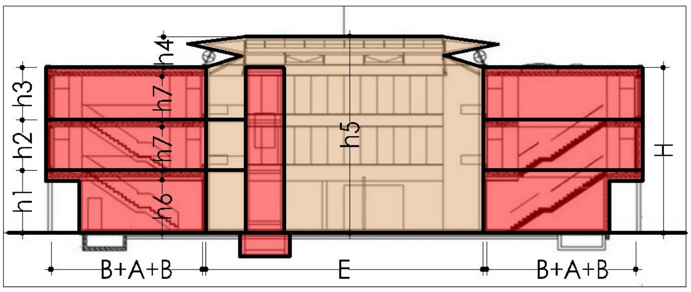
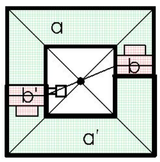



Photo 1: Entrance [4]


Photo 2: Offices [4]


Photo 3: Entrance [4]

- Offices
- Vertical connections
- Horizontal Connections
- Toilets
- Atrium



Polar simmetry

A*≈6m; B*=2m; D*≈40m; E*≈18.5m
h1=4m; h2=3.4m; h3=3.5m; h4=2.1m; h5*=13m; h6*=3.5m; h7*=2.9-3m; H*=10.9m

Floor plan (type 1 and type 2 with combi-office) and section A - Scale 1:500

7. Structure and envelope composition

Structure: Steel structure + two main concrete blocks for staircases + concrete walls;

B) Reduction of heating demand + C) Reduction of cooling demand → Thermal mass trough concrete elements (some of which covered with fabric) with orientation NW/SE.

Floor: Concrete slab and raised floor.

B) Reduction of heating demand + C) Reduction of cooling demand → Thermal mass through the horizontal concrete slab intrados that is exposed in the corridor zones, closed to the transparent facades.

Facade: Ventilated external facade with prefabricated wooden elements, high thermal insulation and large fibre cement panels.

B) Reduction of heating demand → High thickness of the insulation material for the opaque part=30cm with U=0.17W/m²K;
Thermally insulating double glazing with U=1.40W/m²K;
Large transparencies on North front to increase heat gains;
Blower door Test for the airthigness of the building;

C) Reduction of cooling demand → Study of the dimensions of the openings according to the exposition: WWR North=50%, East and South=40%, West=30%;
Night cooling for offices with openable upper part of the big windows;
Control on openings: some parts are fixed, others are openable and directly controlled by users;

D) Maximization of daylighting → High WWR values according to the limitations related to the overheating reduction in summer;

E) Protection from glare and sun radiation → Shading devices: North=No; South=Yes, external shading devices except for the ground floor. This because the ground floor is smaller than the storeys above, which result in overhang; East and West fronts have exterior shading devices;

The internal facades of the atrium have an opaque parapet and the other part transparent with no shading device systems integrated.

C) Reduction of cooling demand → The upper part of the internal facade is openable to improve the ventilation of the building thanks to the openings on the atrium roof;

D) Maximization of daylighting → ¾ of the façade is transparent, ¼ is opaque;

E) Protection from glare and sun radiation → The corners are opaque to have a better control of the daylight;

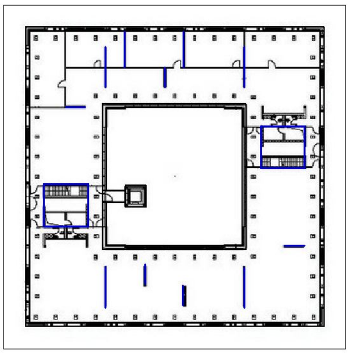
Roof: Green flat roof for the block and grid structure made by steel, wood and glass for the atrium.

B) Reduction of heating demand → High thickness of the insulation material for the opaque roof=20cm with U=0.19W/m²K;
Covering the atrium by a transparent roof exploiting the greenhouse effect;

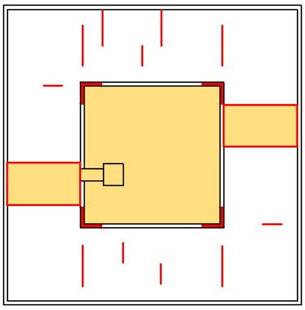
C) Reduction of cooling demand → Night cooling through vertical openings into the roof atrium. They are sloped of an angle of 12°;
Interior shading devices for the glass part;

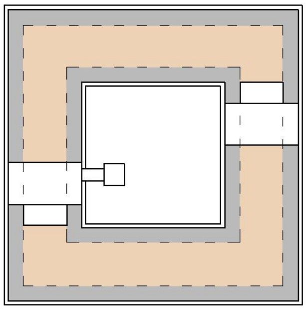
D) Maximization of daylighting → Transparencies on the core part of the building = glazed atrium roof;
Glasses of roof are sloped both on vertical and horizontal positions to improve the diffuse solar radiation.

I) Integration with renewables → The portion of the roof covered by the steel cladding have integrated photovoltaic modules (angle 7°) on each orientation.



Structure - Scale 1:1000





Thermal Mass and Buffer zones - Scale 1:1000

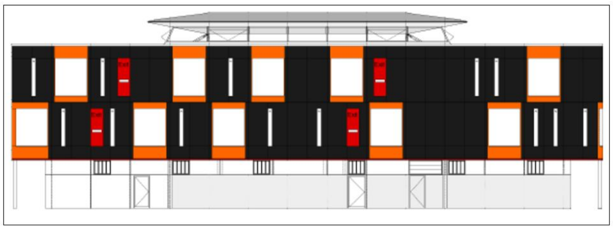
Buffer zone

Thermal mass

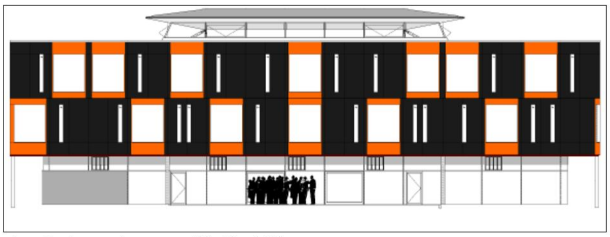
Exposed concrete ceiling

False ceiling made by panels with acoustic property

Photo [4]



West facade WWR=30%

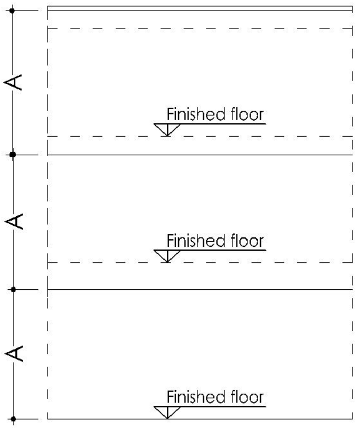


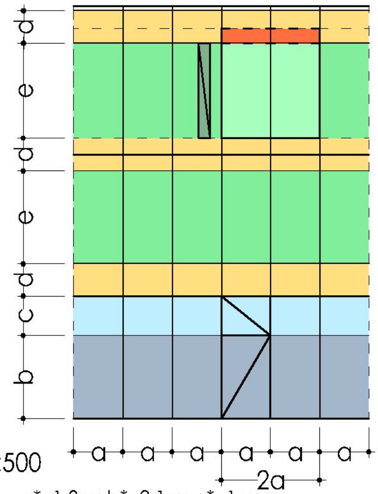
South facade WWR=40%

East facade WWR=40%

North facade WWR=50%

Facades [7]





Facade scketches - Scale 1:500

a*=1.3m; b*=2.1m; c*=1m; d*≈0.85m; e*=2.5m

b = Transparent or Opaque

c= Fixed or Openable window

d= Opaque part

e= Opaque panel or Fixed/Openable window

Grill for ventilation

Openable window by users

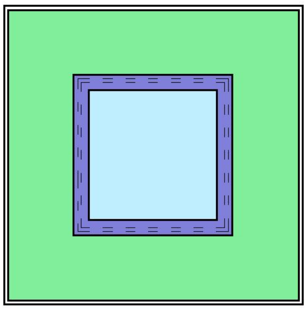
Fixed window

Ground floor [6]

Facade [6]

Grill for ventilation

7. STRUCTURE AND ENVELOPE COMPOSITION

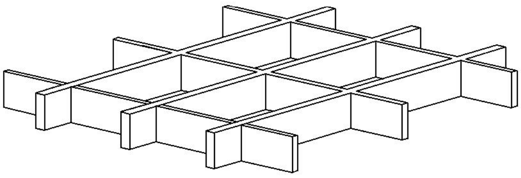


Roof Sketch - Scale 1:1000

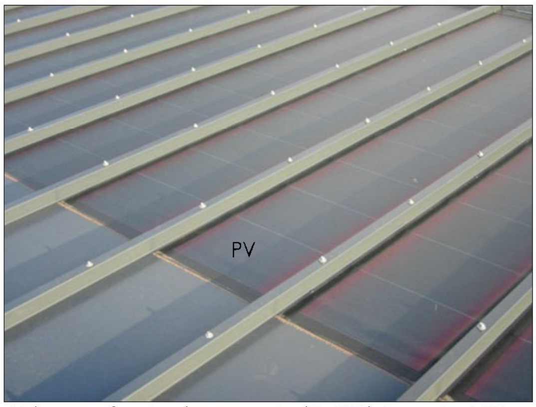
- Green Roof
- PV integrated into the steel part of the atrium roof
- Transparent part

Sloped openings for ventilation

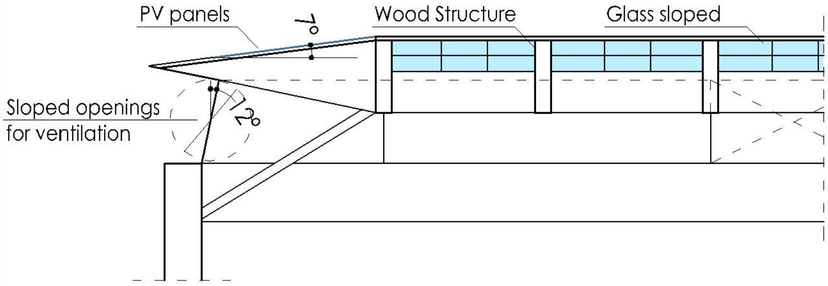
Green Roof and atrium roof [7]



Atrium roof - Wood Structure



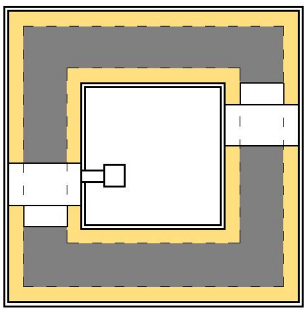
Atrium roof - aluminum part with PV integrated [7]

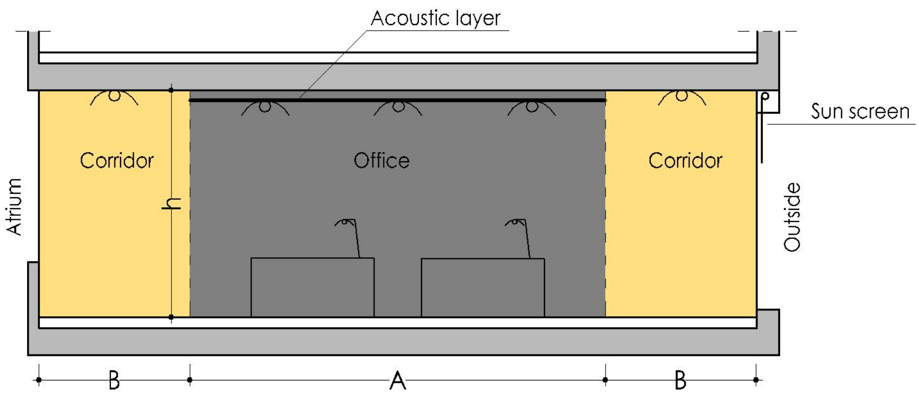


Atrium roof - Scale 1:100

Position for the sloped openings (ventilation)

Atrium roof [7]





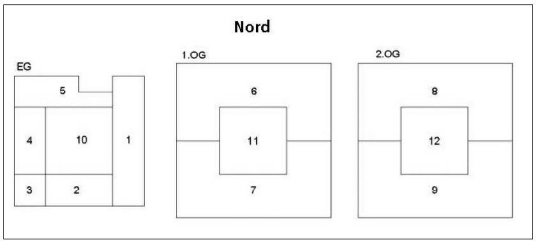
Lighting layout - Plan and Section - Scale 1:1000 and 1:100

A*=6m; B*=2m; C*=3m; h*=3m

- Corridor: 100-300 Lux (11W/m²)
- Office: 300 Lux (ceiling lamps, 7W/m²) + Desk lamp(15W)= 500 Lux

8. Energy concept and Systems

Heating/Cooling and Ventilation: The building heat supply is based, via a heat exchanger, on the company local heating system, which runs on renewable waste wood (wood combustion);
Air extraction system for the indoor ventilation (exhaust air extracted in the central part of the building) while fresh air enters through air supply elements in the facade (this cools during the night offices, factor of 1.5). Otherwise, in summer a recirculating cooler is also activated;
Mechanical ventilation for toilets;
The server room have an air cooler dedicated (cooling load 80W/m²);



Thermal Zoning [7]

L) Optimization of operations → CO2 and mixed gas control system for the ventilation system;
Control temperature system;

Service hot water: A heat pump, integrated into the exhaust airflow, is used for provision of hot water;


System room [7]

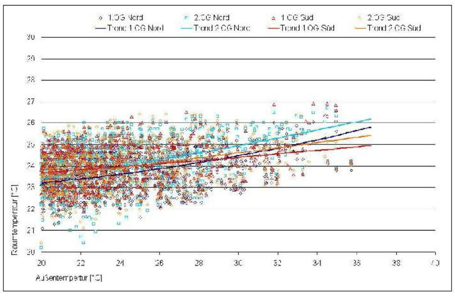
Lighting: Indirect lighting of 300lux for offices on ceiling + lamp desk that reach 500 lux; while corridors 100-300lux;

L) Optimization of operations → 1st floor has a control system of the external light intensity;
2nd floor has a system with sensors which regulates the brightness of the workplace;

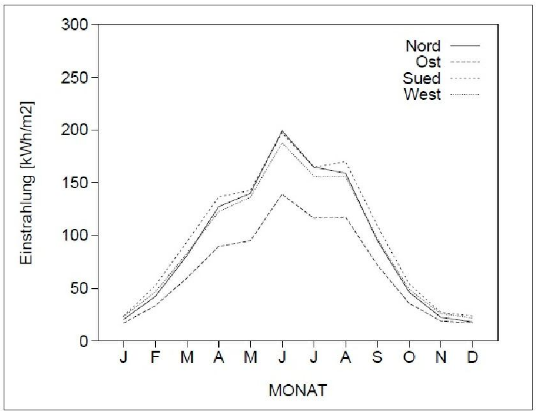
Electricity: Photovoltaic panels installed on the roof to produce electricity;

I) Integration with renewables → Active solar system: angle of the panels=7°, 30 modules, Thyssen SolarTecT2, production of 64Wp.


Lighting system [7]


Room temperature in the office floors and outside temperature for the year 2002 [7]


Heat pump [7]



Photovoltaics - Solar radiation

9. Environmental strategies

The construction represents the loyalty of the Pollmeier Company versus the topic of the sustainability.
The building is low-energy and integrates renewables trough passive and active solar systems and waste wood for the heating system.

10. Monitoring of performance


Photo [7]

Heat consumption and electricity consumption were initially considerably above the target values:

- Lighting, switched on throughout all working hours, increases electricity consumption because the level of daylight in the workplace is reduced by the dark design of furniture, floor and wall panels. A large-scale intervention in the work organization or in the interior architecture could improve the condition; nevertheless the lamps desk had been replace in order to reduce electricity consumption and to improve the comfort;
- The measured heating requirement is between 60-65kWh/m²a, and exceeds the planned values by around 70%. This is accounted for the room temperatures, which are 2-3 degrees higher than estimated.
- As expected, the heat pump covers approximately 10% of the energy consumption. However, due to the poor seasonal performance factor, deactivation of the heat pump in summer must be considered.
- The air extraction system provides demand-oriented ventilation with a high degree of comfort.

Occupant satisfaction in July 2002:

- Good indoor temperatures and air quality level. During the day, users open the windows;
- Large differences in the assessments of the level of daylight: half find it good, while half find it middling to poor. Solar glare occurs in a significant majority of the workplaces, this for the too transparent nature of the sun protection, which entails excessive light intensity in direct sunlight. In addition, the majority considers the artificial lighting to be ok, while one third find it insufficient.

References

1. SOLAROPTIMIERTES BAUEN. Messtechnische Begleitung und Evaluierung des Neubaus des Verwaltungsgebäudes der Fa. Pollmeier in Creuzburg. Kassel, Zentrum für Umweltbewusstes Bauen e.V, Teilkonzept 3, 2004.

2. WAPLER, J. Monitoring, Experimente und Datenanalyse für die Nachtlüftung im Verwaltungsgebäude Pollmeier. Thesis, Institute Solare Energiesysteme, Supervisor: J. Pfafferott, 2002.

3. Verwaltungsgebäude Pollmeier. Portratl n.13, Projektförderung, Bundesministerium für Wirtschaft und Technologie (BMWi).

4. www.enob.com. [Online]

5. www.pollmeier.com. [Online]

6. www.seufert-niklaus.com . [Online]

7. www.zub-systems.de. [Online]

1. Scenario

The German Federal Environment Agency building in Dessau was built after the German Federalism Commission decision (1992) to move from Berlin to Dessau (actually some parts of the Agency are also in Berlin, Langen - Hesse and Bad Elster - Saxony).

The project represents an ambitious recovery project in terms of application of energy efficiency and ecological strategies in an old industrial area where ground was strongly contaminated. The buildings involved are the following:

- the main new building with offices (object of the present study);
- the new and existing library buildings (integration between new and existing);
- the Canteen;
- the 'Wörlitzer Bahnhof' railway station.

The office building becomes the symbol of the zone, an eye-catcher for its colorful and curved aspects designed by Sauerbruch-Hutton Architects.

2. Building description

General Description: The main building is a 4-storey office characterized by a “snake” shape of the block, a core atrium covered by a transparent roof, a forum that constitutes the entrance and the place for all public facilities.

Goals: A) Connection with the context; B) Reduction of heating demand; C) Reduction of cooling demand; D) Maximization of daylighting; E) Protection from glare and sun radiation; F) Maximization of natural ventilation; G) Ecology of building materials; H) Protection from noise pollution; I) Integration with renewables; L) Optimization of operations.

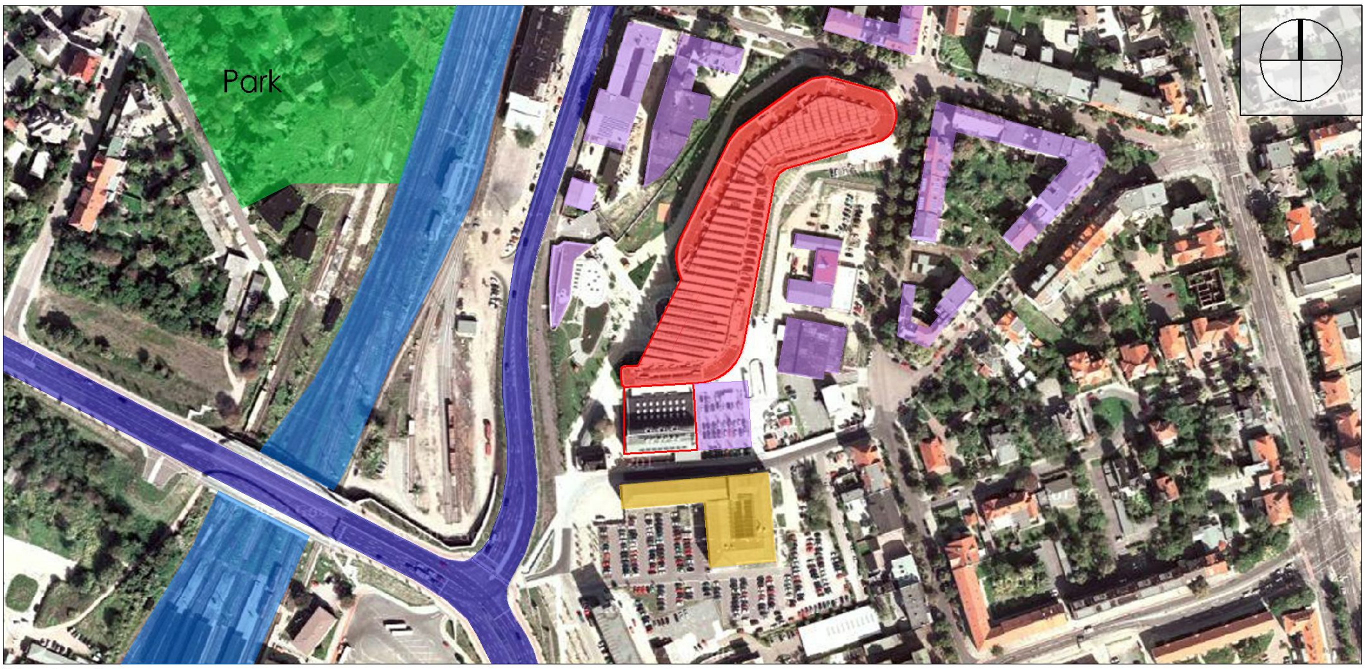
Key aspects: Atrium, Daylight planning, Passive and evaporative cooling, Active solar, Ventilation + Heat Recovery, Heat and power generation, Eco-friendly materials, Optimization of operations.

Data: Number of floors: 4
Number of floors above the ground: 1
Gross Volume: 184855m³
Gross Floor Area: 35765m²
Heated Net Floor Area: 32384m²
Usable Floor Area: 17350m²
Workplace: 790-800
Construction Costs = 1211€/m²
Cost for Technical systems = 415€/m²
Energy indices according to German regulation EnEV: Heating energy demand = 54.2kWh/m²a
Overall primary energy requirement = 73.1kWh/m²a
Measured energy consumption data: Site energy for heating and domestic hot water = 61.8kWh/m²a
Source energy for heating and domestic hot water = 43.3kWh/m²a

Time: Competition: 1998
Beginning of works: 2001
Completion and Inauguration: 2005

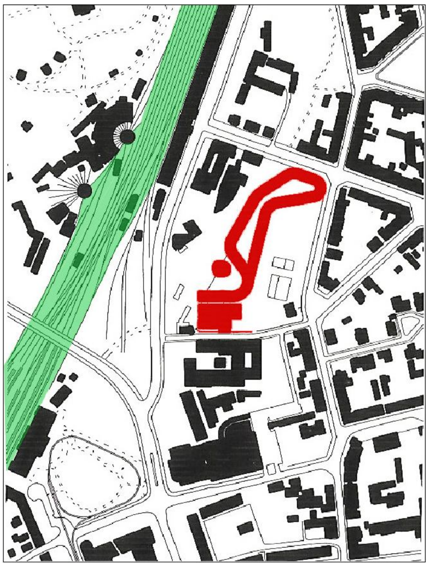
Awards:
2005 Holzbaupreis
2006 Royal Institute of British Architects (RIBA) Award
2006 Premio Balthsar Neumann, menzione speciale
2007 Zumtobel Group Award, menzione d'onore
2007 Award Mies Van Der Roh, opere selezionate

Experts:
Architecture: Sauerbruch Hutton
Statics: Krebs und Kiefer
Simulation/Evaluation: IEMB
Building physics: Müller BBM GmbH
Simulation/building services: ZWP Ingenieur-AG
Evaluation: Fraunhofer ISE

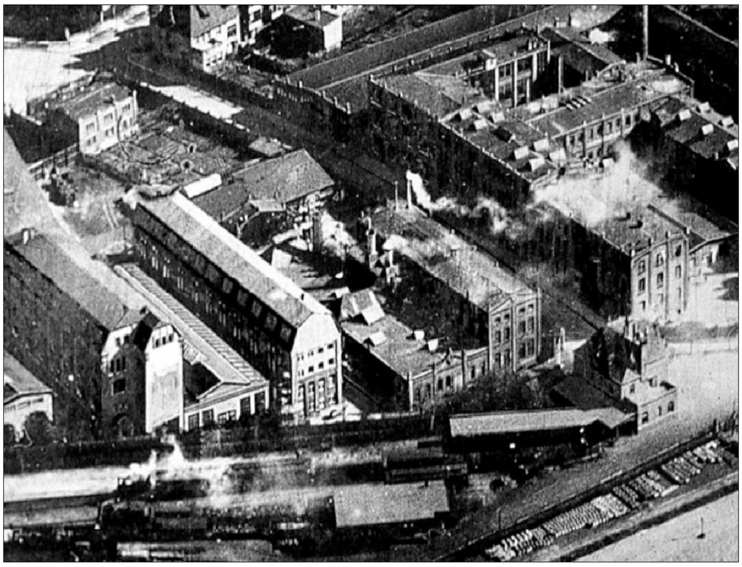


Masterplan

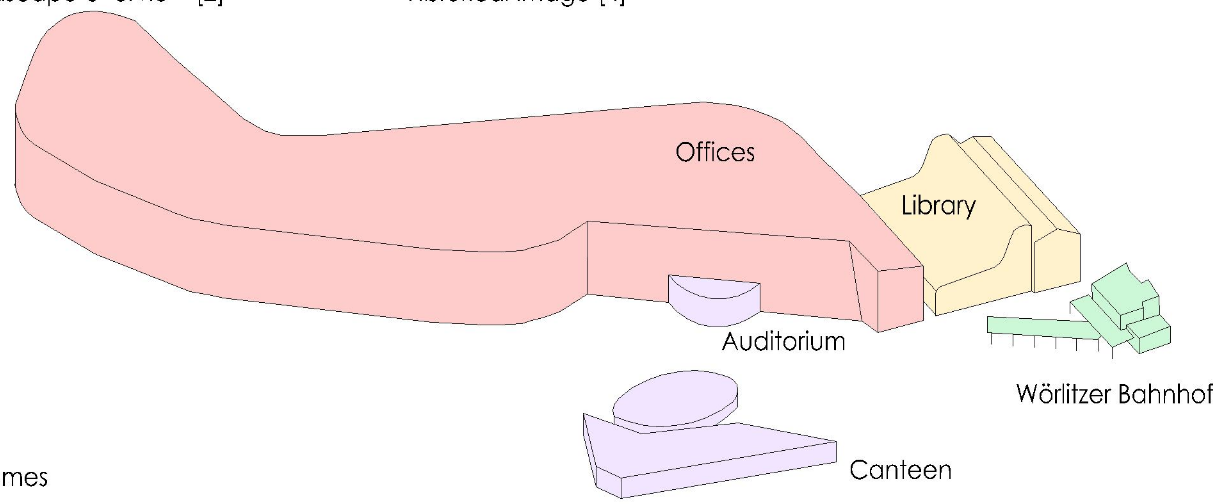
Office building · Retail · Housing · Main traffic stream · Railway



Landscape overview [2]



Historical Image [4]



Volumes

3. Climate data

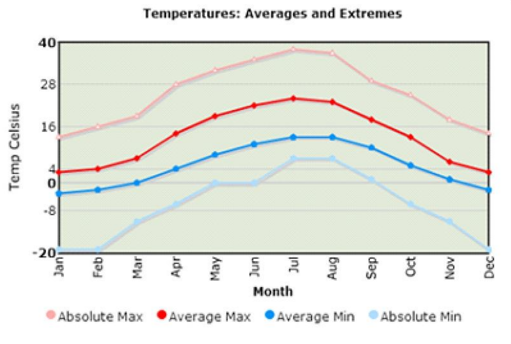
Latitude: 51°50' *Longitude:* 12°14' *Altitude:* 60m

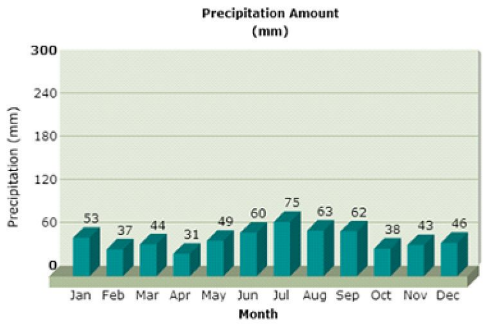
Description: Located in the temperature region, it is influenced by the Atlantic and the close Harz;

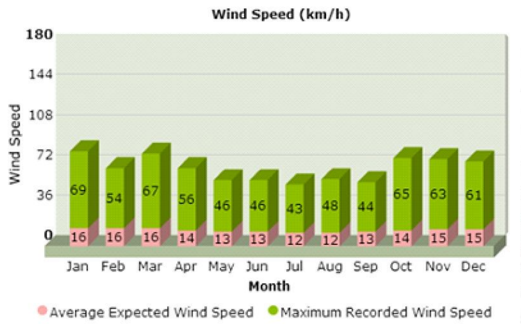
Winter: Mild winter that can reache low temperatures as -19°C (December, January, February);

Summer: Moderate summer that can reaches also high temperatures as 35°C;

Winds: From North/West.







Climate characterization

4. Site location and site quality

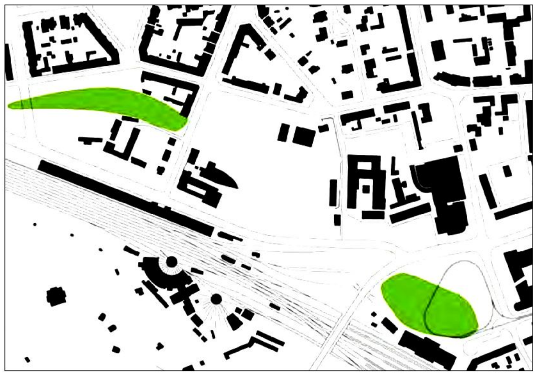
Site Location: Am Wörlitzer Platz 1, 06844 Dessau-Roßlau (DE), Sachsen-Anhalt;

Site quality: Recovery of the old gasometer area (1855-1991) and of the railway station area;

Nearby Buildings / Position and Morphology: Development of individual lots in an independent manner during the time; housing are either grouped or isolated. North: Residential buildings, South: Retail and residential buildings of the 1990s, East and West: Residential buildings in Gründerzeit style, West: Rail and main street. The buildings are distributed in a way that do not create shadows on the building.

Vegetation / Position and Typology: On West side there is a park.

Infiltration and intenisity of noise sources near the site (rail, street traffic, industry)



Connection with the contest - Environmental impact [4]

5. Orientation and shape

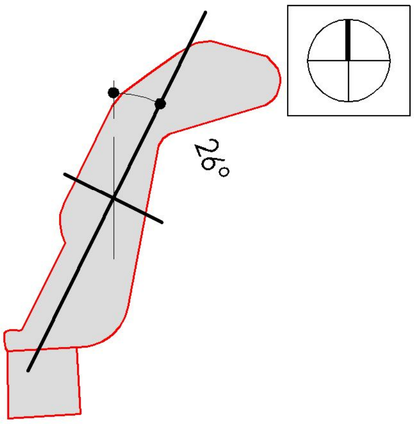
Orientation: The main axe is approximately North-South oriented with an angle from the North of 26°;

A) Connection with the context → Parallel to the main street and the railway;

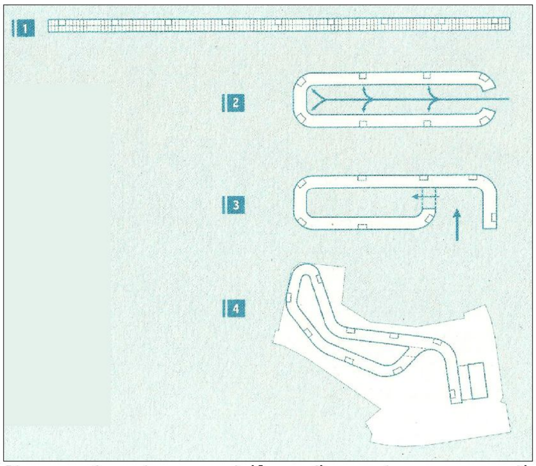
Shape: The building is like a "snake". The idea develops from a linear shape with a corridor with cellular offices double pronged to a moved and closed on itself line in order to improve the energy performance and obtain a compact form; The close part creates a private space, the second one a semi-public space; A/V = 0.34m²/m³ => Compact.

A) Connection with the context → Articulated shape with the entrance on South/West which dialogues with the surroundings;

B) Reduction of heating demand → The block is closed on itself creating an atrium covered by a roof to reinstore the compact shape.



Orientation

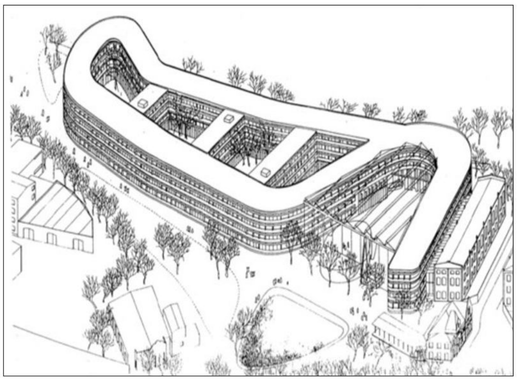


Shape development (from linear to compact) [8]

Semi - public

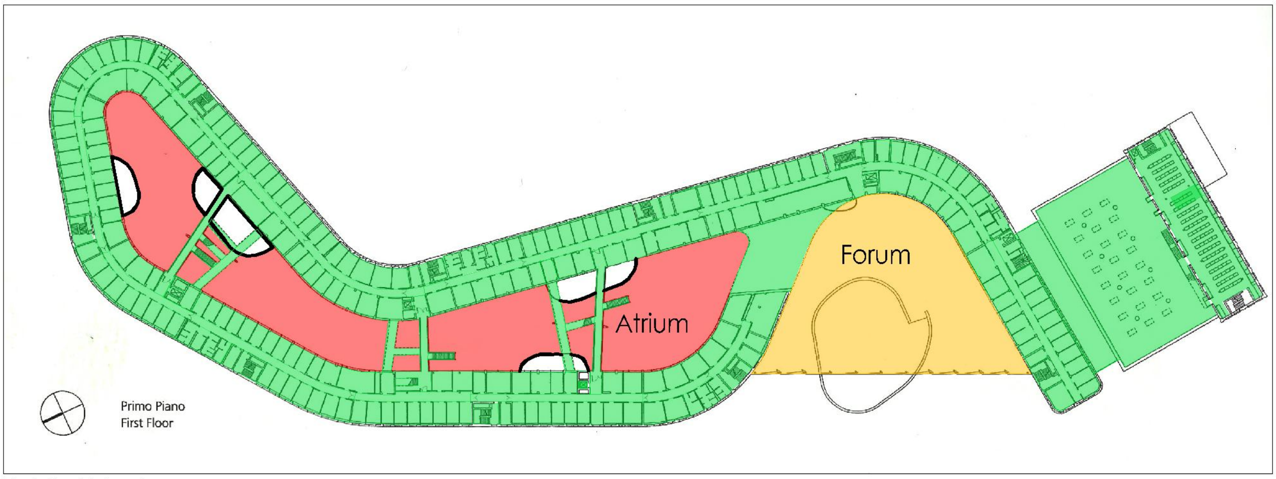
Public

Private



Sketch [6]

Model [6]



Public/Private spaces

6. Internal layout

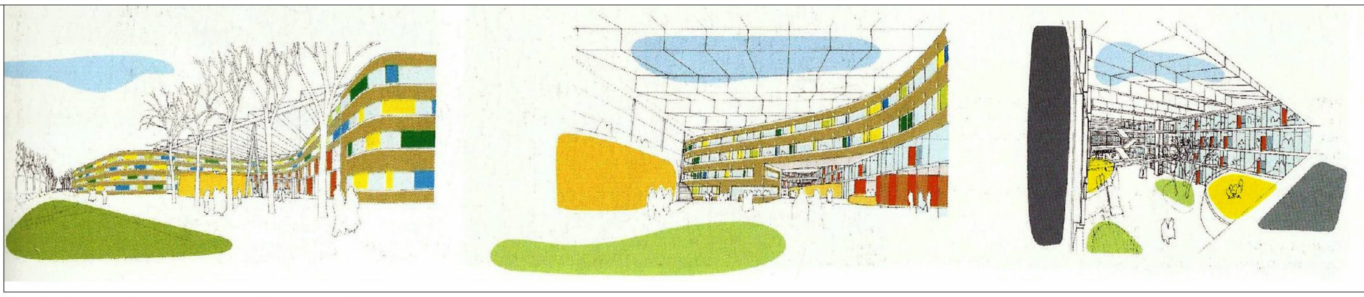
Office Spaces: Cellular offices distributed along double strips interrupted by service zones. Hierarchy of spaces according to the way of work; the office size depends by the type (minimum area: 12m²);

Meeting room/Conference room/Video conference: Meeting rooms are located on the ground floor with direct access from the atrium (they represent the "stones" in the Atrium). At every floor, there are spaces for internal staff meetings;

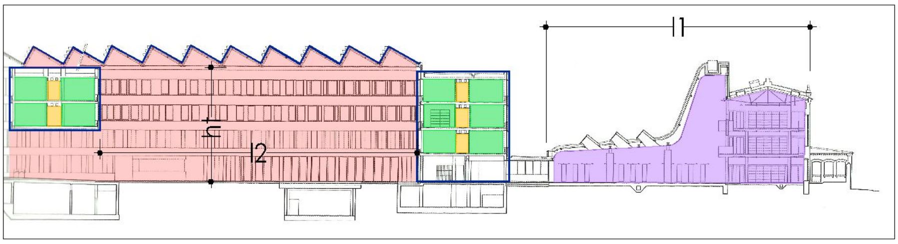
Services (break areas, toilets, technical spaces): Toilets are closed to the vertical connections while technical spaces are located in the basement;

Connections: Circulation is designed as the structure of a tree: Forums as roots, Atrium as the trunk, walkways and corridors as the large and small branches. Vertical connections: there are 10 staircases + other staircases in the atrium + 4 lifts (in the Library: 3 staircases + 1 lift). Horizontal Connections: corridors (1.5m wide) in the middle of the two offices' strips + 3 groups of bridges at different level which pass through the atrium;

Atrium and Forum: A relax spaces, sort of garden.



Sketches - Atrium and Forum [2]



Vertical section - Scale 1:1000

Offices

Horizontal Connections

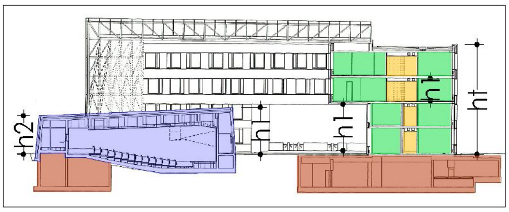
Library

Atrium/Forum

Auditorium

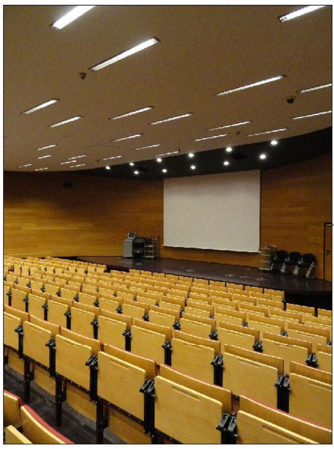
Technical spaces

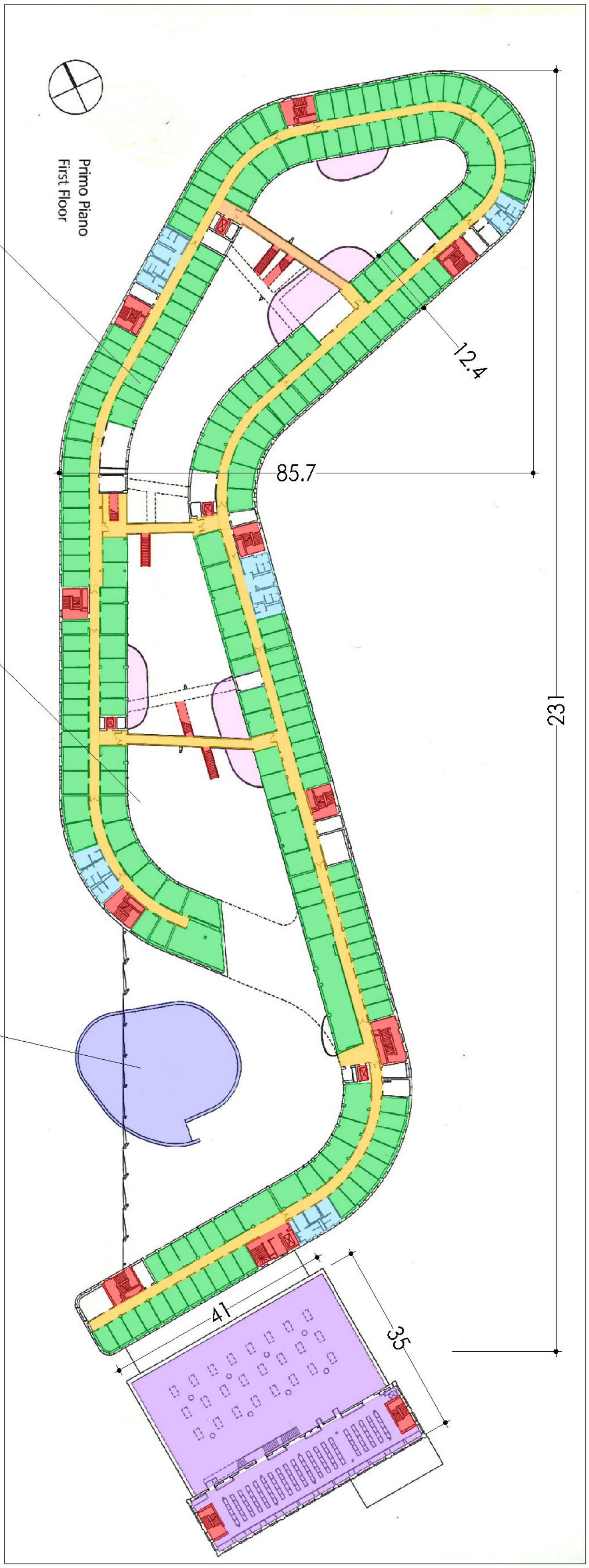
l1=35m; l2=42m;
ht=15m; hi=3m; h1=6m; h2=5m;



Vertical section - Scale 1:1000

Photos





First floor - Scale1:1200

- Offices
- Vertical connections
- Horizontal Connections
- Library
- Meeting rooms
- Auditorium
- Toilets

7. Structure and Envelope Composition

Structure: Reinforced concrete structure with a grid of 5.5m;

Floor: Concrete slab with raised floor;

Facade: Eight horizontal strips alternating wood and glass for the external and the internal facades. Strips of colored glass of different widths and different colors and different thickness of the facades.

A) Connection with the context → Curved facade that follows the sinuous building that reflects the landscape with the use of 7 families of different colors that match the surrounding urban color: North/East: warm colors of red because is the part that looks the city; West: green and blue colors that match the colors of the park.

B) Reduction of heating demand → Thick insulation for the opaque part and high insulation for windows ($U=1.2W/m^2K$) with triple glazing;

D) Maximization of daylighting → Important percentage dedicated to transparencies, with a significant concentration on the interior front. Specifically, 60% is glazed (considering the total area), with WWR=35% for the exterior facade and WWR=60% for the interior f acade;
Windows without lintel;

E) Protection from glare and sun radiation → Internal shading devices with horizontal blinds;

F) Maximization of natural ventilation → Night cooling thanks the integration of openable parts on the external facade (grill into the depth of the windows);

G) Ecology of building materials → Use of untreated larch wood and glass;

H) Protection from noise pollution.

Roof: Flat roof for the offices with a mounting system of solar collectors and transparent roof for the atrium with a shed geometry and a structure of glass and steel (40m).

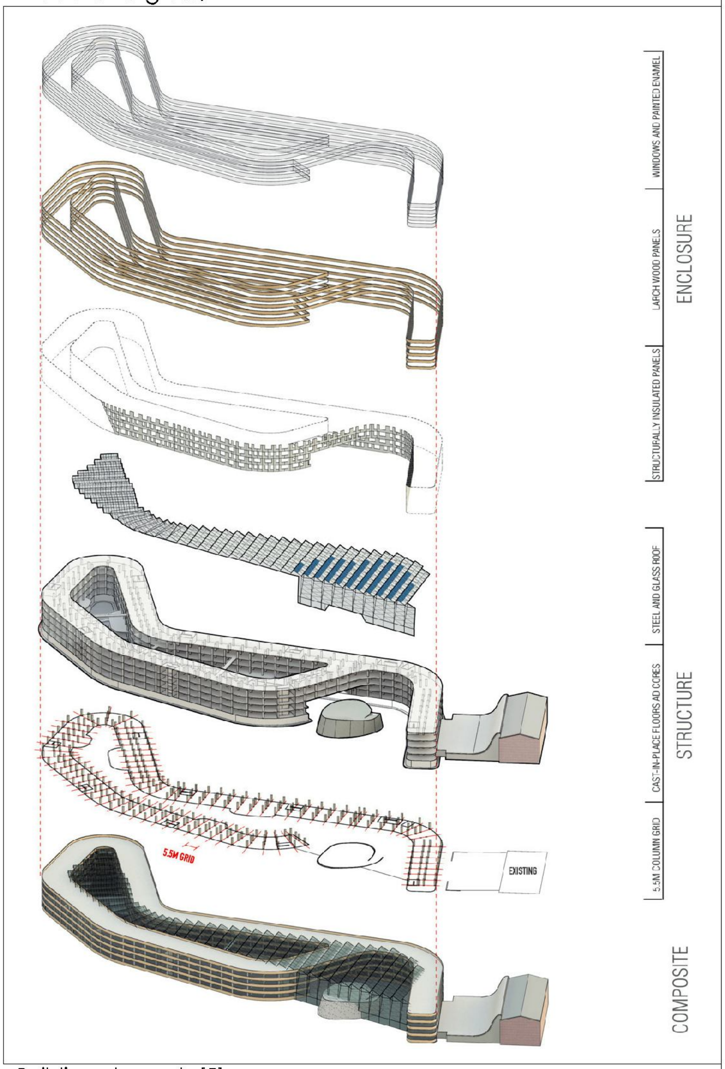
B) Reduction of heating demand →
High thermal insulation of the flat roof;
During winter period the openings of the atrium roof are closed and it works as a buffer zone exploiting the greenhouse effect;

C) Reduction of cooling demand + F) Maximization of natural ventilation →
Openings on the top of the atrium roof that work automatically during summer and during night.

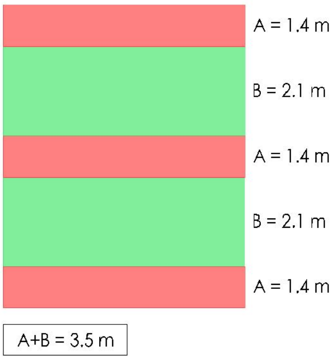
D) Maximization of daylighting →
High percentage of transparencies: Transparent roof=$4590m^2$ versus Opaque roof=$2660m^2$;

E) Protection from glare and sun radiation →
Internal shading devices for the roof of the atrium;

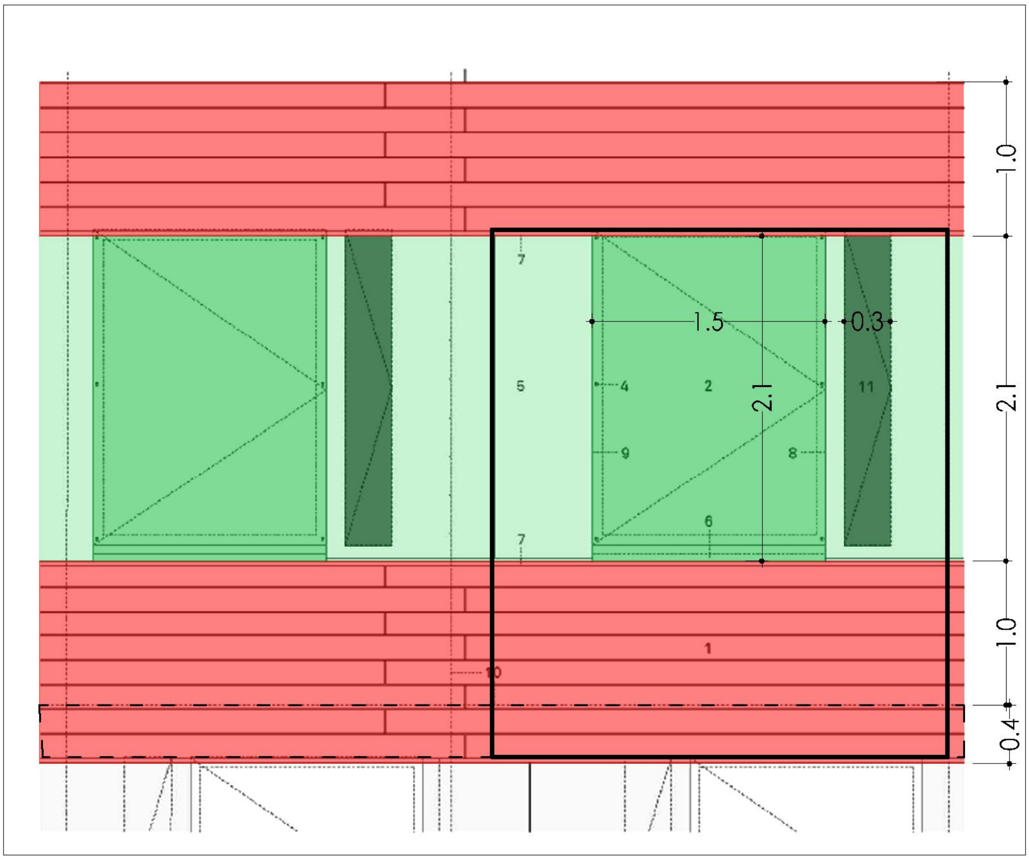
G) Ecology of building materials → Prevalent use of glass.



Building elements [5]



Exterior facade - Sketch



Exterior facade - Exterior elevation - Scale 1:200

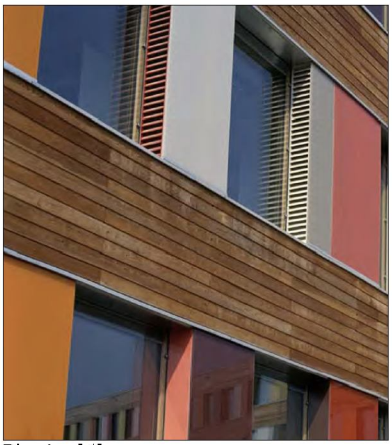
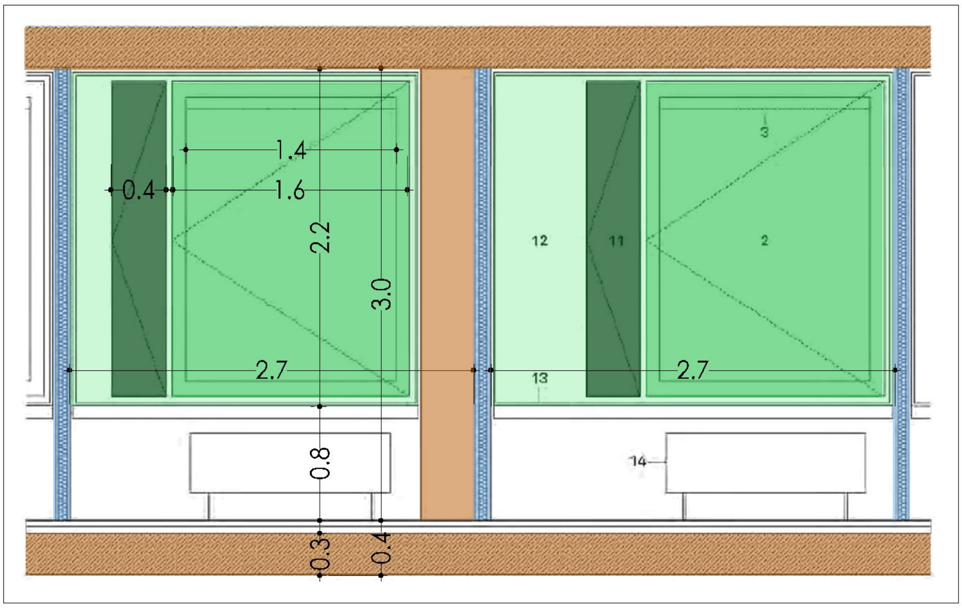
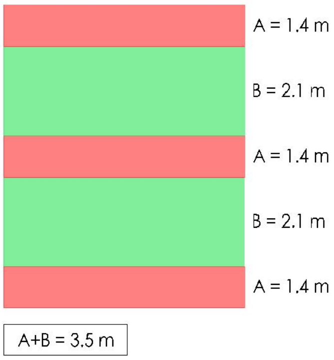


Photo [4]



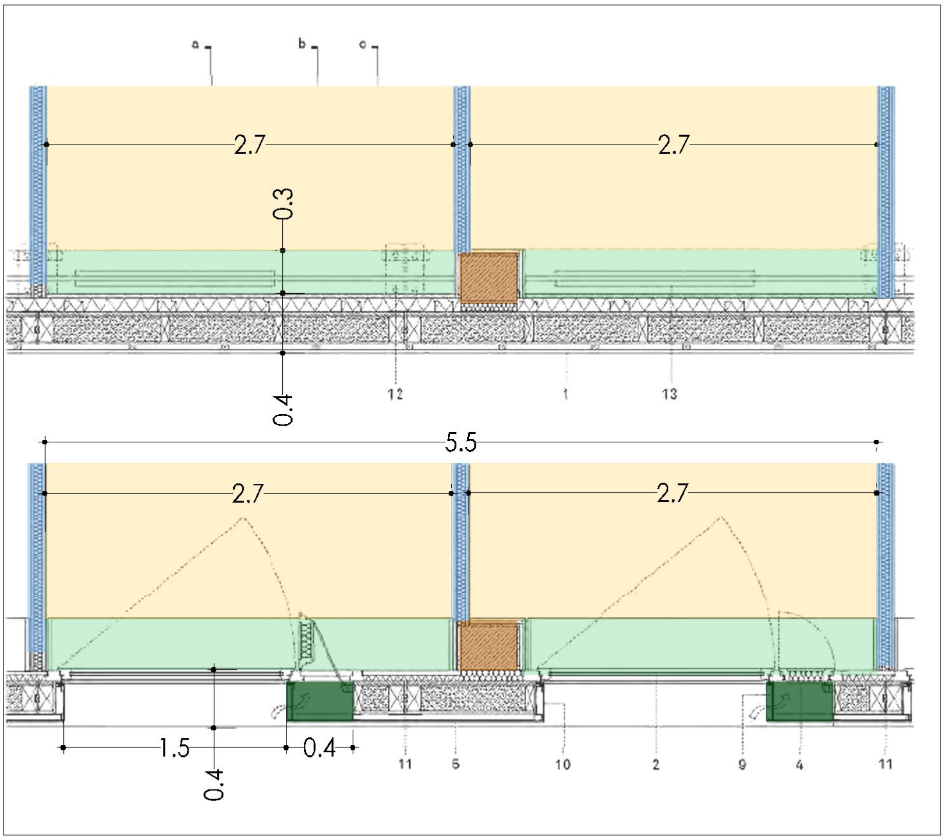
Exterior facade - Interior elevation - Scale 1:200

- Sprandrel larch cladding
- Glass panel
- Timber - framed window - openable
- Window for night cooling
- Office cellar
- Structure - 5.5m grid
- Interior partitions

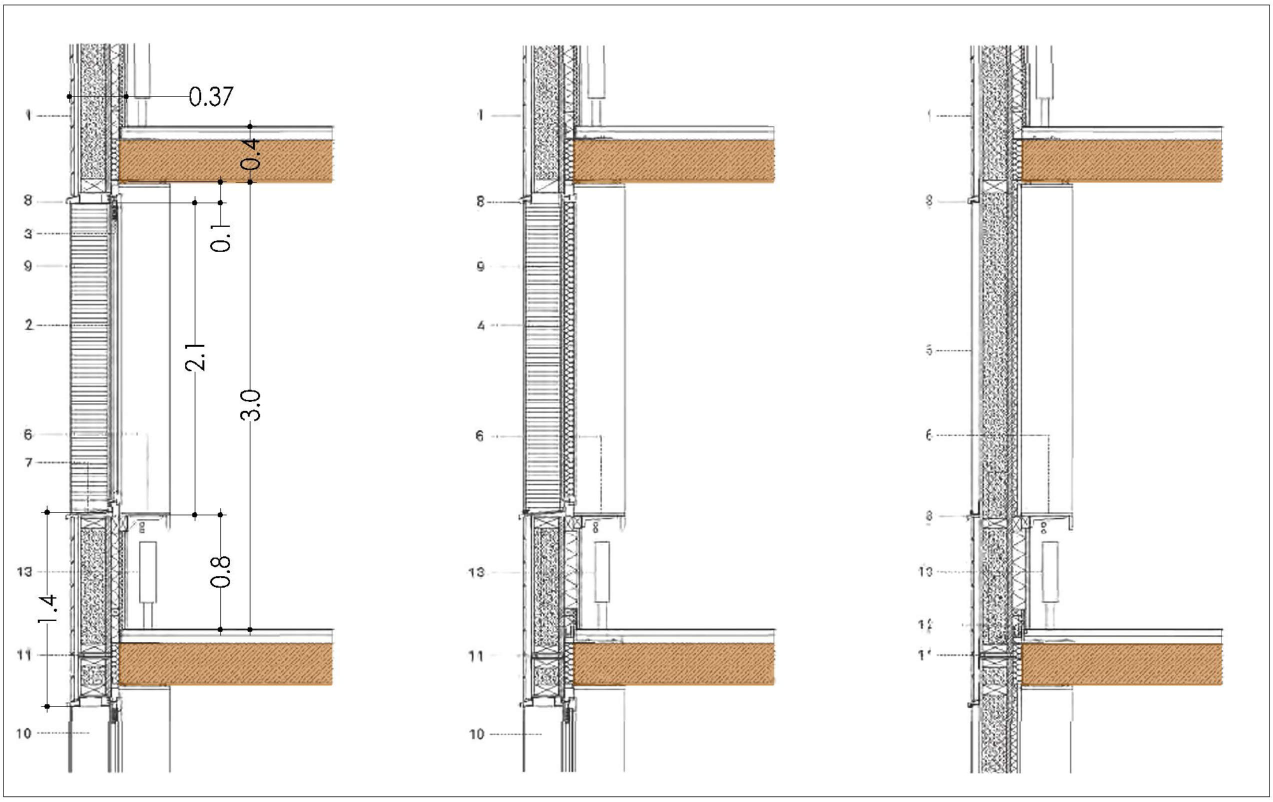


Exterior facade - Sketch

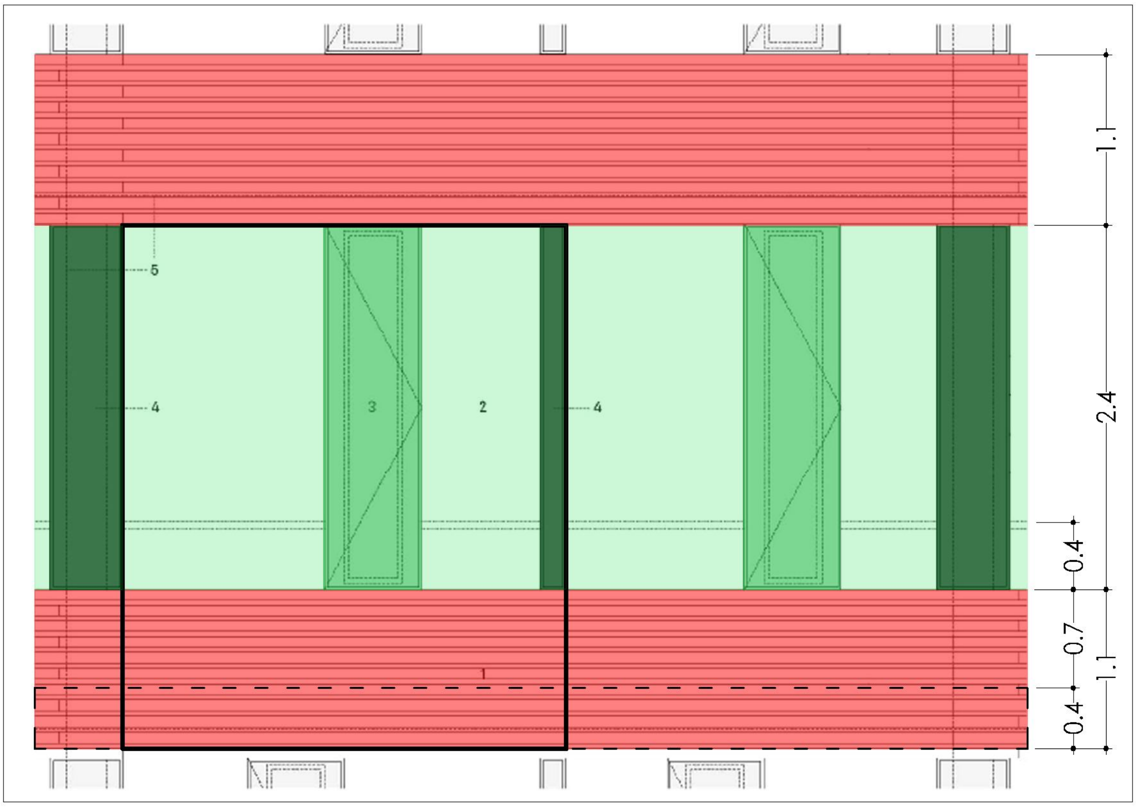
- Office space
- Perimeter zone
- Window for night cooling
- Structure - 5.5m grid
- Interior partitions



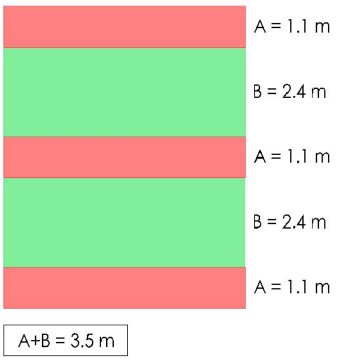
Exterior facade - Horizontal section - Scale 1:200



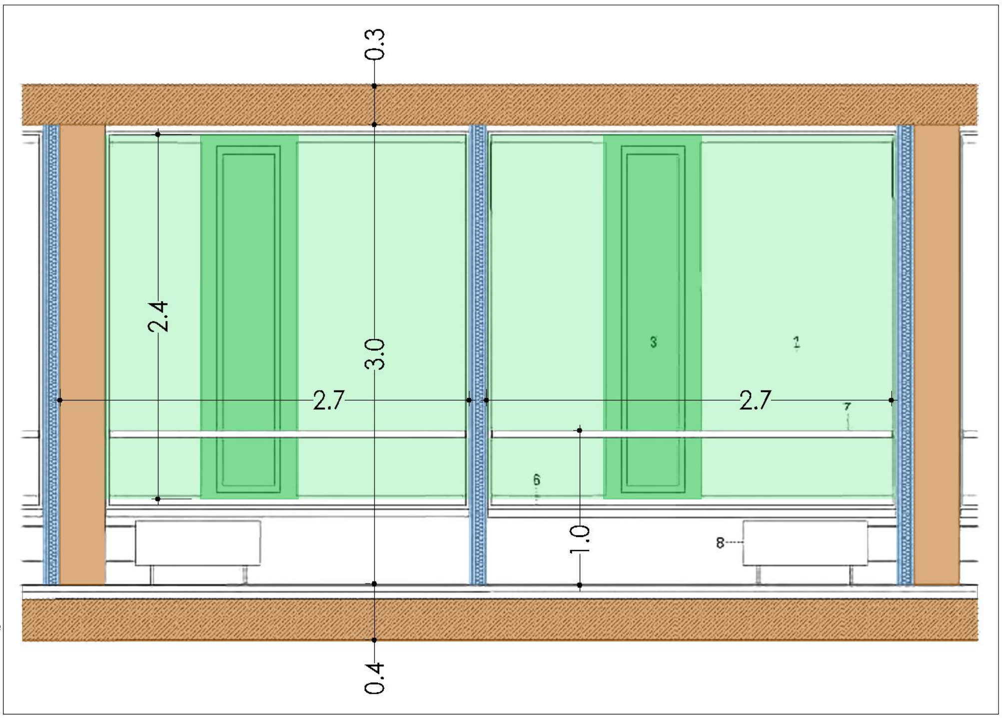
Exterior facade - Vertical section - Scale 1:200



Interior facade - Exterior elevation - Scale 1:200

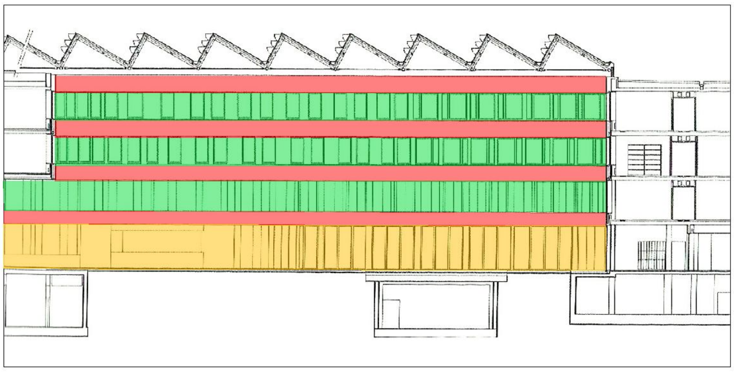


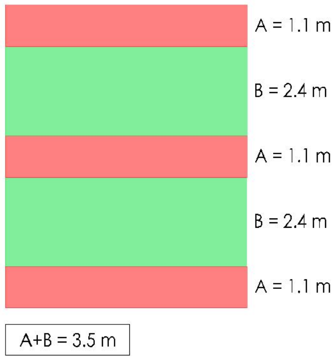
Interior facade - Sketch



Interior facade - Interior elevation - Scale 1:200

- Sprandrel larch cladding
- Casement window - openable
- Timber - framed window
- Glass panel
- Office cellar
- Structure - 5,5 m grid
- Interior partitions

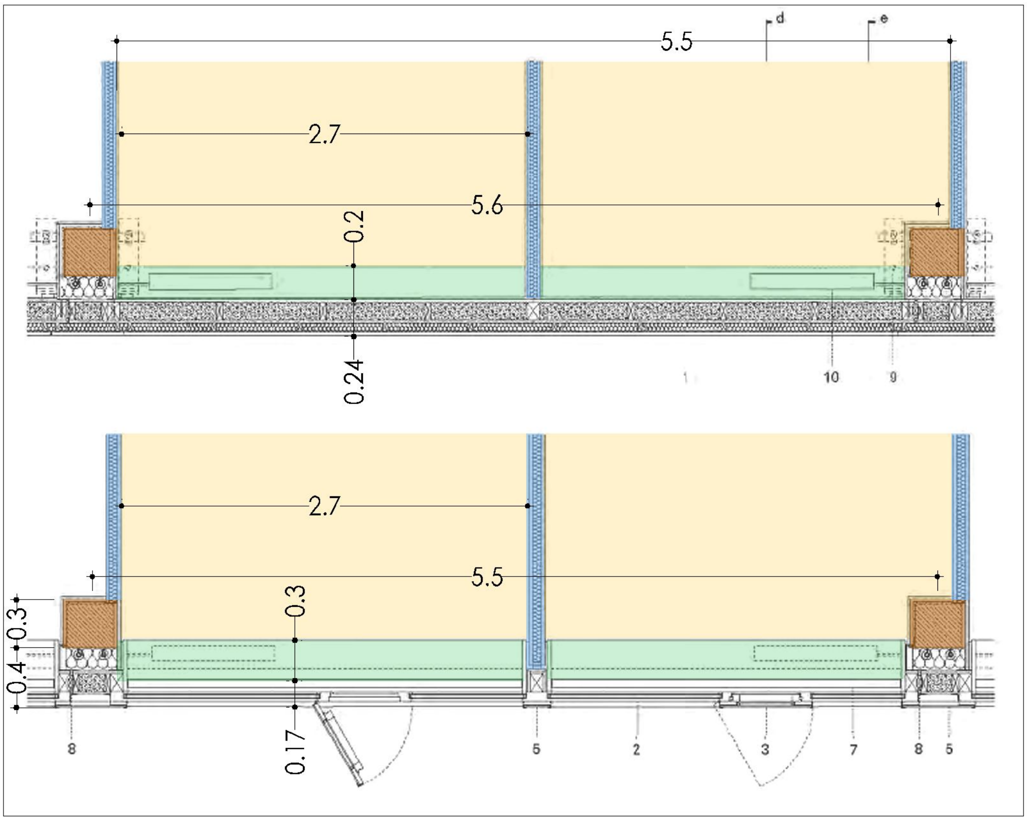




Interior facade - Sketch

Photo 1

Photo 2 [4]



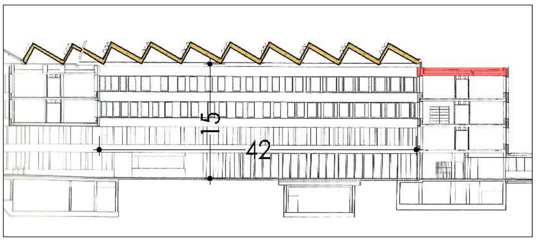
Office space

Perimeter zone

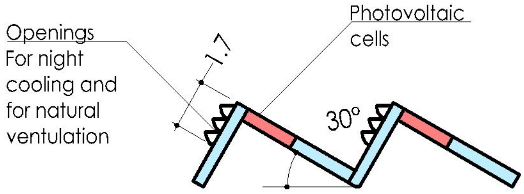
Structure - 5.5m grid

Interior partitions

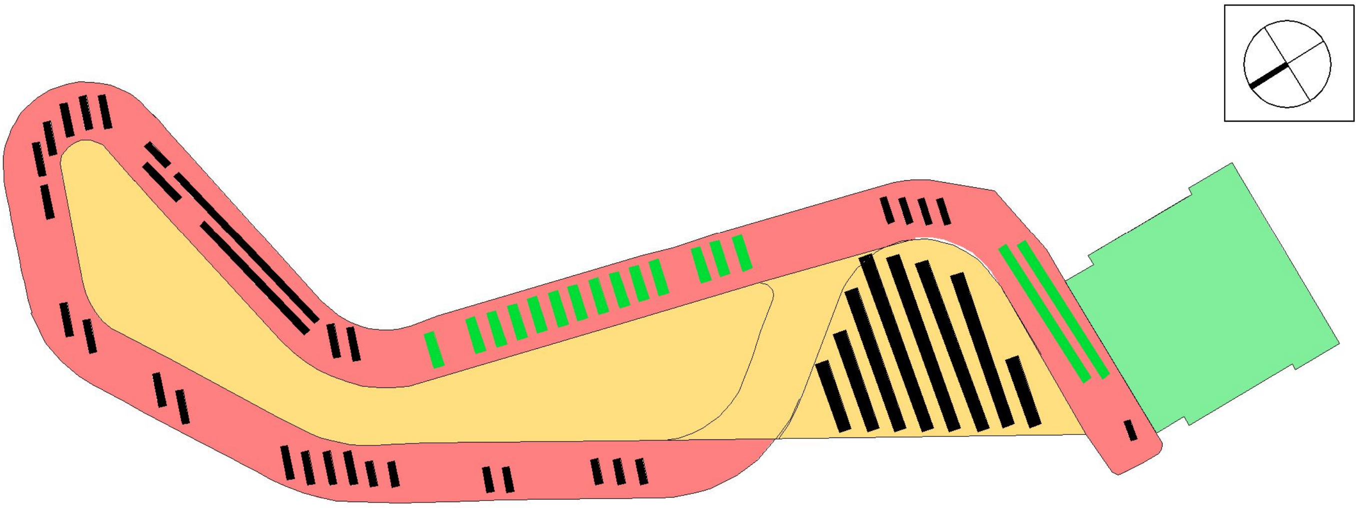
Interior facade - Horizontal section - scale 1:200



Roof - Vertical Section



Sketch



Exhisting building

Horizontal roof - On top photovoltaics panels

Atrium and Forum roof - Transparent roof - Integration with photovoltaics

Photovoltaic panels

Solar panels

Forum

Integration with photovoltaic cells

8. Energy concept and Systems

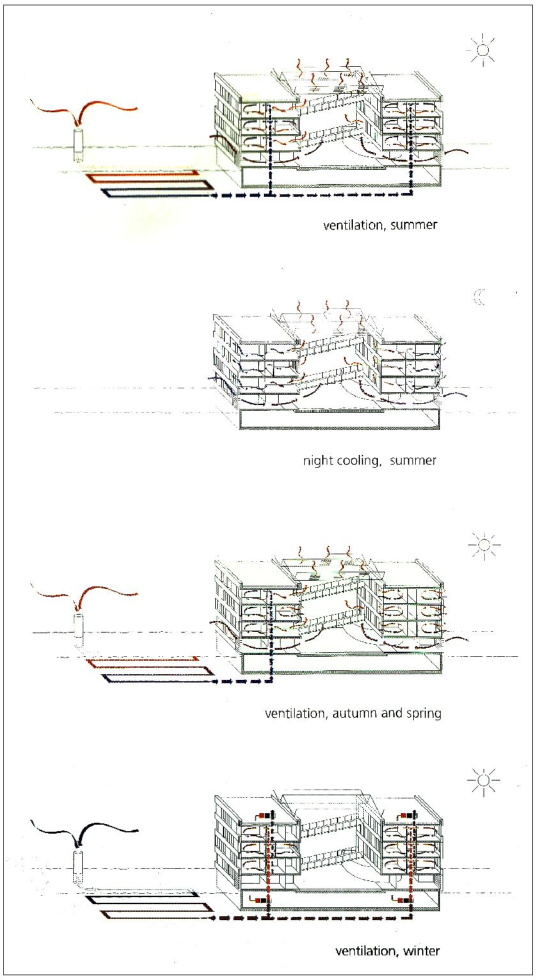
Heating/Cooling and Ventilation: Heat is distributed through panel radiators with thermostat valves and a mechanically ventilation is provided into the offices. When outdoor temperatures are low or high, the supply air in the building is conditioned/heated by an earth-to-air heat exchanger. The geothermal heat exchanger is made by horizontal pipes of 5Km length with 4 field on West and South sides. The exchange of energy is between the ground and the air that takes place through the intake structures (height=3-4m) and passes into the pipes. Before entering in the office, air passes via the air-handling unit and trough some filters. Night cooling during summer is also provide.

H) Protection from noise pollution → Mechanical ventilation during working hours for the West offices;

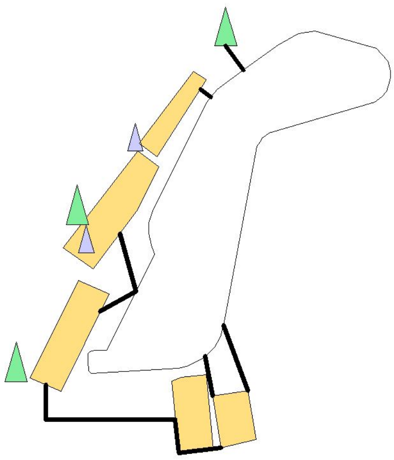
I) Integration with renewables → Earth-to-air heat exchanger composed by collecting pipes (diameter=150cm, reinforced concrete block) and grid pipes (smaller, distance between pipes=1m, propylene) positioned 2.50-3.7m above the ground;
Biomass production;
Energy from gas wastes.

Electricity and Service hot water:

I) Integration with renewables → Solar thermal collectors on top to produce hot water;
PV panels on top (354m², 2kWp, Energy Production= 24.1kWh/m²a).



Energy concept [3]


Sketch



Intake structure and pipe

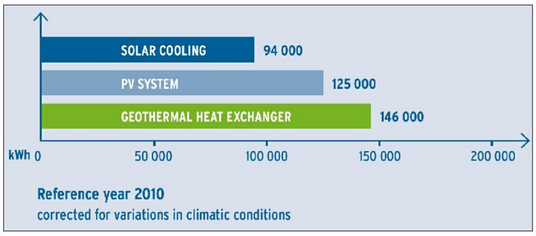
9. Environmental startegies

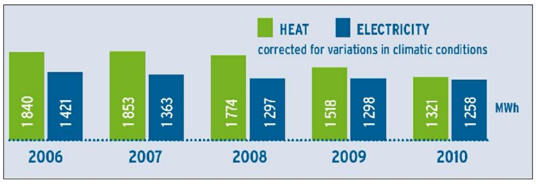
Comprehensive conceptual analyses and simulations with the aim of achieving the ecological goals characterized the planning process. An ecological specification document was the basis for this. Expert committees advised the client and the planners regarding efficient energy use, the use of ecological building materials, soil protection, indoor air hygiene and many other topics.

A) Connection with the context →	Renovation of an old industrial area; Increasing the public transport and the use of bicycles (Bicycle parking=367); Accessibility for disabled persons;
G) Ecology of building materials →	Untreated wood and glass for the entire building;
I) Integration with renewables→	Geothermic; Biomass production; Energy from gas wastes; Active solar systems.

10. Monitoring of performance

Monitoring of the environmental impact of the geothermal heat exchanger, monitoring of consumes.
Primary Energy covered for the 15% from renewables.





Monitoring tables [8]

References

1. FORMAT2. Xella. July 2006.

2. HASCHER, R, JESKA, S. and BIRGIT, K. Office Buildings. A design Manual. Berlin, Birkhäuser, 2002, pag. 132-135.

3. HERZOG, T. Uffici sostenibili. Architetture premiate in Europa. Bologna, Proctor Edizioni S.p.A., 2009, pag. 10-19.

4. www.cbe.berkeley.edu/research/facade-symposium.htm. [Online]

5. www.christopherjdoherty.com. [Online]

6. www.enob.de. [Online]

7. www.sauerbruchhutton.de. [Online]

8. www.umweltbundesamt.de. [Online] + Brochure by UmweltBundesAmt

1. Scenario

Cucinella Architects designed for the Italian lighting manufacturer "iGuzzini Illuminazione srl" a new office in addition to the existing building in the industrial district of Recanati (IT). The building becomes the symbol of a new kind of architecture in Italy where the maximization of daylighting and natural ventilation become promoter of the architectural design.

2. Building description

General Description: The building is a 4-storey rectangular office with a core atrium with overall dimensions of 40x19,3m, linked to the adjacent existing building.

Goals: A) Connection with the context; B) Reduction of heating demand; C) Reduction of cooling demand;
D) Maximization of daylighting; E) Protection from glare and sun radiation; F) Maximization of natural ventilation;
L) Optimization of operations.

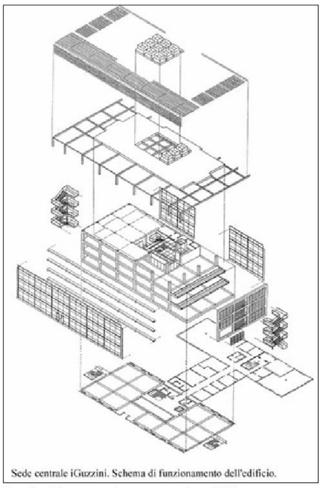
Key aspects: Atrium, Daylight planning, Façade design, Passive strategies to improve the natural ventilation, Night cooling, Optimization of operations.

Data:
Number of floors: 4
Number of floors above the ground: -
Gross Volume: 10000m³
Heated Volume: 7760m³
Gross Floor Area: 2700m²
Heated Gross Floor Area: 2330m²
Net Floor Area: Ground floor=1st floor=580m² Atrium: 200m²
Usable height: 3m
Workplaces: 120
Working hours: 9h
Total investment cost: 1550€/m²
Total mechanical installations cost: 125.3€/m²

Time: Inauguration: 1997

Awards: 1999 Eurosolar, Italian Solar Award
1999 Metra "Sistema D'Autore" award for the facades

Experts: Architecture: Cucinella Architects;
Statics: Stefano Sabbatici
Environmental strategy: Alistair Guthrie, Ove Arup & Partners



Building elements [3]

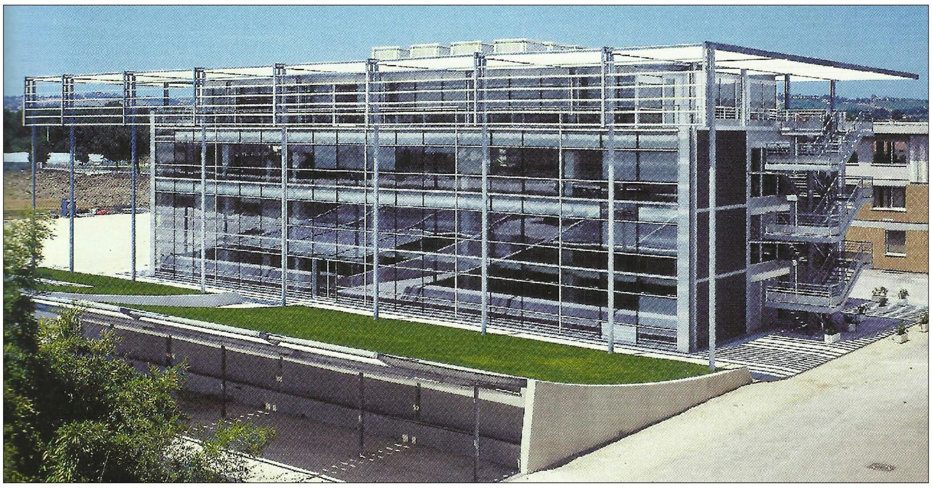


Photo [2]

Masterplan

3. Climate data

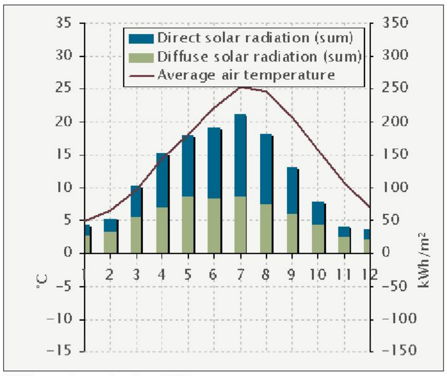
Latitude: 43°23' *Longitude:* 13°33' Altitude: 296m

Description: Recanati has a Mediterranean and continental climate;

Winter: Usually quite cold and rainy with possible fog;

Summer: Hot and sunny;

Winds: Cold winds from the North. Prevailing winds from North/West.



Climate data [9]

4. Site location and site quality

Site location: Via Mariano Guzzini, 37 and Strada statale 77, Recanati (IT)

Site quality: Industrial district subject of a requalification plan, in the suburbs of Recanati;

Nearby Buildings / Position and Morphology: The building is an addiction to the existing one and it belongs to the industry area, positioning on the North/East side. North: Existing block, car-parking and main street; South: Garden with the main entrance and street for the internal circulation in the industrial area, West: Office building, East: secondary street and warehouses.

Vegetation / Position and Typology: North: trees for shadowing the car park, South: small trees that divide the street and create a dedicated space.

5. Orientation and shape

Orientation: Main axis East/West with an angle of about 21° from the North.

A) Connection with the context → The block has the same orientation of the existing building;

D) Maximization of daylighting + F) Maximization of natural ventilation → Orientation rotated of an angle in order to dispose the main fronts perpendicularly to the prevailing winds and have an approximately exposition South/North.

Shape: A/V = 0.23m²/m³ => Compact; Rectangle shape (≈40x19.3x13m) with a core rectangular atrium covered by a transparent roof.

6. Internal Layout

Office Spaces: Combi-office, with cell and open-space layout with high flexibility and hierarchical distribution (top floor smaller than the other storeys with terrace and more space dedicated to workers, this because it accommodates the management offices, while the first three floors house the administration offices).

Services (break areas, toilets, technical spaces): Services are located in the North position at every level, close to the conjunction with the existing block;

Meeting room/Conference room/Video conference: Small meeting rooms distributed each floor with the biggest to the ground floor. They are close to the atrium on West and East sides.

Connections: Vertical connections are located on North side, close to the atrium and on East and West sides on external position; horizontal connections as double strips of corridors that link the zones.

Atrium: Central location with a full-height and a Japanese garden with bamboo.

D) Maximization of daylighting → Transparent atrium roof, glass staircases, light colors and large surfaces for the windows overriding to diffuse the daylight;

F) Maximization of natural ventilation → The dimension is 13x6m with the longer front located perpendicularly the main direction of winds in order to increase the air motion thanks also the introduction of skylight-shaped chimneys.

7. Structure and Envelope composition

Structure: Reinforced concrete with regular grid 6-7x5-7m;

Floor: Concrete floor slab with floating floor;

Facade: Curtain wall on North and South fronts and stone cladding façade on West and East sides.

B) Reduction of heating demand → Low-e glazing for the curtain wall;
High thermal insulation for the opaque facades (U = 0.7W/m²K) that have the following composition: gypsum + aerated block + air + aerated block + insulation material + stone cladding;

C) Reduction of cooling demand → Opaque wall for East and West facades that work as thermal mass;
Night cooling thanks two parts of the façcade openable automatically;

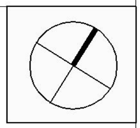
D) Maximization of daylighting → North and South fronts are transparent;
In the upper part, a horizontal shelf reflects light on the ceiling to maximize the illumination of the room;
Daylight factor with covered sky between 6.1-10.3% and 5.7-10% (if roof shadowing), with sunny sky 7.4-13% and 7.4-12.7% (if roof shadowing);

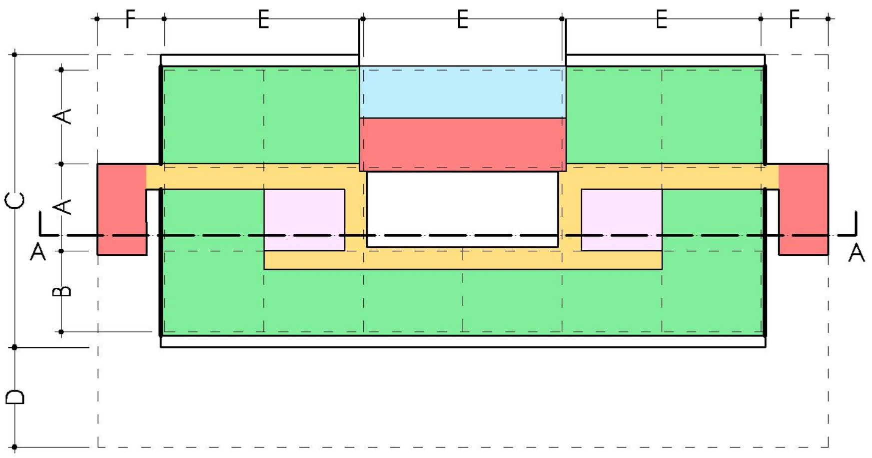
E) Protection from glare and sun radiation → East and West fronts that are usually more difficult to control, are opaque;
Internal blinds for the offices close to the atrium;
For the South facade, there is an aluminum external structure (H=3.7m x L=6.7m) with horizontal louvers (space between slats=40cm). They have been designed considering the 21st June.

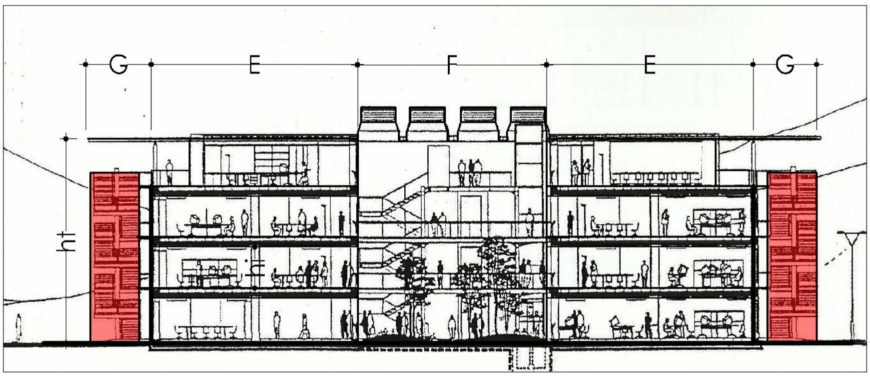
F) Maximization of natural ventilation → South and North facades have two strips openable automatically.

Roof:

D) Maximization of daylighting + F) Maximization of natural ventilation → Core atrium with transparent roof constituted by skylights;
Turrets with aerodynamic geometry (they increase the air velocity) and vertical openings that contribute to the natural ventilation;







A=6m; B=5m; C=19m; D=6.6m;
E=13m; F=4.2m; hi=3.3m; ht=13.5m

- Offices
- Vertical connections
- Horizontal Connections
- Toilets
- Meeting rooms

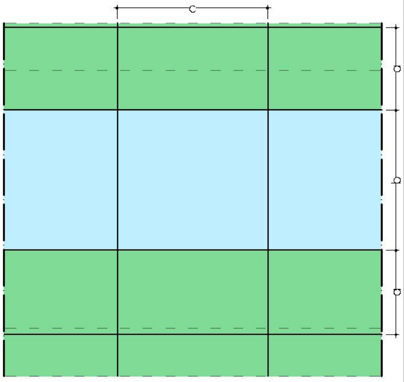
Internal layout and Section A - Scale1:500

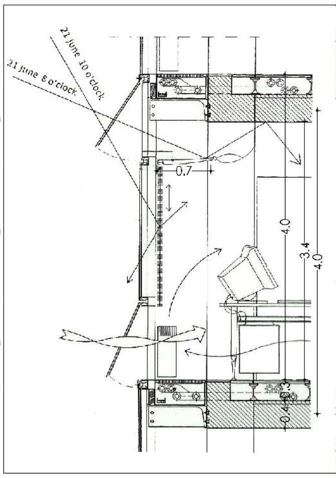
Photo 1 [3]

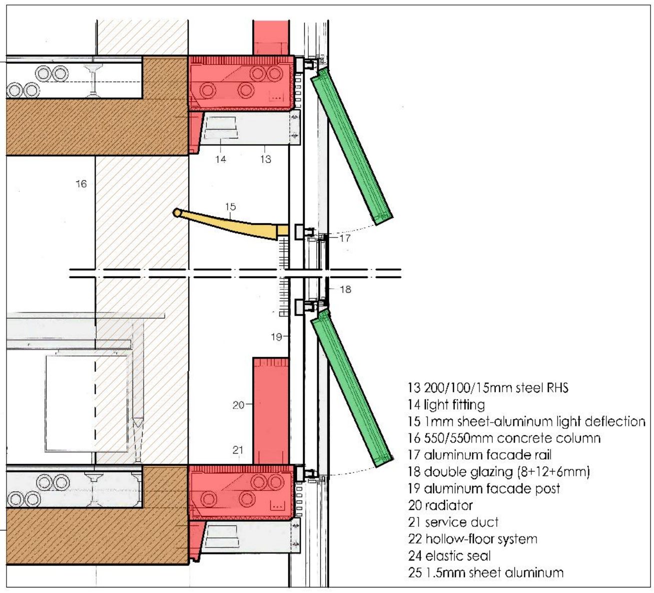
Photo 2 [4]

Photo 3 [2]

a=1.1m; b=2m; c=2m;





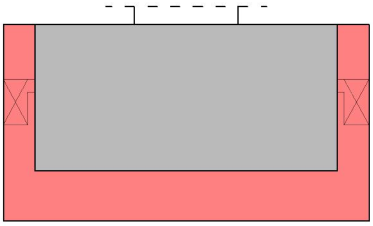


Openable part (automatically)

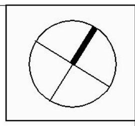
Systems | Structure | Window | Shelf

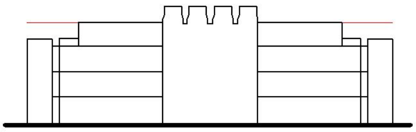
Curtain Wall - Skecthes - Scale 1:100

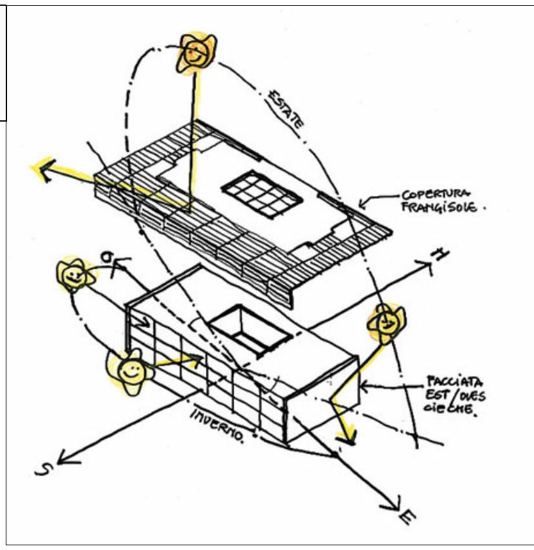
Curtain Wall - Section- Scale 1:50



South facade - Anti-sunscreen







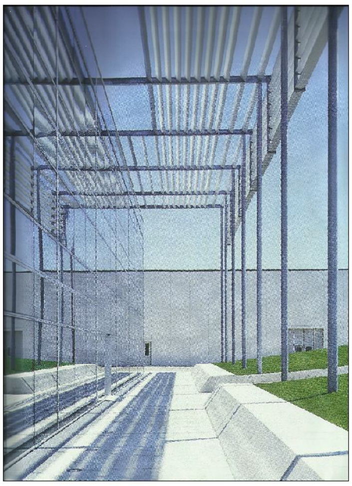
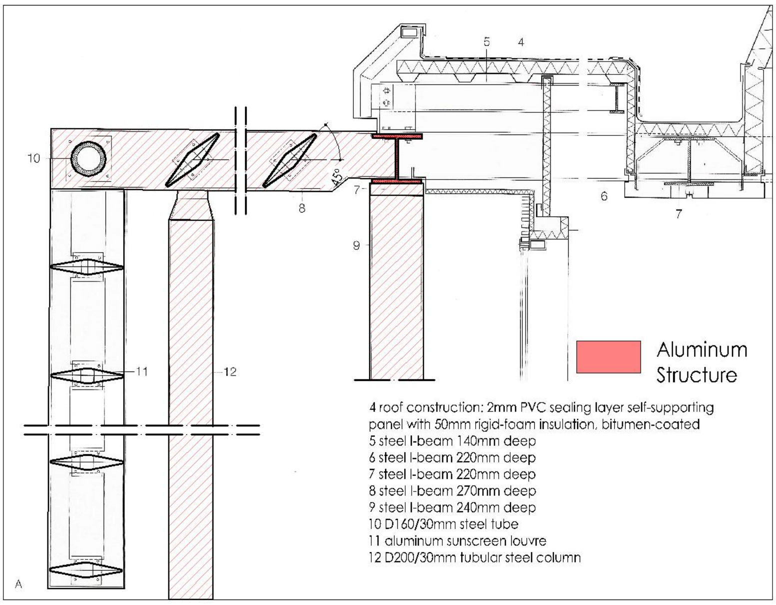
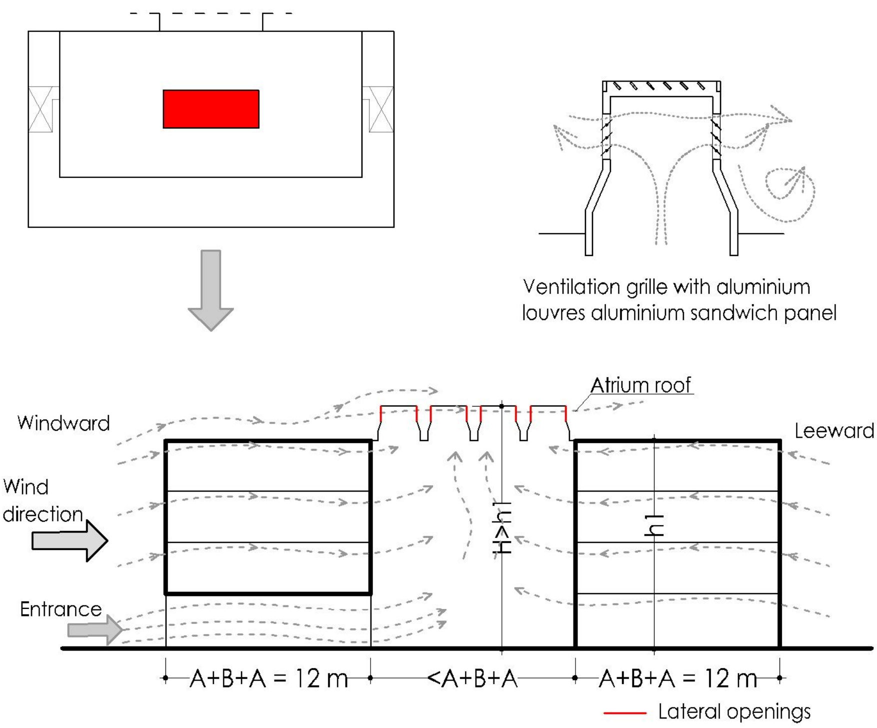


Photo 1 [2]

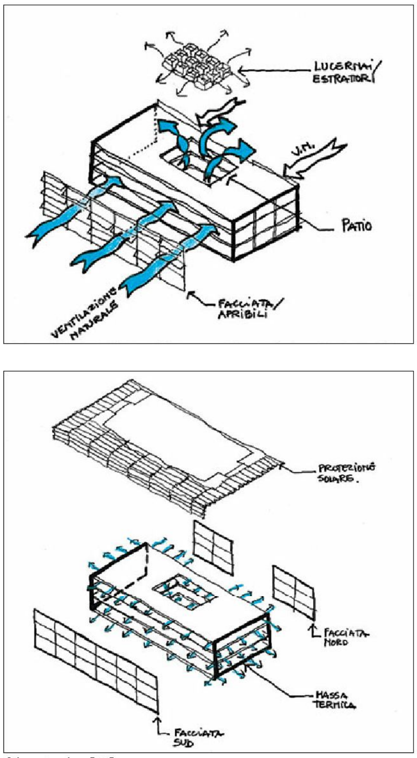
Photo 2



Horizontal Louvers for the South fronts [3]



Passive design strategies to increase the air circulation



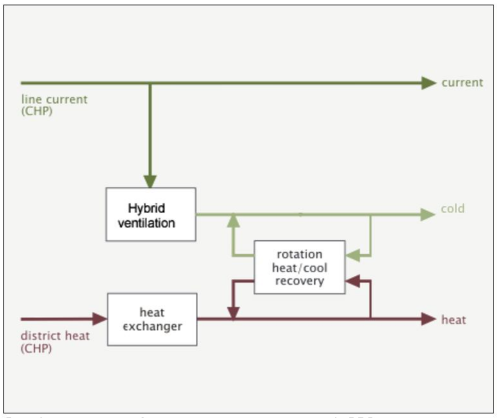
Sketch [1]

8. Energy concept and Systems

Heating/Cooling and ventilation: Four-tube fan-coil system is used to warm and cool the spaces during winter and summer seasons. The control system allows the building to operate depending by the period/time, the external weather conditions and the temperatures.

A hybrid ventilation system is provided: Natural ventilation is realized through the stack effect generated into the atrium; fresh air from the open windows into the offices (upper part of the curtain walls) goes through a louver located on the highest part of the partition panel (partition between the open-space and the atrium) and rises to the turrets (atrium). During the occupied period all the high-level louvers are open (5cm); while in the nighttime, all lower level louvers are open in the maximum position of (25cm) if Ti>17.5°C and if wind speed is <4m/s (otherwise louvers are closed). Instead, when Ti<20 °C or Ti>23°C the building operates also under a mechanical mode which activates the fan coil system. In addition, users can adjust the local temperature level in a range of ± 3°C around the values of 20°C and 23°C, in order to have their own control on thermal comfort. Above the atrium, the twelve skylights (2.8m high) have adjustable grills that open/close depending the required airflow. The total area of openings in the skylights is equivalent to half the total opening area of office windows.

Lighting: The design of the building with the northern and southern transparent facades provides the use of natural light within the offices. The shading devices ensure good daylighting levels. Light is also brought into the building through the central glazed atrium. In the open-space artificial lights are installed to reach 300-500 lux for the workplaces. They represent the 30% of the electrical energy consumption.



Systems and energy concept [9]

9. Environmental strategies

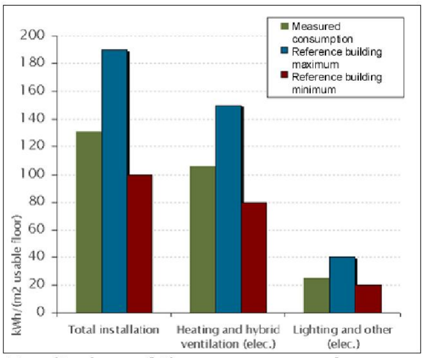
The building represents the loyalty of the iGuzzini Company versus the topic of the sustainability.
The building is low-energy and integrates renewables trough passive strategies with a particular attention to the maximization of daylighting and natural ventilation. The project constitutes one of the main representative examples in Italy of green buildings.

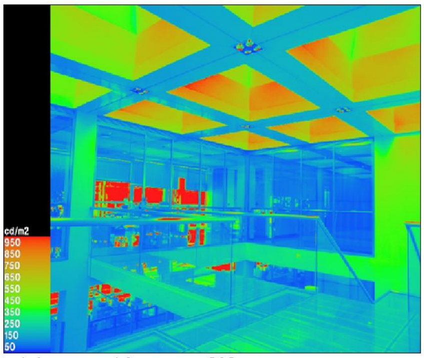
10. Monitoring of performance

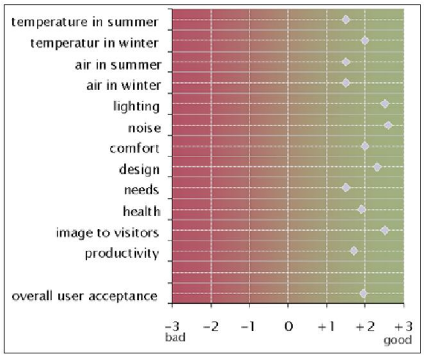
Monitoring of the energy performance: The total energy consumption was monitored for 1 year (August 1998 - July1999). The annual delivered energy consumption is 130.4kWh/m²a; the mechanical installation for the heating system and the hybrid ventilation is 105kWh/m²a; for lighting is 25kWh/m²a.

Monitoring of the interior visual comfort: Good distribution of luminance on surfaces, also into the depth of the rooms (Location: Atrium 4th floor, the view is of south-facing facade; sky condition: sunny day with direct sun on facade). The skylights louvers on roof diffuse daylighting.

User acceptance: The natural ventilation is expected as the 55% of the total; despite after the dissatisfaction of the users, a mechanical mode is improved and different temperatures ranges are selected. The average vote is 1.96 which means a good evaluation, in particular the office building thus rates well on productivity, occupant control, a very good lighting quality and air quality (as shown the responses of the occupants voting on a seven-point scale from bad (-3) to good (+3)).







Monitoring of the energy performance - Tables and image [9]

References

1. HASCHER, R, JESKA, S. and BIRGIT, K. Office Buildings. A design Manual. Berlin, Birkhäuser, 2002, pag. 132-135.
2. HERZOG, T. Uffici sostenibili. Architetture premiate in Europa. Bologna, Proctor Edizioni S.p.A., 2009, pag. 10-19.
3. Detail. Solar Architecture. Strategies, Visions, Concepts. Germany, Christian Schittich Ed. Birkhäuser, 2003, pag. 118-123.
4. www.ediliziainrete.it. [Online]
5. www.europaconcorsi.com. [Online]
6. www.iguzzini.com. [Online]
7. www.mcarchitects.it/project/sede-direzionale-iguzzini. [Online]
8. www.mxstudio.eu. [Online]
9. www.new-learn.info. [Online]
10. www.theplan.it. [Online]

1. Scenario

Immersed in a green area and renovated zone of Milano, "FIN.ZETA Fondo Pensioni Siemens" commissioned two square administration buildings (52000m²) to accommodate offices for various companies.
Certified LEED-CD (core and shell), the buildings pursue sustainable criteria offering one example of high performance building in Italy.

2. Building description

General Description: Two buildings of 10-storey characterized by a square shape with an open atrium, a flexible organization of the interiors that can accommodate 187-230 workplaces each floor and a hall at the ground level.

Goals: B) Reduction of heating demand; C) Reduction of cooling demand; D) Maximization of daylighting; E) Protection from glare and sun radiation; F) Maximization of natural ventilation; G) Ecology of building materials; L) Optimization of operations.

Key aspects: Atrium, Daylight planning and optimized lighting, Heat recovery wheel, Optimization of operations

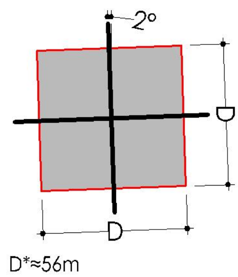
Data: Number of floors: 10
Number of floors above the ground: 3
Gross Floor Area (1 Floor type): 2650m²
Storey height: 3.25m
Usable height: 3m
Workplaces: 2000

Time: Inauguration: 2005

Photo [1]

Experts: Architecture: Arch. V. Benati & Arch. A.Gallo (Consultant: Prof. Stanke)
General Contractor: Maire Engineering S.p.a. - ex Fiat Engineering
Progetto VVF: STZ - Studio Tecnico Zaccarelli

Masterplan - Scale 1:5000



3. Climate data

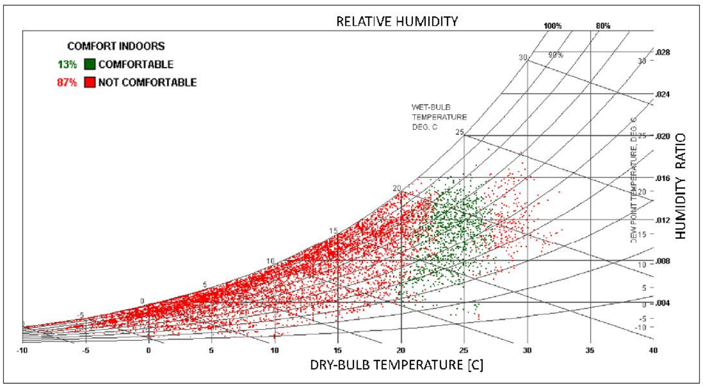
Latitude: 45.62° *Longitude:* 8.73° *Altitude:* 122m

Description: Milan is located in the Po Valley and this position gives it a semi-continental climate.

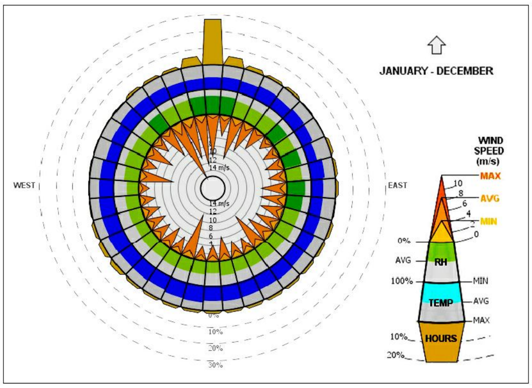
Winter: Quite cold.

Summer: Summers hot, humid and muggy.

Winds: Prevailing winds from North/West direction.



Psychrometric chart



Wind directions

4. Site location and site quality

Site Location: Via Spadolini 5/7, Milano (IT)

Site quality: New renovated area in Milano, in a residential zone, close to downtown and the university and retail zones.

Nearby Buildings / Position and Morphology: Buildings are integrated into the urban area; in 800m it is possible to find services and retail spaces (as church, bank, restaurants, market, etc.). Nearby multi-storey houses have square geometry or U shape or a core open atrium.

Vegetation / Position and Typology: The area is near the Park "Memorie Industriali" that is situated on North side. In addition, the external green spaces of the area are designed bigger than local standard (25% more) and local plants were selected (34%of the total green area) to have less maintenance and water need.

5. Orientation and shape

Orientation: Polar symmetry with axes North/South and West/East;
C) Reduction of cooling demand → Prevailing wind from North/West side. This orientation contributes to increase the wake in the leeward.
D) Maximization of daylighting → Best exposition of offices on North and South sides.

Shape: Square shape of the block with square core atrium.
B) Reduction of heating demand → $A/V = 0.32\ m^2/m^3$ => Compact.

6. Internal layout

Office Spaces: Combi-office layout with offices distributed along each side that guarantees a direct contact with the outside. Each floor could be split for separate tenancies and a high flexibility permits to have from 187 to 230 workstations for each floor.

Meeting room/Conference room/Video conference: In the exterior ring close to the entrance at every level and other spaces dedicated at the ground level.

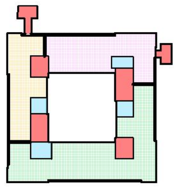
Services (break areas, toilets, technical spaces): Four groups of toilets and break areas located into the ring close to the atrium. Toilets are positioned at the corners and in a core position near the vertical connections. Technical spaces are distributed at the basement levels.

Connections: 6 groups of vertical connections with 4 positioned into the ring close to the atrium while 2 groups of staircases are external to the perimeter and are located in North and East sides. Core ring as horizontal connection.

Atrium: Core square open atrium. It looks as a garden and a public space.

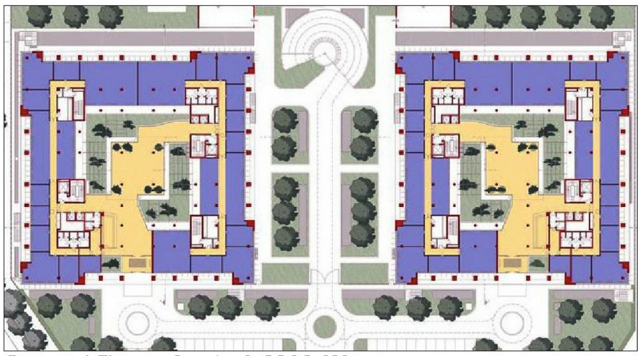
- Offices
- Break areas
- Vertical connections
- Technical spaces
- Horizontal Connections
- Toilets
- Meeting rooms, Conference rooms, etc.
- Entrance zone, reception, etc.
- Car park

A*≈6.3m; B*=1.8m; C*=2.4m; D*≈58m; E*≈27m
H=34m

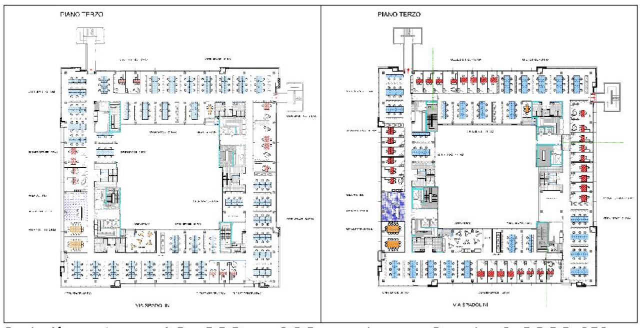


Typical division

Floor plan and Section A - Scale 1:1000



Ground Floor - Scale 1:2000 [3]



Solution A and B: 230 or 180 workers - Scale 1:2000 [2]

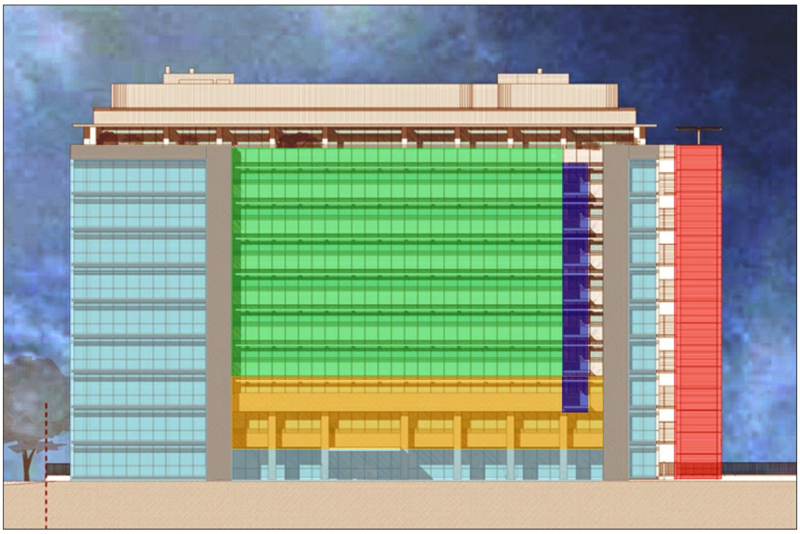
7. Structure and envelope composition

Structure: Reinforced concrete with regular grid of 8-10m;

Floor: Concrete slab with raised floor of 22cm;

Facade: Aluminum curtain wall with a module of 135cm + ventilated facade with stone cladding.
B) Reduction of heating demand → Double glazing for the curtain wall = 5+5/16/5+5 with high thermal insulation U = 1.30W/m²K;
H) Protection from noise pollution → Acoustic insulation for 42dB.
D) Maximization of daylighting → Large transparencies (WWR≈50%) and glazing with high VT=0.54;
E) Protection from glare and sun radiation→ Provision to the installation of interior tents; Curtain walls have exterior overhang louvers on the upper part of the windows.

Roof: Flat opaque roof.



North front

- 1/2 Opaque 1/2 Transparent (Glass)
- Transparent
- Vertical connections
- Opaque
- 1/2 Opaque 1/2 Transparent
- With Balcony

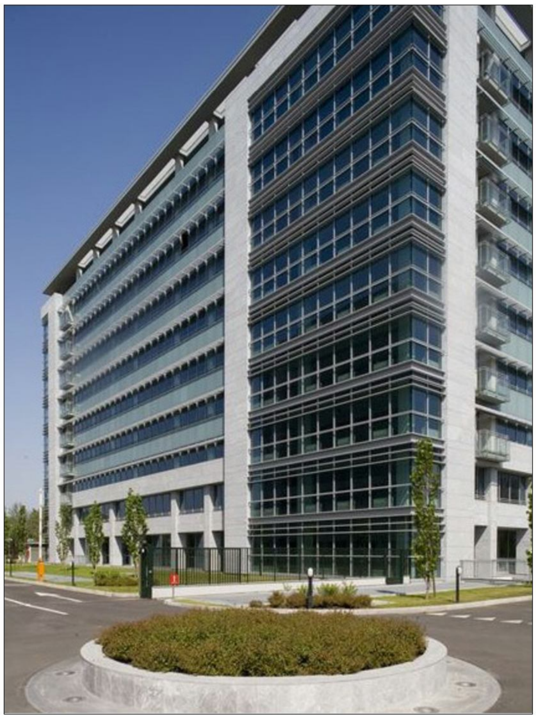
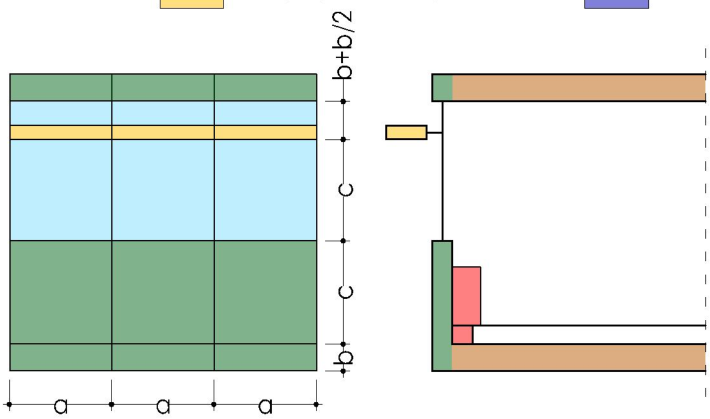


Photo 1 [1]



Facade scketches - Scale 1:100

- Overhang with louvers
- Systems
- Opaque part
- Structure
- Openable transparent part

a=1.35m; b*=0.35m; c*=1.5m;

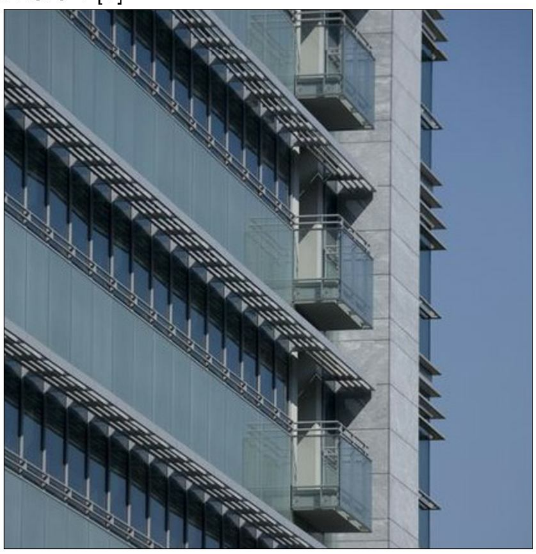


Photo 2 [1]

8. Energy concept and Systems

Heating/Cooling and Ventilation: Ventilation air system with heat recovery wheel that reduces of 10% the energy demand; 40m³/h per or 2vol/h are guarantee in the office spaces;

Lighting: Lighting with fluorescent lamps integrated into the false ceiling made by metal panels;

L) Optimization of operations → Safety control system and energy control system.

9. Environmental strategies

A) Connection with the context → External green area bigger than local standard with local plants that requires less water;
Promotion of low-emission car and electric cars with dedicated car parks (basement) close to the entrances;
Reduction of the heat island effect with car parks located into the 3 floors above the ground (170 moto, 643 cars);

G) Ecology of building materials → 10% of recycled materials: glass, steel and aluminum;
Concrete comes from the region;

No smoking zone for 8m around the building, with two external areas dedicated.

10. Monitoring of performance

No information.

References

1. www.archilovers.com. [Online]
2. www.centroleoni.com. [Online]
3. www.ordinearchitetti.mi.it. [Online]
4. www.tecnostrutture.eu/referenze/edifici-alti. [Online]

1. Scenario

Highly-praised building designed by Sauhercruch Hutton Architects and constituted by a office tower and a low-rise building that place beside the existing office of 17-storey (built during 1950s). Registered project at EXPO 2000, the GSW Haus (the largest housing association in Berlin) impressed the specialists for its urban planning, its architectural qualities and its sustainable energy concept. The complex consists in 24500m² of office and retail spaces (1700m² for businesses and gastronomic outlets), 900m² for special areas (conference zone, etc.), 163 underground car parks and a mechanical car parking system for 228 cars.

2. Building description

General Description: The building is a 22-storey office characterized by a curved rectangular shape positioned alongside the existing building with a base constituted by a 2/3-storey block dark colored that runs along Kochstraße. At the end of the low-rise building an oversized yellow/green 'Pillbox' is perched.

Goals: A) Connection with the context; B) Reduction of heating demand; C) Reduction of cooling demand; D) Maximization of daylighting; E) Protection from glare and sun radiation; F) Maximization of natural ventilation; G) Ecology of building materials; H) Protection from noise pollution; L) Optimization of operations.

Key aspects: Façade design, Sunscreen system and optimized lighting, Thermal mass, Free cooling, Natural ventilation, Sail structure, Optimization of operations

Data: Number of floors: 22 New Tower (17 existing building)
Number of floors above the ground: 1
Gross Floor Area: 50000m²
Usable height: 3.3m. It is determined by the height of the existing building because the buildings are linked at each level.
Gross construction cost: 94.6m €

Time: Competition: 1990
Construction and Inauguration: 1992-1999

Awards:
2003 Benedictus Award
2003 Bauphysikpreis
2001 Architekturpreis Beton (special mention)
2001 Mies Van der Rohe Award (finalist)
2001 World Architecture Awards (shortlisted)
2001 Deutscher Fassadenpreis
2000 Architekturpreis, BDA Berlin
2000 ar+d Award (high commendation)
2000 RIBa Award (shortlisted for Stirling Prize)

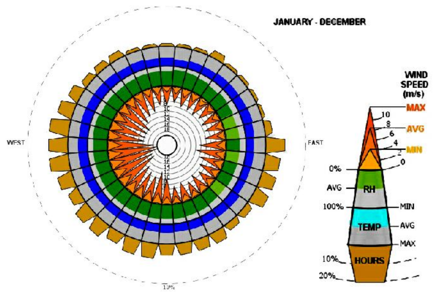
Experts: Architecture: Sauhercruch and Hutton

3. Climate data

Latitude: 52°31 Longitude: 13°25'

Description: Berlin has a temperate oceanic climate (Cfb Köppen classification) with a microclimate in the city of 4°C more than the surrounding areas. It has moderate rainfall throughout the year and light snowfall from December through March;

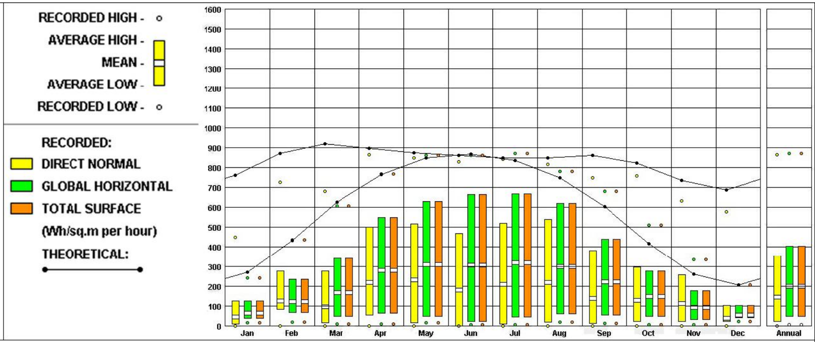
Wind directions and velocity



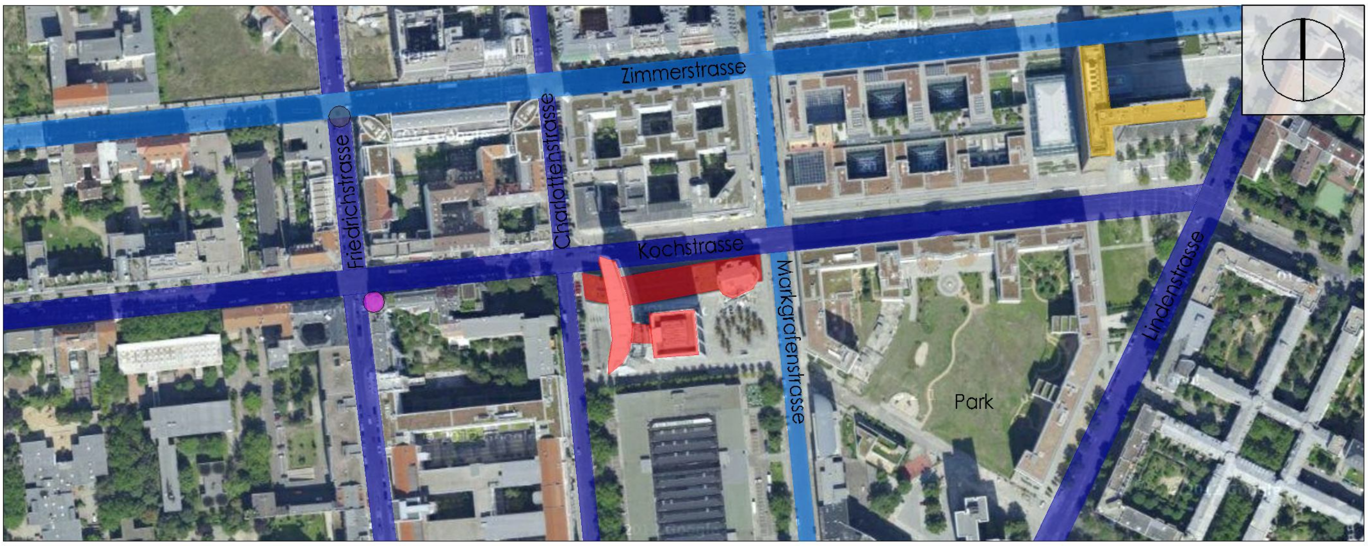
Winter: Winters are relatively cold with average high temperatures of 3°C and lows of −2 - 0°C;

Summer: Summers are warm and sometimes humid with average high temperatures of 22-25°C and lows of 12-14°C;

Winds: Prevailing winds from West direction.

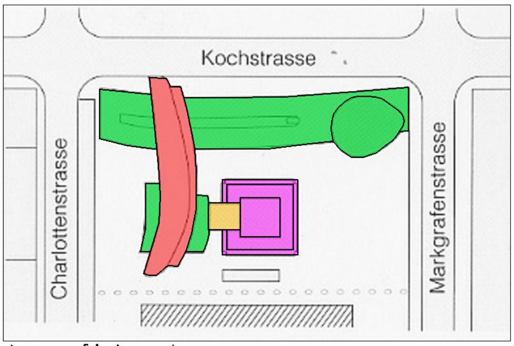


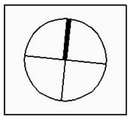
Solar radiaton range



Masterplan

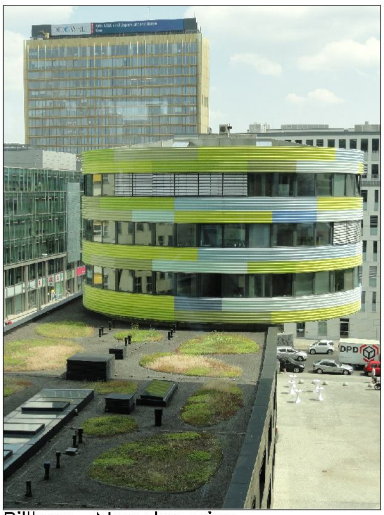
- Office building
- Main traffic stream
- Secondary traffic stream
- High-rise buildings
- Tube Station
- Check Point Charlie





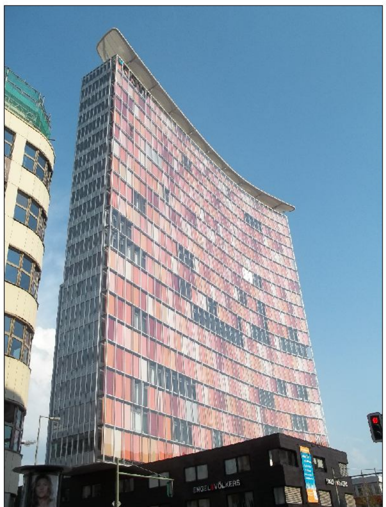
- New Tower
- Existing Tower
- Pillbox - New low rise

Area of interest



Pillbox - New low rise

Existing Tower [4]



New Tower

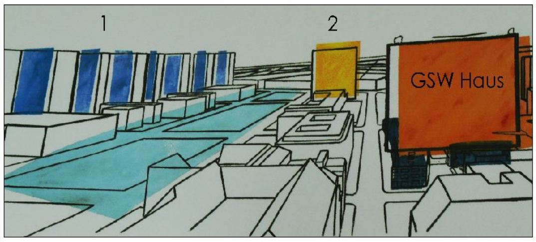
4. Site location and site quality

Site Location: Charlottenstraße 4, Kreuzberg, Berlin (DE)

Site quality: Renovated area of Berlin after the reunification, it is located in the district of Kreuzberg, closed to the shopping street of Friedrichstrasse and to the Checkpoint Charlie.

Nearby Buildings / Position and Morphology: On East position the building is directly linked with the '50 tower and its height changes the skyline of the zone talking to the other multi-storey buildings of Springer and Ullstein. The surrounding buildings are low-rises with various shapes, with the atrium one recurring;

Vegetation / Position and Typology: Plants are distributed within the atria and courtyards of the buildings;



Photos

5. Orientation and shape

Orientation: Main axe North/South with the main fronts with East/West exposition.

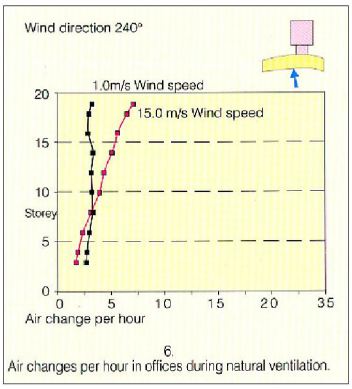
F) Maximization of natural ventilation→ Longest axe is perpendicular to the direction of the prevailing winds increasing the wake in the leeward side;

Shape: Parallelepiped with aerodynamic morphology: the floor plan geometry obtained is a curved rectangle.

D) Maximization of daylighting → Limited depth of the block (11.5m) with biggest transparencies on facades and into interior partitions;

F) Maximization of natural ventilation → Curved shape to create vortex;
Curved angles that increase the wake in the leeward side;
Limited depth of the building for the cross ventilation.

Prevailing winds [2]



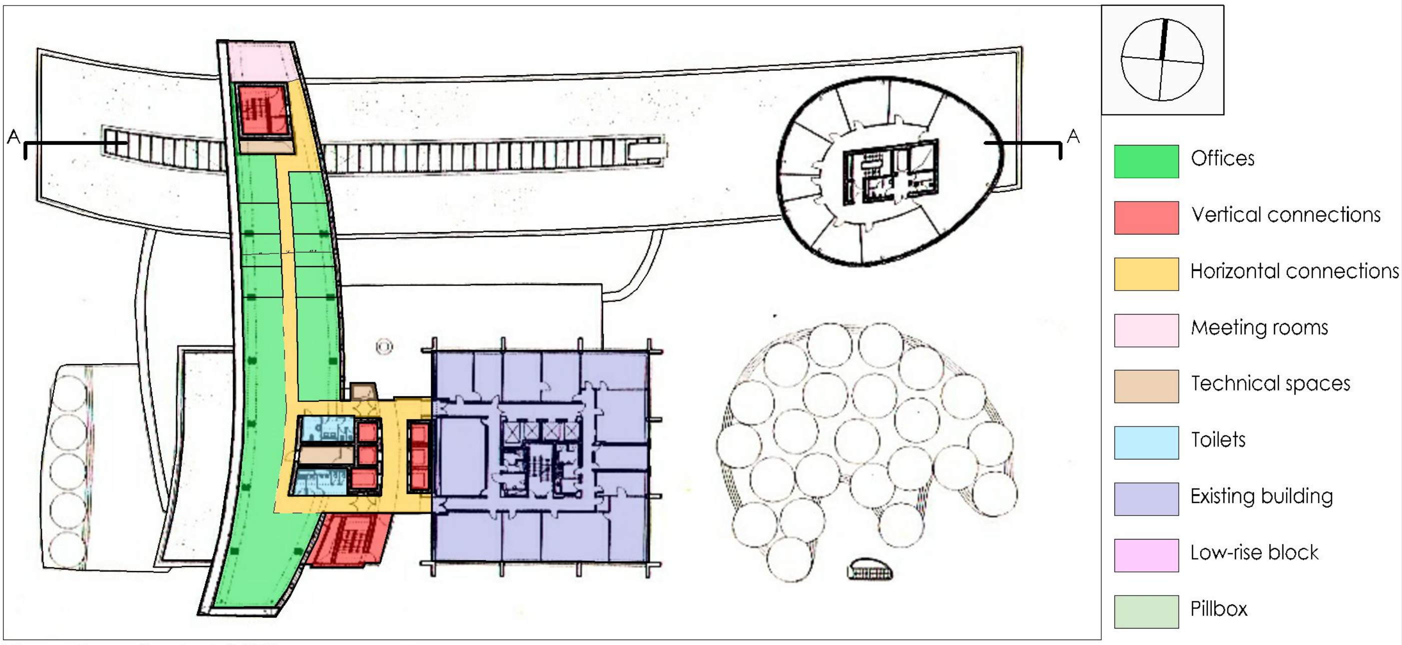
6. Internal layout

Office Spaces: Combi-office layout with open offices mixed to cellular ones with a flexible layout: GSW shares the office and the retails space with other users that can choose the internal layout;

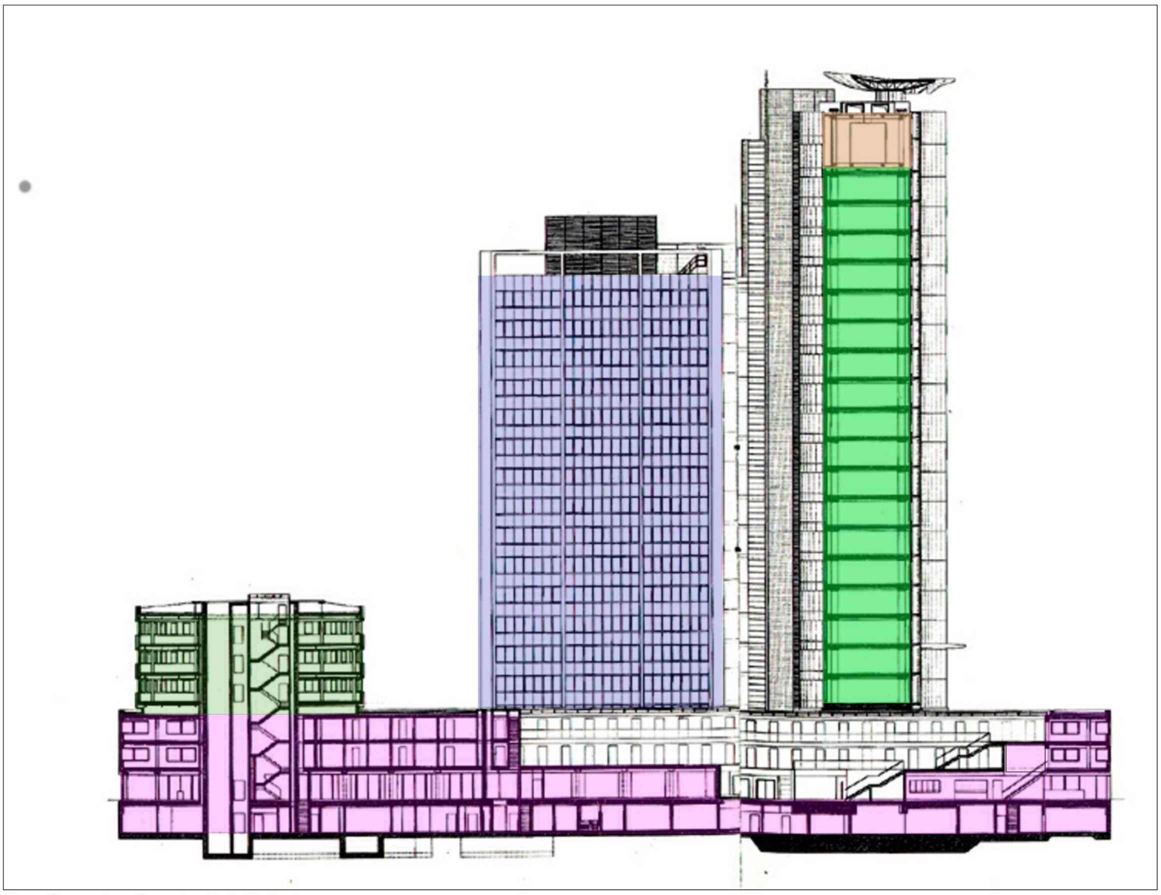
Meeting room/Conference room/Video conference: They are disposed in the North position and in the low-rise block.

Services (break areas, toilets, technical spaces): They are grouped with the vertical connections in the North part and in the core position in correspondance to the connection with the old block. Lobbies and other common spaces are disposed in the low-rise block. While two level of technical spaces are disposed on the last two floors.

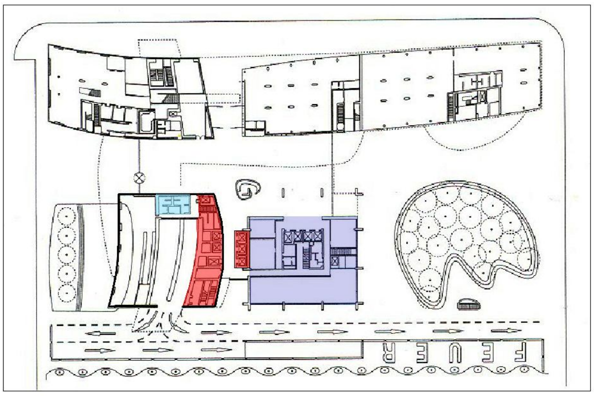
Connections: Vertical connections are located in the North and in the core connection between the two towers while a central corridor (axe North/South) shares the double strips of offices.



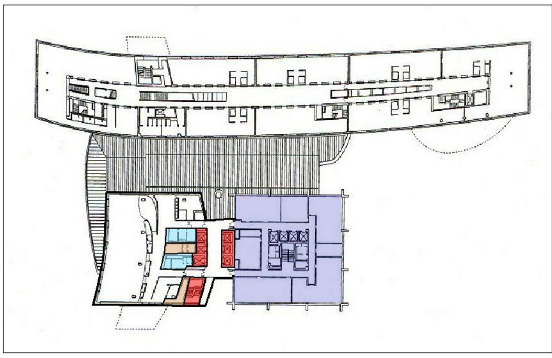
Floor plan - Scale 1:1000

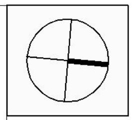


Section A - Scale 1:1000



Ground floor - Scale 1:2000





First floor - Scale 1:2000

- Offices
- Vertical connections
- Horizontal connections
- Existing building

Photo 1 - Interior

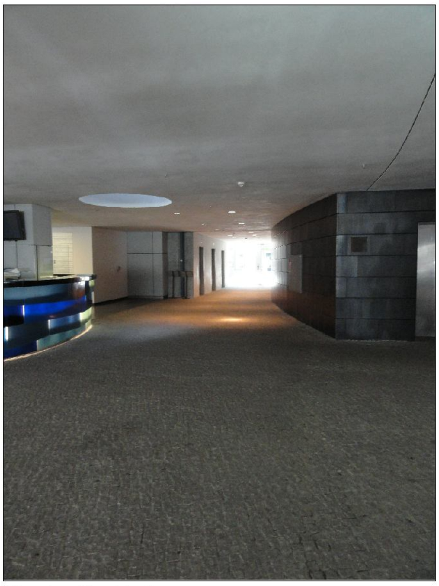


Photo 2 - Hall

Photo 3 - Low-rise block

Photo 4 - Office space

Photo 5 - Pillbox - Meeting room

7. Structure and envelope composition

Structure: Mixed structure: concrete and steel + two reinforced concrete blocks in correspondence to vertical connections and services. The two towers are structurally independent, while piles and diaphragms constitute the foundations.

Floor: Concrete slab with raised floor. Systems are integrated into the raised floor according to a small height imposed by the existing building.

B) Reduction of heating demand + C) Reduction of cooling demand → Thermal mass constituted by exposed concrete ceilings.

Facade: East and West fronts are double-skin facades with a different size of cavity (West:1m; East:0.20m).

B) Reduction of heating demand → High thermal insulation of materials: Uglass=1.6W/m²K, Uwall=0.3W/m²K; Buffer zones created by the two facades (hot air into the cavity);

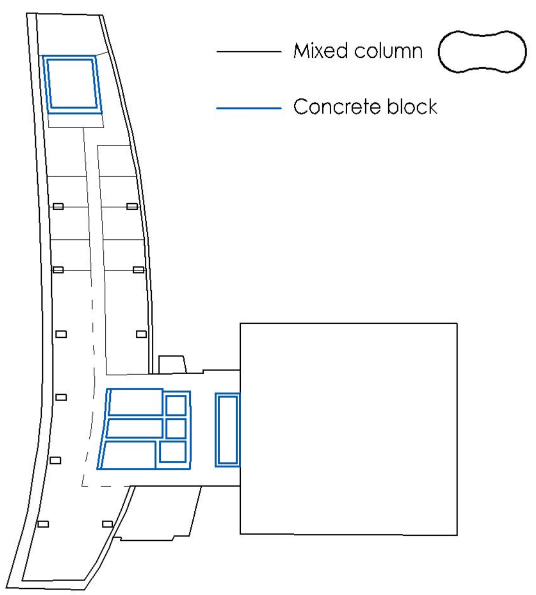
C) Reduction of cooling demand → Buffer zones created by the two facades (air circulates into the cavity); Nighttime cooling through the openings into the interior layer of the façade (ex. they cool the thermal mass of the exposed concrete ceiling);

D) Maximization of daylighting → Transparent facades on East and West fronts with also interior glass partitions to let in the sun radiation;

E) Protection from glare and sun radiation → West facade with vertical sun shading located into the cavity of the double skin. The user can regulate them and they contain the 18% of perforation guarantying the view from the inside spaces; East facade with slat blinds located in the space between the windows; South facade has fixed horizontal slats;

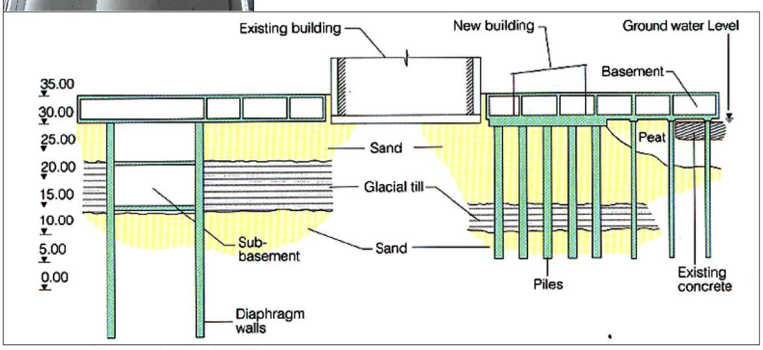
F) Maximization of natural ventilation → Cross ventilation for the small depth of the building and the disposition of the openings in the perpendicular directions of prevailing winds; Convection facade on East side that for suction bring the fresh air to each level (small section of the cavity);

H) Protection from noise pollution → Double-skin facades work as acoustic insulation layers from the traffic noise;

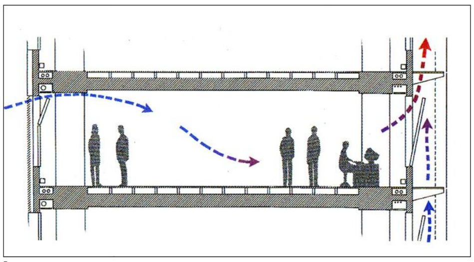


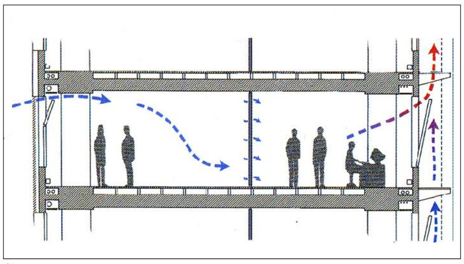
Structure sketch - Floor Plan

Photo

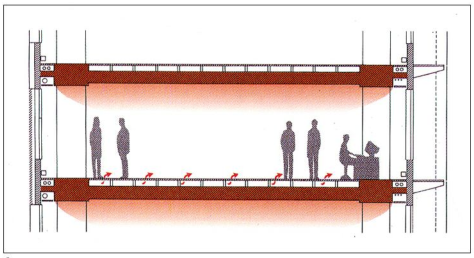


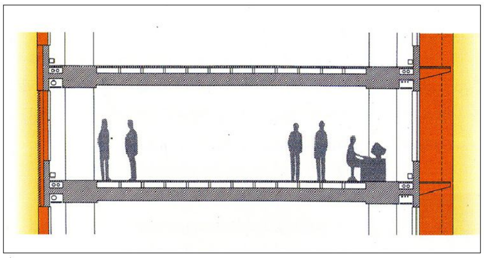
Foundations sketch [2]

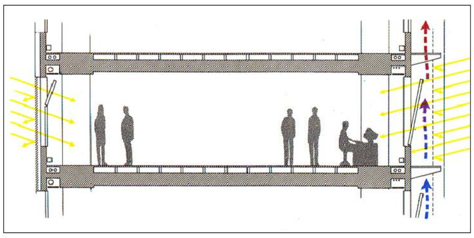

1

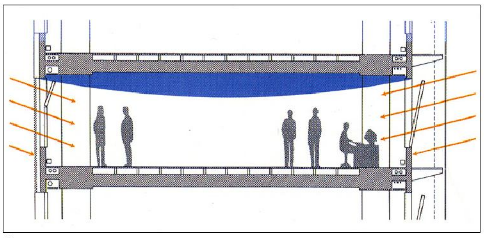

2

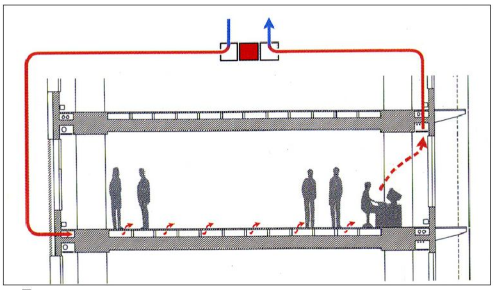
1.-2. Cross ventilation from the openings on East facade to the West side;
3. Thermal mass (exposed ceiling);
4. Buffer zones (facades);
5. Solar protection;
6. Maximization of daylighting (transparent facades and small depth of the construction);
7. Heat recovery;
8. High-rise floor
[2]

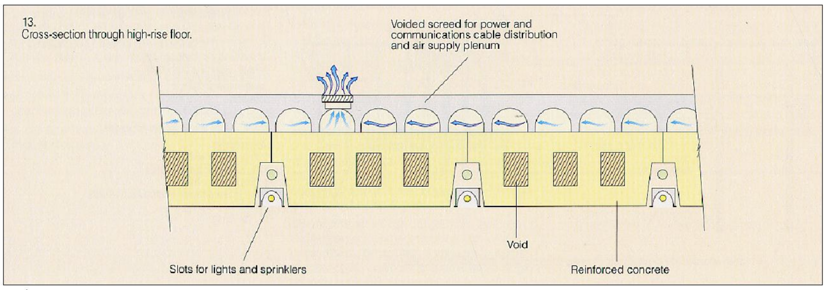

3


4

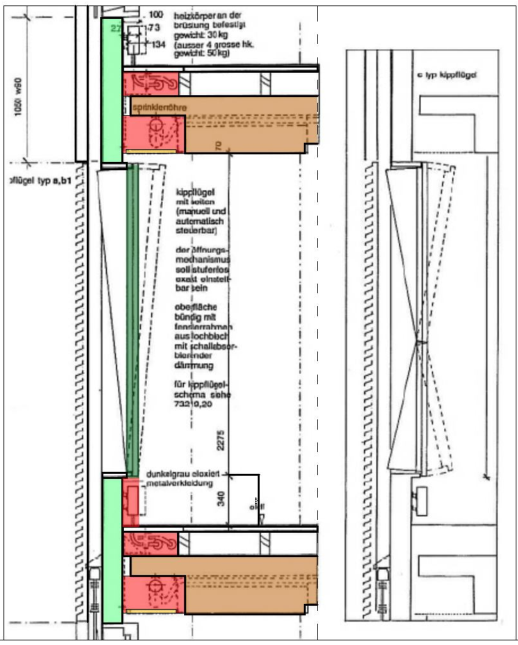

5


6


7

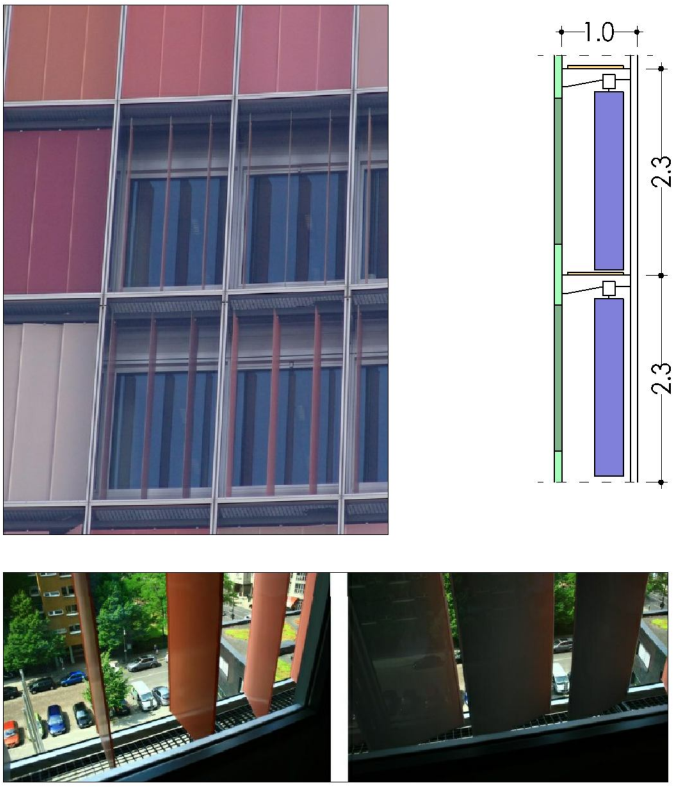


8

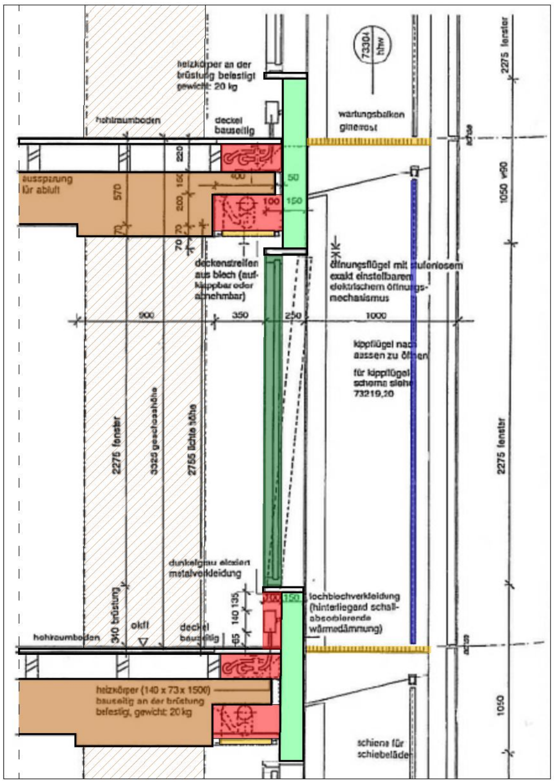


East Facade - Section 1:50 and Photos

Openable part | Opaque panel | System
Grill | Vertical shadow device | Structure



West Facade - Sketch and Photos



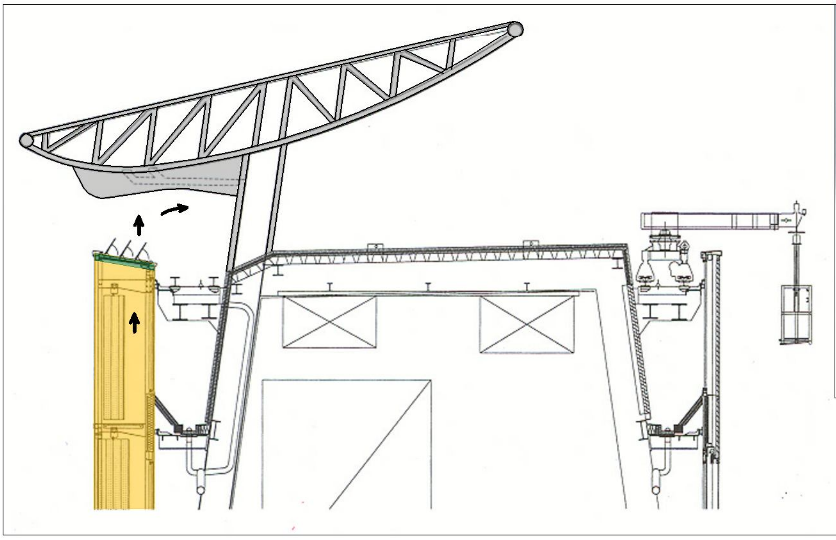
West Facade - Section - Scale 1:50

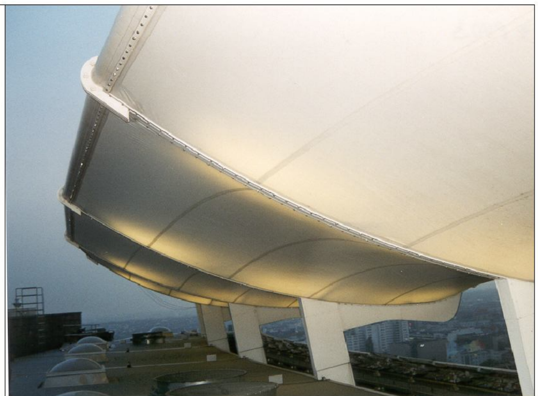
(dark green)	Openable part (Vasistas)	(light green)	Opaque panel
(yellow)	Grill	(red)	System
(blue)	Vertical shadow device	(brown)	Structure

Roof: Flat opaque roof with a mounted wind sail.

B) Reduction of heating demand → High thermal insulation of materials: U=0.25W/m²K;

F) Maximization of natural ventilation → Curved wind sail made by steel and textile membrane that increase the negative aerodynamic pressure increasing the air velocity that comes from the West facade (Venturi effect). Tests in wind tunnel were made.





(green)	Openable part		
(yellow)	West Facade	(grey)	Steel structure

Roof structure - Section and Photo [4]

8. Energy concept and Systems

Heating/Cooling and ventilation: Heat exchanger with heat recovery;
Cooling based on spray coolers and desiccant thermal wheels. The latter regenerated using the district heating supply in winter provides the heat source for the air handlers and radiators. The heat required to dry the desiccant thermal wheels in summer comes from electricity generation;
VAV (Variable Air volume) system;
Perimeter radiators are provided with individual thermostatic radiator valves, while the main air-handling plant is in a two-storey plant room at the 22nd floor below the roof.

L) Optimization of operations → Mechanical ventilation initiated by the BMS;
Occupants can select individual zones within a floor in either mechanical or naturally ventilation mode by a wall-mounted zone controller.

Lighting: Small building depth, glass facades and glazing partitions contribute good daylight level of the office floors + Linear fluorescent lamps integrated into the slab (300lux) + Lighting control system

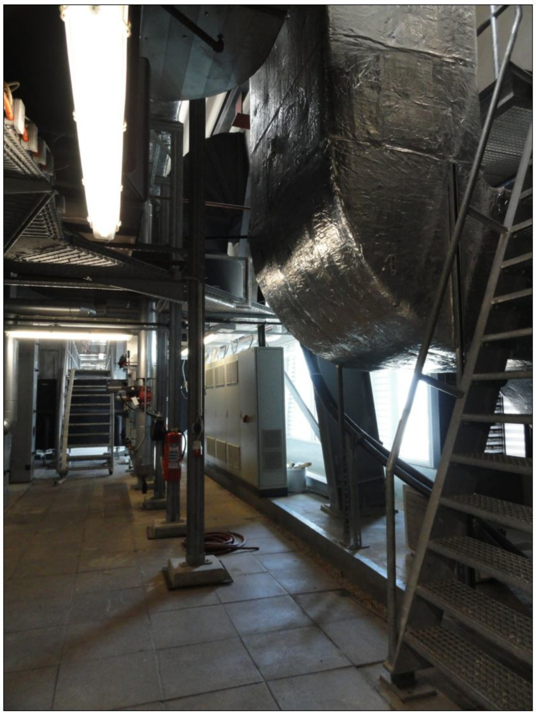


Photo - Floor plan with systems - made by the author

8. Environmental Strategies

Energy saving of 40%, the building represents one of the first example of sustainable design for high-rise building in a city under renovation.

A) Connection with the context → Use of color according to the different block size and in relation with the city. It inserts in the period of the reconstruction plan of Berlin;
Direct connection with the existing tower;
Curved shape that influences the microclimate of the exterior public space;

B) Reduction of heating demand → Green roof for the low-rise block;

10. Monitoring of performance

Consumes are metered as also climate characteristics on top of the building. Many studies has been carried on the efficiency of the facades.

References

1. www.betterbricks.com. [Online]
2. www.mech.hku.hk. [Online]
3. www.sauerbruchhutton.de. [Online]
4. www.tensinet.com. [Online]

1. Scenario

Designed by Arup Associates for the UK property company British Land, Ropemaker Place is an 83710m² offices located on the borders between the City of London and London Borough of Islington. The client wanted it to be "inspiring, sustainable and impressive and above anything, they wanted commercial success from day one".

2. Building description

General Description: The building is a 21-storey office characterized by a parallelepiped geometry with a series of roof gardens (the 50% of the roof area), which diminish the floor area at Levels 8, 12, 16 and 20. In addition, there are three ground floor retail units with the main located on Chiswell Street. Part of the interiors have been let on completion according to a multi-tenant idea.

Goals: A) Connection with the context; B) Reduction of heating demand; C) Reduction of cooling demand; D) Maximization of daylighting; E) Protection from glare and sun radiation; F) Maximization of natural ventilation; G) Ecology of building materials; H) Protection from noise pollution; I) Integration with renewables; L) Optimization of operations.

Key aspects: Atrium, Façade design, Daylight planning and optimized lighting, Green roof, Recycled materials, Solar water heating, Photovoltaics, Biofuel boilers, Optimization of operations.

Data:
Number of floors: 21
Number of floors above the ground: 3
Gross Floor Area: 83710 m²
Usable height: Level 1-2=3m; Level 3-20=2.75m; Basement 3=4.35m; Basement 2=4.85m; Basement 1=3.15m; Ground (Main Entrance) =7.55m (varies); Trading Floor Level 1=4.50m; Trading Floor Level 2=4.20m; Office Levels 3-20=3.95m; Retail North=4.80m; Retail South=6.15m (min 5.80m)

Time:
Acquisition of the land: 2006
Completion & Inauguration: 2009

Awards:
2011 World Architecture News, Shortlisted, Commercial Category
2010 British Construction Industry Awards, Major Building of the Year
Mitsubishi, Property Week Deal of the Year
2010 Association of Interior Specialists Awards, Gold Award, Interior Fitout Category
2010 World Architecture Awards, Shortlisted, Office Category

Experts: ARUP Associates

3. Climate data

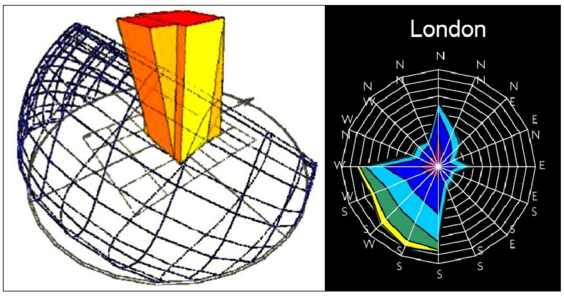
Latitude: 51°30' *Longitude:* 0°07' *Altitude:* 24m

Description: London has a temperate oceanic climate (Köppen: Cfb) influenced by the Gulf Stream as many cities in the southern Britain. Frequents but limited rainfalls characterize the city.

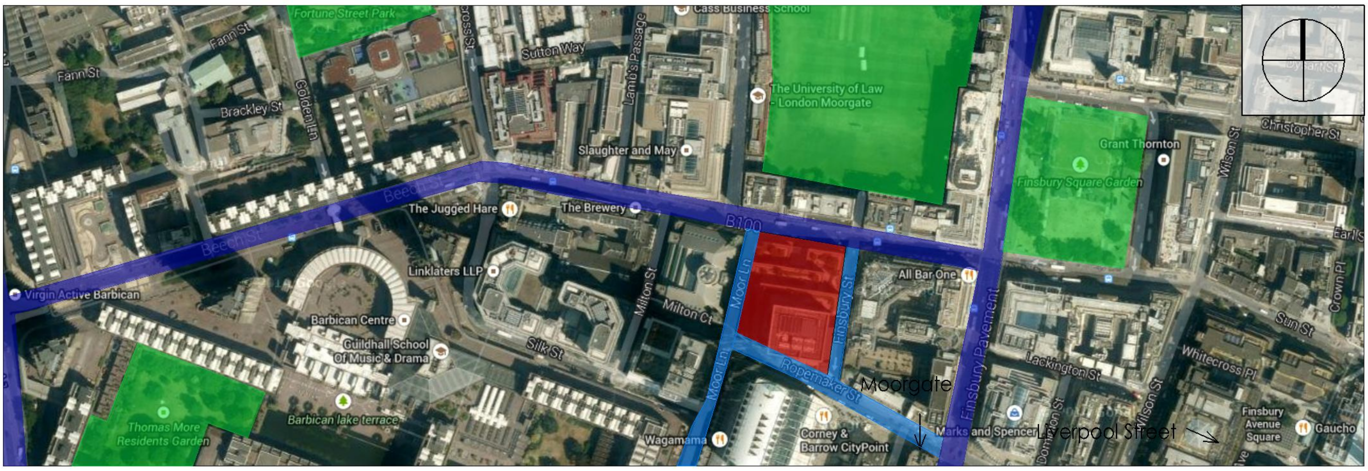
Winter: Cold with snowfall and temperatures beside the 0 especially in the suburbs.

Summer: Generally warm and sometimes hot. There is an urban heat island effect making the centre of London 5°C warmer than the suburbs and outskirts.

Winds: South/West direction of the prevailing winds.

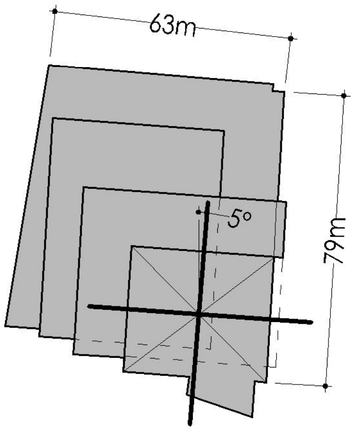


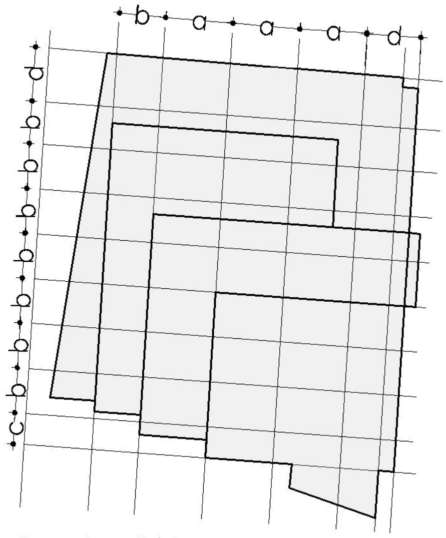
Solar radiation and Winds directions [2]



Masterplan

- Office building
- Park
- Main traffic stream
- Secondary traffic stream





Floor plan Grid

a=13.5m; b=9m; c*=6m;d*=10m

Ropemaker Place [5]

4. Site location and site quality

Site Location: Ropemaker Street, London (UK)

Site quality: Located near the City and between Moorgate and Islington in the core of London;

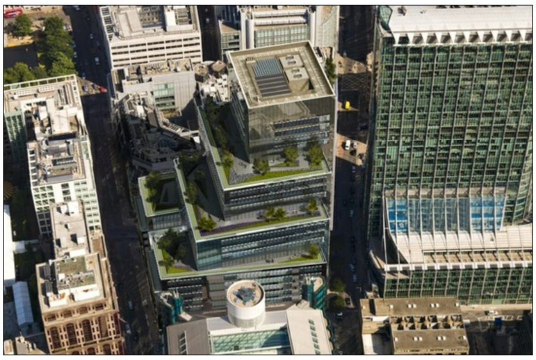
Nearby Buildings / Position and Morphology: The building is integrated into the urban grid; in 800m it is possible to find services and retail area as (church, bank, restaurants, market, etc.);

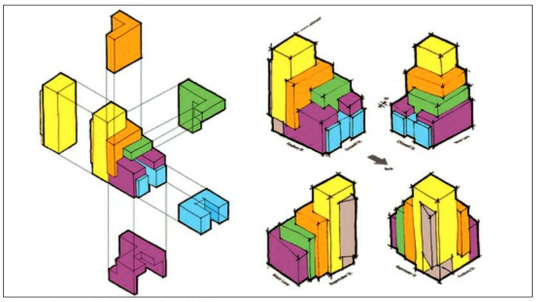
Vegetation / Position and Typology: Green zones in the area bigger than the local standard of 25% with regional plants (34%of the total is green). Nearby, gardens and park are presents.

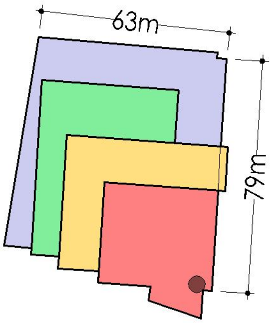
5. Orientation and shape

Orientation: Angle of 5° from the North position. Each side brings to one of the cardinal points;

Shape: Polar symmetry with squares centered on one vertex (South/East). Arup designed the building as a simplified Chinese puzzle, with six large-scale interlocking cubic forms that rise up as a series of garden terraces;







Puzzle of blocks [3]

Geometry Floor plan

6. Internal layout

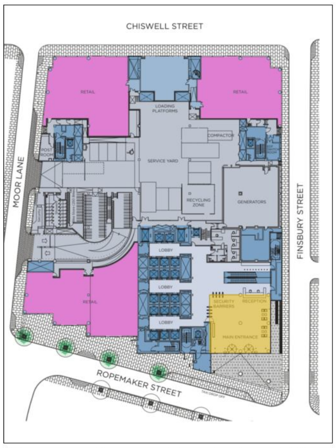
Office Spaces: 20 levels of office open-space on each side that guarantee views over the City and Islington. Each floor could be split for separate tenancies for this reason the planning grid of the building is 1.5m. Levels 1 and 2 are designed to accommodate future trading capacity. Levels 6, 8, 12, 16 and 20 have external terrace areas. Levels 8, 12, 16 and 20, of which also have green roofs, tenant amenity areas and landscaping.

Services (break areas, toilets, technical spaces): Three level basement accommodating landlord plant, tenant storage, motorcycle and car park. The remainder of the landlord's plant and space for future tenant plant is contained in a double height plant enclosure at Roof Level 21.

Connections: Main entrance on the corner of Finsbury Street/Ropemaker Street with a separate secondary office entrance on Ropemaker Street + Two vehicular accesses from Moor Lane.
The building has been split into three independent zones to offer maximum lift performance (Main Core, Low Rise Zone: 6lifts serving Ground Level to Level 7; Main Core, Mid Rise Zone: 6lifts serving Ground Level and Levels 7 to 12; Main Core, High Rise Zone: 5lifts serving Ground Level and Levels 12 to 20 + Firefighters' Lifts: 1000kg 13 person). Levels 7 and 12 are used as transfer floors permitting inter-floor travelling between the low, mid and high-rise zone levels during out of peak hours transfer periods.

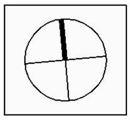
Atrium: Glazed atrium, midway along the Chiswell Street frontage, provides light to Levels 2-7. Ceiling formed from painted aluminum curved profiles, incorporating lighting and acoustic absorption. Ceiling surrounds will be formed with a painted flush plasterboard soffit, with recessed feature lighting and high quality services terminal devices.

Basement -1 - Scale 1:2000



Ground floor - Scale 1:2000

1st Floor - Scale 1:2000

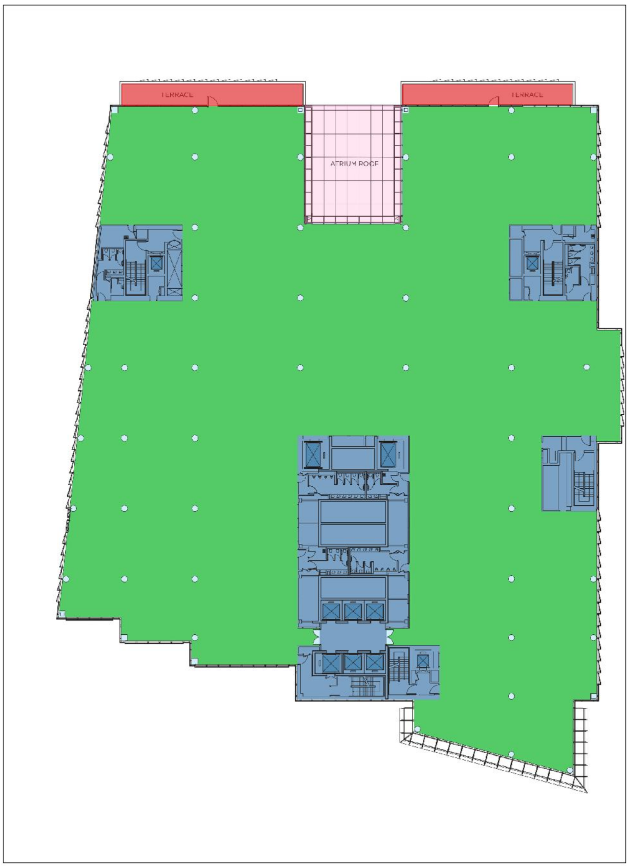


- Offices
- Vertical connections + Services
- Horizontal Connections
- Entrance
- Terrace
- Atrium
- Basement

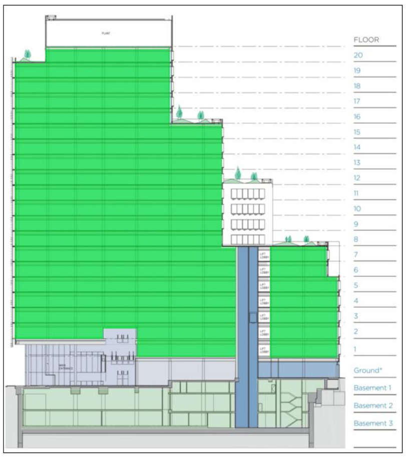
8th floor - Scale 1:2000

16th floor - Scale 1:2000

21st Floor - Scale 1:2000



6th Floor - Scale 1:1000



Section - Scale 1:2000

7. Structure and envelope composition

Structure: Mixed structure with reinforced concrete and steel. The building is planned with a grid around 9mx13.5m;

Floor: Reinforced concrete slab and raised floor (Levels 3-20 have raised floor height of 15cm, while Level 1-2 45cm);

Facade: Diversification of curtain walls according to different orientations (1.5m modular cladding) designed as a series of storey-height isolated cassettes with projecting and tilting elements. The external cladding comprises high performance custom designed aluminium/glass assemblies; the cladding is rich in color, texture and minimize energy consumption.

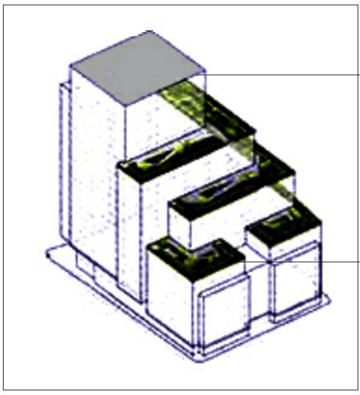
A) Connection with the context → At the City side the glass façade creates a grand entrance, while on the north front the gardens can be seen from miles;

B) Reduction of heating demand → High thermal insulation glazing and airtighness in the building envelope. The use of a double pressure gasket line reduces the air leakage rate to 5m³/hours of facade at a pressure of 50Pa (UK Building Regulations Part L requirement of 10m³);

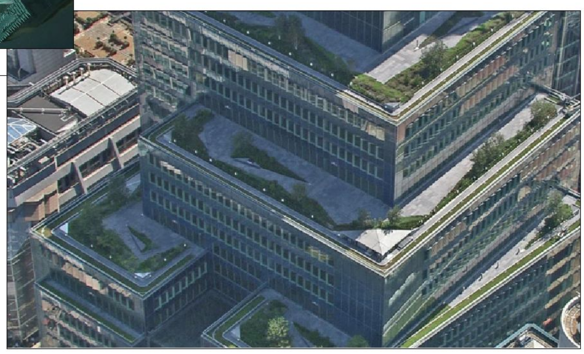
D) Maximization of daylighting → Facades are transparent for the major part;

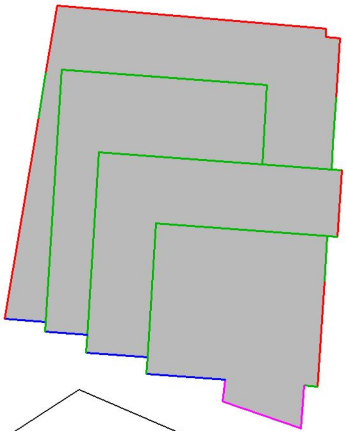
C) Reduction of cooling demand +
E) Protection from glare and sun radiation → East and West fronts: the windows project from the flat façade and tilt in the vertical axis away from the sun towards the North to reduce incident solar radiation;
South front: windows are rotated around a horizontal axis, leaning forward. The rotation allows as element of self-shading and also for the reduction of solar transmission of the glazing due to the increase in the solar angle of incidence;
The combination of them reduces the average annual energy consumption for cooling by up to 27% compared to a flat façade;
Horizontal external shadow devices for the sun protection on South/East position;

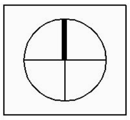
Roof: Large areas of extensive green roof are installed at different levels (Levels 8, 12, 16 and 20), while the top of the building is flat with solar collectors;



Flat roof and Green roof [5]

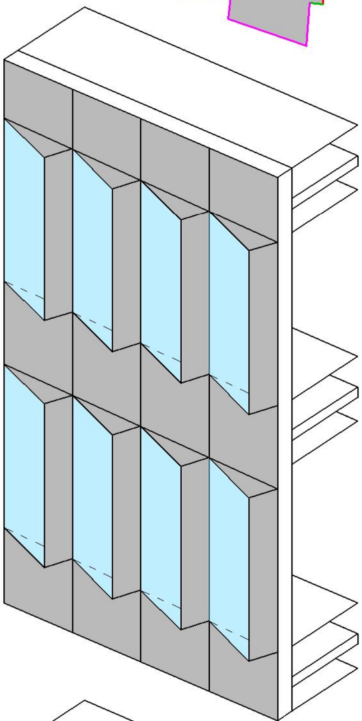


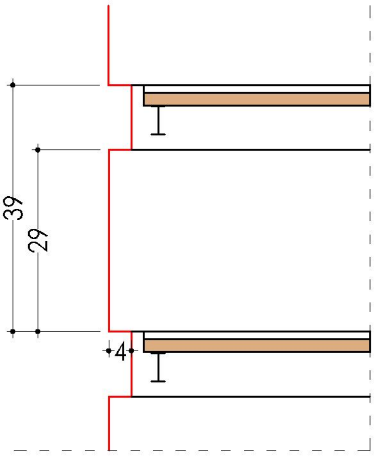




Floor plan - Facade types

- Facade type 1
- Facade type 2
- Vertical facade
- Vertical facade + horizontal sun screen

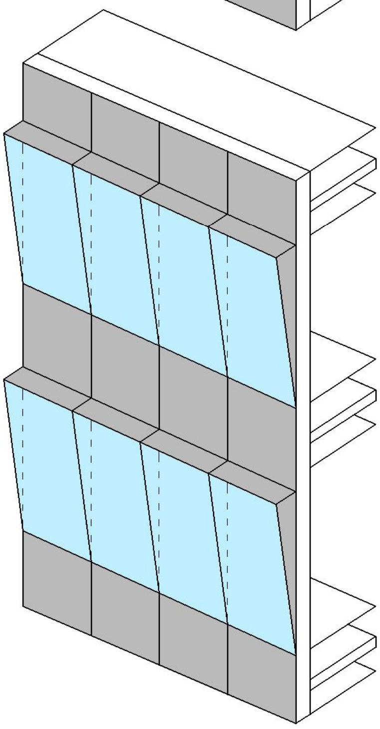


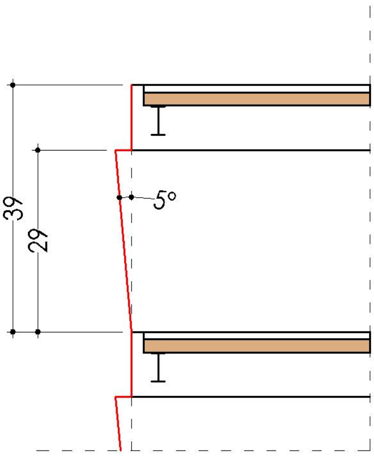


Curtain wall - Transparent part

Opaque part

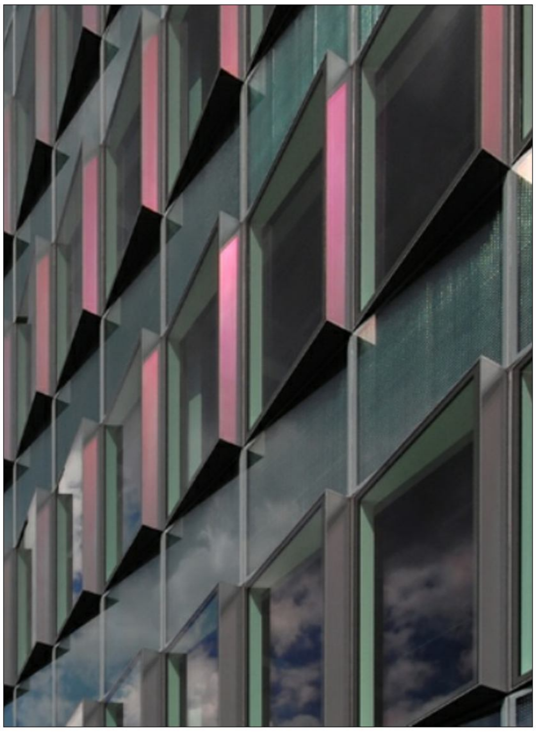
Structure



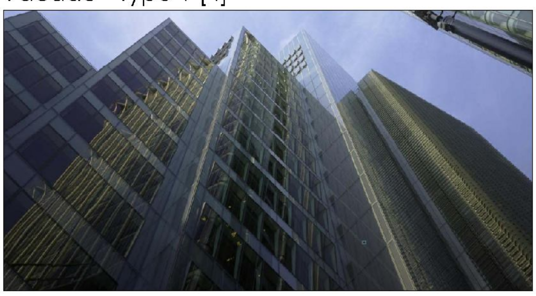


Facades sketches - Type 1 and 2 - Scale 1:100

Vertical facade + horizontal sun screen [4]



Facade - Type 1 [4]



Facade - Type 2 [4]

8. Energy concept and Systems

Heating/Cooling/ventilation and service hot water: Hot water for heating and services is generated by a combination of biofuel boilers located at basement level. The LPHW (Low Pressure Hot Water) distribution system consists of heating circuits serving the air-handling units located in the basement; while tenants LTHW (Low Temperature Hot Water) riser circuit are located in the cores.
Independent duty and standby inverter driven chilled water pumps, packaged chilled water pressurization units and associated controls are located at basement level. Space is provided in the basement plant area to allow the tenant to add additional chillers; while chilled water riser circuits are located in the cores.
Air Handling Units located in the middle basement level, distribute air to risers 1 and 2 terminating at the lower terrace levels, and to risers 3 and 4 terminating at the higher terrace level. One roof mounted distributes from the roof in riser 4 (16 l/s per person of fresh air).
Base build cooling, heating and ventilation systems will designed to allow tenants to install their own preferred air conditioning system including:

1. fan coil units with primary air supply ducted to the inlet of the fan coil unit;
2. passive chilled beams with primary air supply ducted to ceiling mounted diffusers;
3. active chilled beams with integral primary air supply;
4. chilled ceilings with primary air supply ducted to ceiling mounted diffusers.

Gas: The incoming supply, which includes an allowance for tenant's kitchen facilities, is terminated at a manifold in a ventilated room in the basement. Metering is provided at the incoming supply room for the landlord's supply and by the tenant's chosen gas supplier.

Lighting: Maximization of daylight for offices with a diversification of artificial lighting for the spaces of the property owners. Linear and compact fluorescent luminaires for toilets, core areas, plant room areas while a mixture of light sources to complement the architectural features of the zone for the reception and atrium. Exterior Lighting for security, aesthetics and landscape areas.

Photovoltaic: PVs disposed on the roof;

I) Integration with renewables → Overall, renewable energy technologies and energy efficiency measures will displace up to 20% more CO2 emissions than current 2006 Building Regulations. Solar water heating, Photovoltaic cells (PVs) and biofuel boilers will provide up to 10% carbon emission reductions and 20% energy demand reductions.

L) Optimization of operations → BMS system.

8. Environmental Strategies

The sustainability strategies applied, follow the policies described in the 'London Plan' published in February 2004 that focuses on the social, environmental and economic development of London over the next 15-20 years. The building is designed to achieve a BREEAM rating of "excellent".

A) Connection with the context → Car park disposed in the basement for the small area insert in the urban grid; Important areas dedicated to plants (North side) that have minor water need. In addition, a rainwater harvesting system and wastewater recovery can provide water for green roof irrigation or flushing of WCs on the lower floors; Use of different materials for the exterior to demarcate the zones;

G) Ecology of materials → Sustainably sourced timber and recycled materials; Natural stone finishes; A fully ventilated soil and waste drainage installation are provided to serve all floor levels above the ground floor. The drainage system will discharge by gravity into the Local Authority sewers. Soil and waste drainage from the basement levels are pumped.

10. Monitoring of performance

All consumes are metered and integrated into a Building Management System + Fire Alarm System + Security system control

References

1. KRAGH, M. Façade engineering and building physics. Intelligent glass solutions. Engineering in Glass.
2. KRAGH, M. Ropemaker Place, London. Milano, ARUP, 4° Forum Architettura - GREEN BUILDING, May 2011.
3. www.arupassociates.com. [Online]
4. www.e-architect.co.uk. [Online]
5. www.ropemakerlondon.com. [Online]

1. Scenario

With its height of 122.5m, the Unipol tower overtakes the medieval "Torre degli Asinelli" (97m) changing the skyline of the city of Bologna and arises from the ex-industrial suburbs area, close to the "Autostrada Adriatica" and object of a requalification plan. The plan entails four main buildings: the office tower, the hotel, the retail block (covered by steel structure with integrated PV) and the car park.

2. Building description

General Description: The main building is a 27-storey office characterized by a trapezoid geometry with the last 4 floors dedicated to the panorama view and with a sloped roof that integrates photovoltaic modules.

Goals: A) Connection with the context; B) Reduction of heating demand; C) Reduction of cooling demand; D) Maximization of daylighting; E) Protection from glare and sun radiation; G) Ecology of building materials; I) Integration with renewables; H) Protection from noise pollution; L) Optimization of operations.

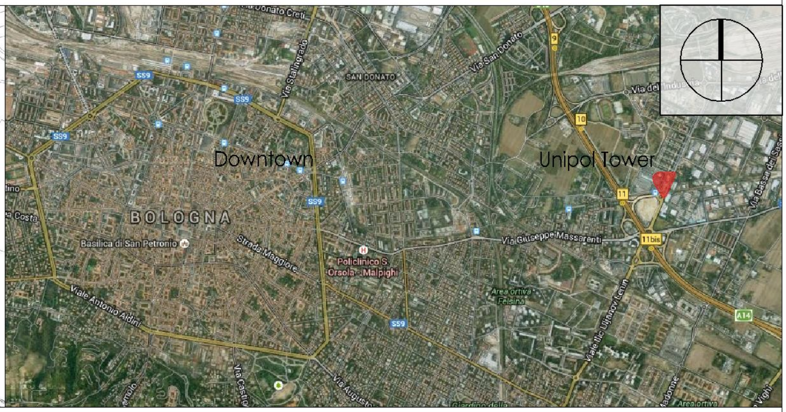
Key aspects: Daylight planning and optimized lighting, Façade design, Free cooling, Heat recovery, Photovoltaics, Optimization of operations

Data: Number of floors: 27
Number of floors above the ground: 3
Gross Volume: 100000m³
Gross Floor Area: 29000m²
Workplaces: 1050

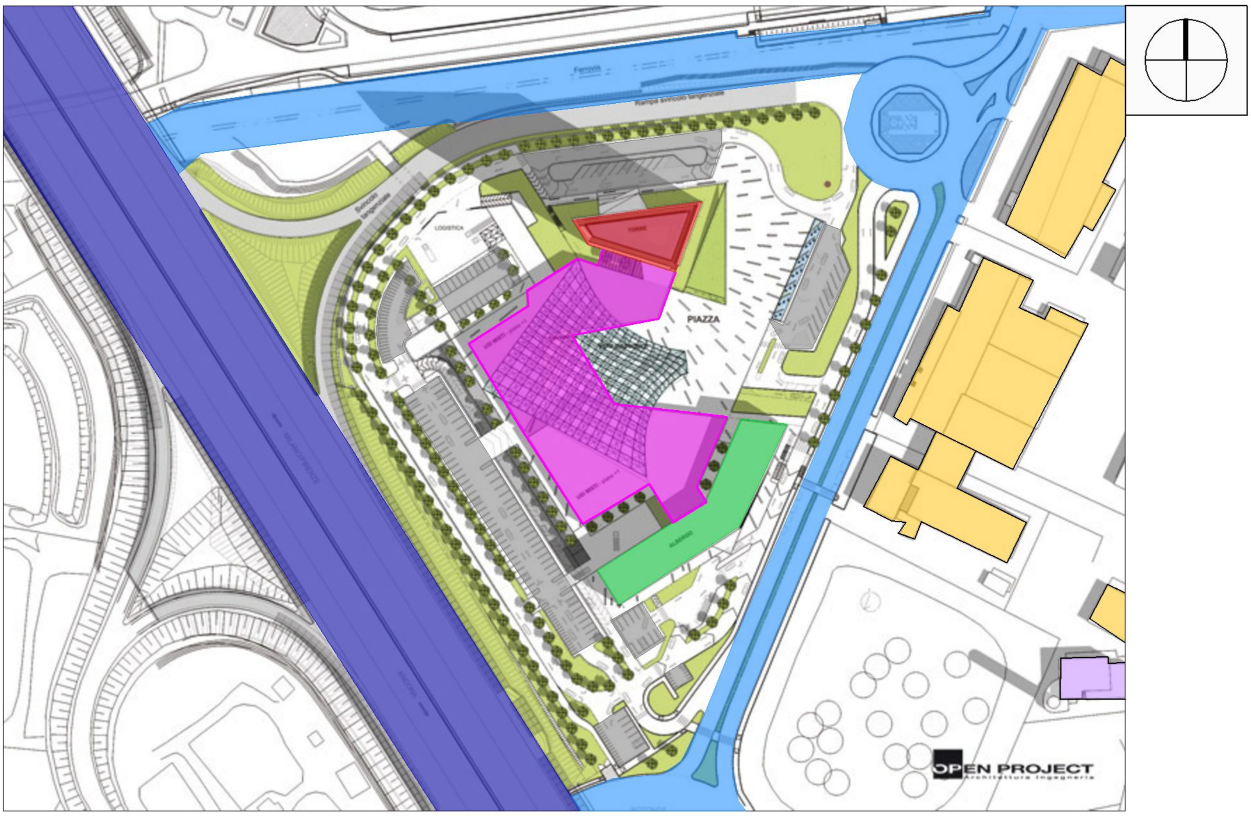
Time: Design period: Urban plan and acceptance >10 years; "Progetto esecutivo": 1 year
Construction: 48months
Completion and Inauguration: 2012

Experts: Architecture, Landscape planning, Acoustic planning, Photovoltaic project: Open Project srl
Landscape planning: Open Project srl + Frassinagodiciotto
Statics: Studio Tecnico Majoviecki
Building physics and building services: ICS (fire prevention, renewable energies, and photovoltaic project)
Building services (systems: heating, cooling, ventilation, electric): Betaprogetti
Counseling LEED: Habitech - Distretto Tecnologico Trentino

View of the area [7]

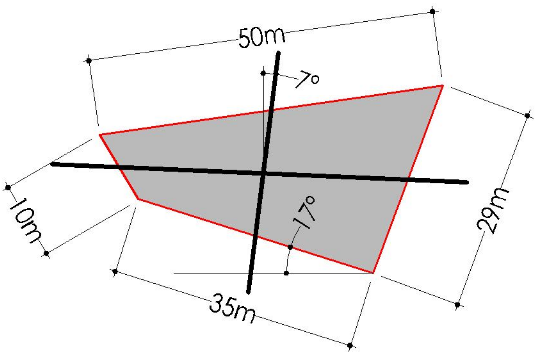


Masterplan [7]



Masterplan - 1:2500

- Office building
- Mixed area (retail, services, etc.)
- Industrial constructions/Warehouse
- Hotel
- Main traffic stream
- Secondary traffic stream
- Car park
- Antenna



3. Climate data

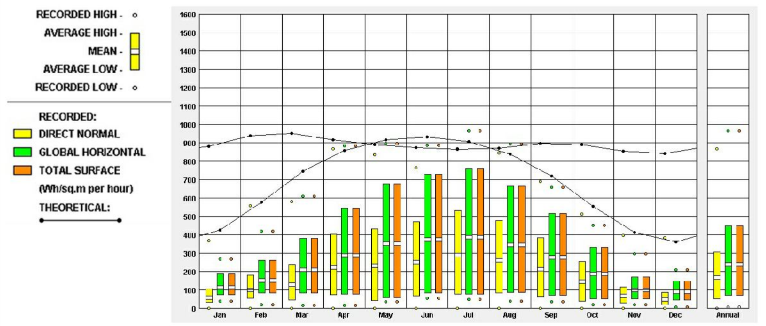
Latitude: 44°29' *Longitude:* 11°20' *Altitude:* 54m

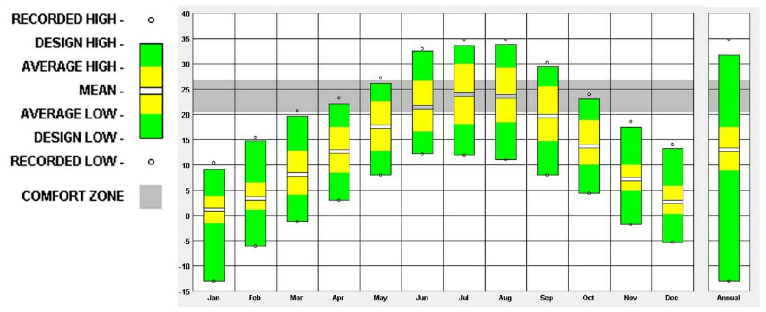
Description: Bologna has a continental climate with frequent snowfall.

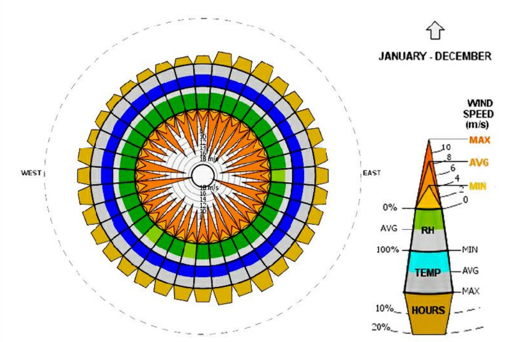
Winter: Cold winter with snowfall;

Summer: Warm and dry summers with short and mild mid seasons;

Winds: Moderately windy with occasionally tramontane winds. For this reason Bologna is generally foggy. During summer could be windy.







Charts: Solar radiations, temperatures and Wind velocities and directions.

4. Site location and site quality

Site Location: Via Larga 8, Bologna (IT);

Site quality: Suburb district subject of a requalification plan, in the East part of Bologna;

Nearby Buildings / Position and Morphology: New blocks with retail, services and a hotel on South side. In addition, a steel curved structure with ETFE film modules and PV covers the square. The area is surrounded by a system of streets, which carry to the main "Autostrada Adriatica";

Vegetation / Position and Typology: The entire area have green zones as also the top of the lower buildings;

5. Orientation and shape

Orientation: The main axe is East/West with main fronts approximately on North and South orientation.

A) Connection with the context → The building has one front parallel to the North street while the South front is directly linked to the other building;

D) Maximization of daylighting→ Three fronts embark on South even if with different tilt angles while the third is oriented to North;

Shape: Trapezoid geometry of the floor plan. A/V = 0.18m²/m³=> Compact.

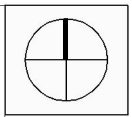
6. Internal layout

Office Spaces: Cellular offices distributed on North and South fronts. They can have different size depending the number of workplaces with high flexibility of interiors;

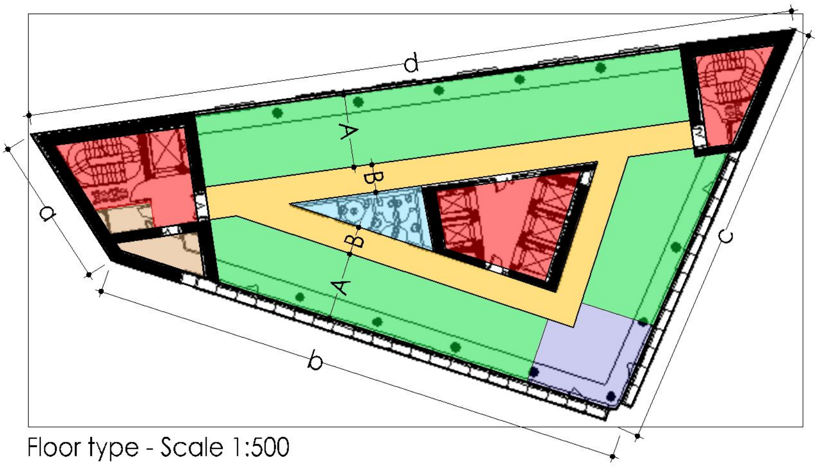
Meeting room/Conference room/Video conference: They are located preferable on the corner on South position where there is a beautiful panorama;

Services (break areas, toilets, technical spaces): Services and toilets are disposed on East side and in the core of the building. Café, reception and common spaces are disposed at the ground level;

Connections: Three main groups of vertical connections on East, West and core positions with 6 lifts and 2 staircases. Corridors create a triangle that links the extremes of the floor plan.



Ground floor - Scale 1:1000



Floor type - Scale 1:500

a*=10m; b*=35m; c*=29m; d*=50m
A*=5m; B*=1.8m;

- Offices
- Vertical connections
- Horizontal Connections
- Toilets
- Technical spaces
- Hall/Entrance
- Cafe
- Meeting rooms, Conference rooms, etc.

Photo 1 [1]

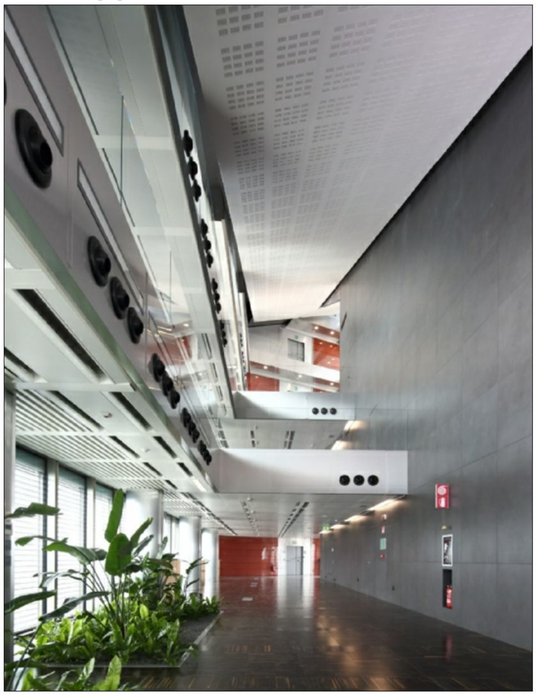


Photo 2 [1]

Photo 3 [1]

7. Structure and envelope composition

Structure: Concrete cores (C40/50) with middle steel belt-truss and top concrete belt-truss (C60/75 S5 and fiber reinforced). Structure: Mixed structure (reinforced concrete and steel) and three reinforced concrete vertical blocks. Foundations has piles and chests that constitute the basement. Steel columns (S355) has a crux section and there is a double warpage of steel beams. In addition, tests in wind tunnel have made to count the interaction between structure and facade.

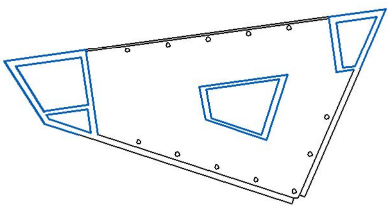
Floor: U-shaped steel sheet and concrete characterized the slab + raised floor.

Facade: Diversification of the solutions according to the exposition: East and South fronts are double skin facades, the North side is a curtain wall (cell) while West is a ventilated opaque facade. Schüco designs the double skin and the curtain wall for this project (system SFC 85 and realized by Tosoni Company).

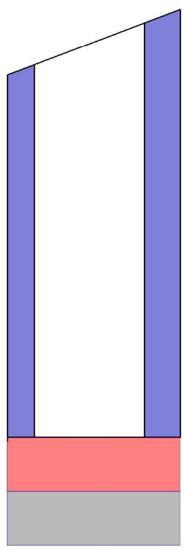
- B) Reduction of heating demand → Adoption of low-e glass and high thermal insulation layer;
  The colder front is transparent increasing solar gains;
  East and South facades can be closed during wintertime working as buffer zones;
- C) Reduction of cooling demand → East and South facades can be open during summertime to cool the surfaces. They have horizontal corridors with fans to improve the ventilation into the cavity;
  The West side is opaque on its entirety to reduce overheating;
- D) Maximization of daylighting → Glass facades for each orientation except the West side. This permits that the 93.88% of the occupied space is naturally lighted;
- E) Protection from glare and sun radiation → Shading devices on South and East sides into the cavity (Horizontal blinds);
- F) Maximization of natural ventilation → Openings on facade in correspondance of the grilles (separated by the double skin facade);
- H) Protection from noise pollution → Use of stratified glazing which protects from the noise of the traffic as also the cavity of the double skin facade;
- I) Integration with renewables → The West vertical facade integrates PV modules in the cladding;

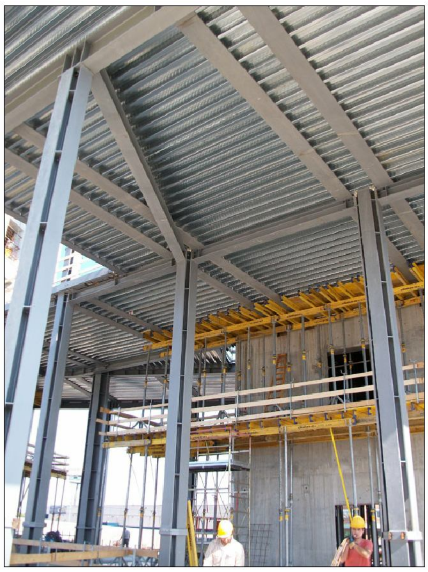
Roof: Sloped opaque roof.

- I) Integration with renewables→ The roof's angle of 20° permits the allocation of PV modules for the production of electricity.

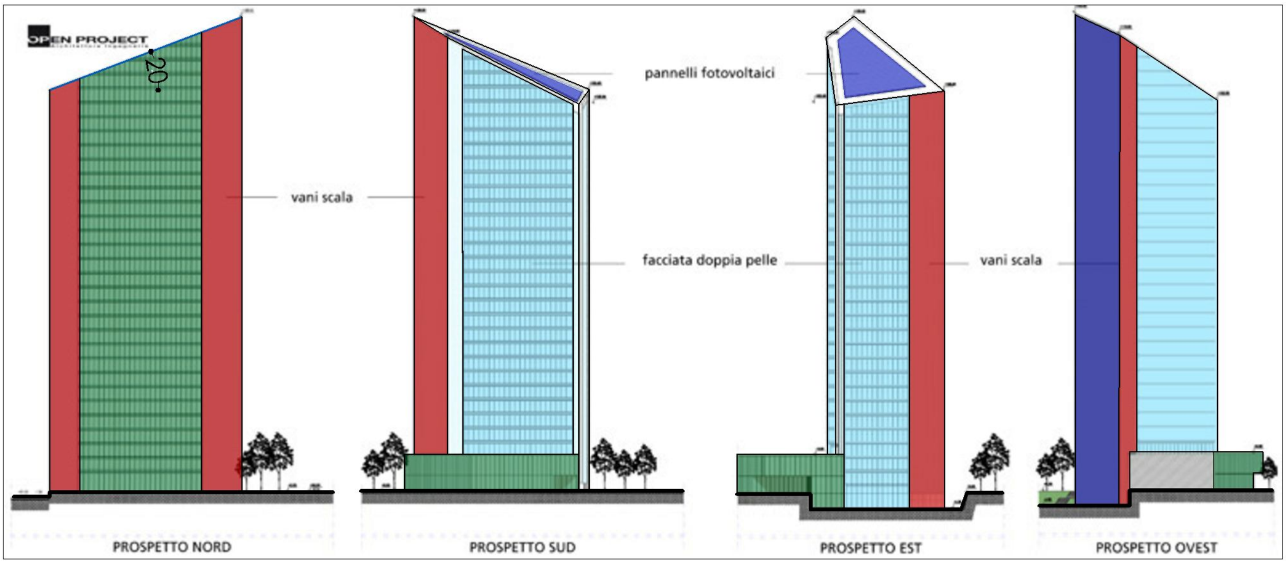


Structure sketch - Plan and section



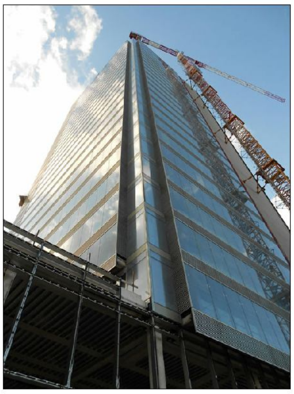


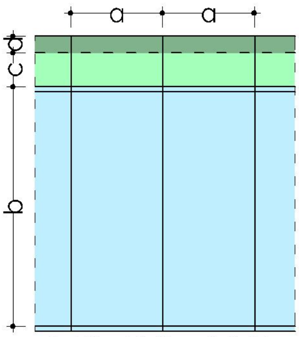
Floor slab



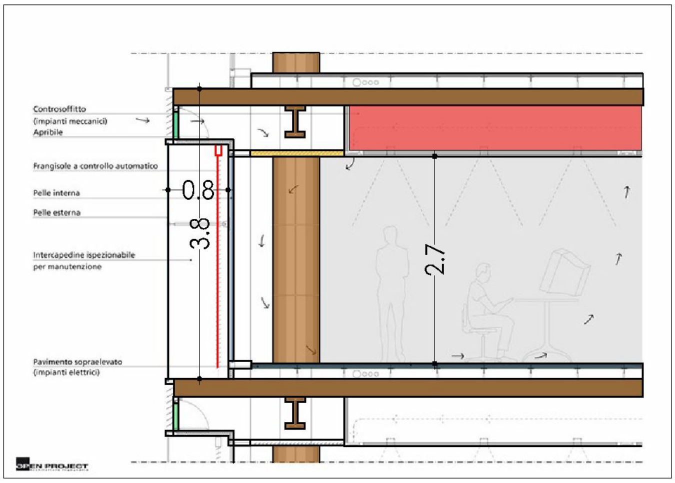
Facades - Scale 1:2000

Ventilated facade - Opaque	Double skin facade
PVs modules	Curtain wall - cell





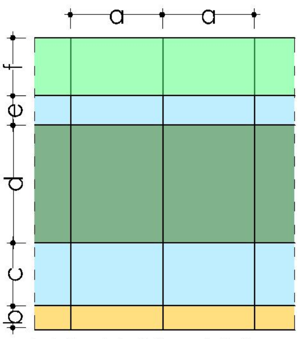
a*=1.2m; b*=3m; c*=0.45m; d*=0.2m;



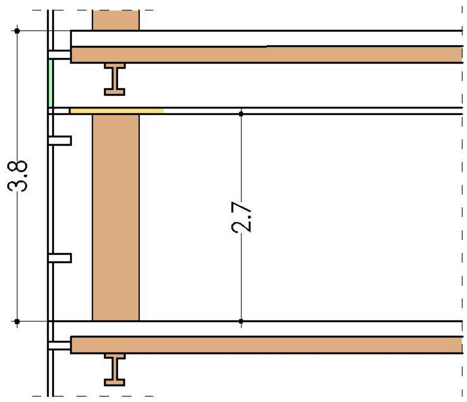
Double skin facade - Scale 1:100

Fixed part	Grill for ventialtion
Structure	Grill + Openable part for free cooling
System	Grill + Structure
	Blinds

- Fixed part - Transparent
- Structure
- Openable part for free cooling
- Openable part by users
- Fixed part - Opaque



a*=1.2m; b*=0.3m; c*=0.8m; d*=1.5m; e*=0,4;f*=0.7m



Curtain wall - Scale 1:100

8. Energy concept and Systems

Heating/Cooling and Ventilation: Multi-tenant design with a heating space with heat recovery, radiative heating floor, cooling system at each floor and VRV (Variant Refrigerant Volume) air systems. During the mid-seasons, exterior air inlet are present for the free-cooling.

L) Optimization of operations → Occupational sensor;
Mitsubishi VRF Systems.

Service water: Reduction of 52.2% for the consumes of the WC water, while reduction of 41.7% for the potable water using efficient systems;

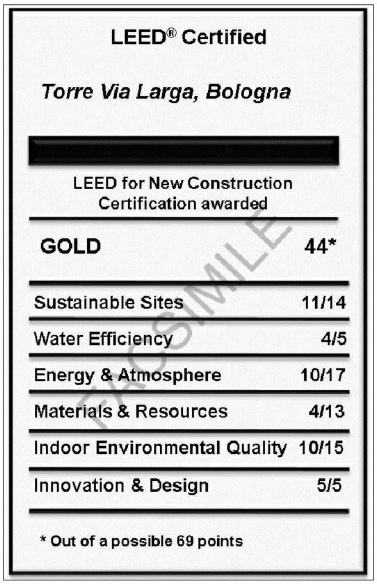
Lighting: Reduction of the power of the ceiling lamps preferring lamp desk and systems of lighting control.

L) Optimization of operations → Sensors for the daylighting in the perimeter zone and for the regulation of artificial light;

Electricity: Photovoltaic panels installed on the roof and on facade to produce electricity:

I) Integration with renewables→ PVs on the West vertical façade and on the sloped roof (total power 100 kW);

Energy consume reduction of 32.9% (comparing to the reference building), 3.53% from renewables (photovoltaics), 35% of electricity need comes from renewables.


LEED® Certified

Torre Via Larga, Bologna

LEED for New Construction
Certification awarded

GOLD	44*
Sustainable Sites	11/14
Water Efficiency	4/5
Energy & Atmosphere	10/17
Materials & Resources	4/13
Indoor Environmental Quality	10/15
Innovation & Design	5/5

* Out of a possible 69 points

FACSIMILE

8. Environmental Strategies

2012 LEED Gold certificate thanks Habitech that has supported the project.

A) Connection with the context → Creation of an area with many services well- connected with the city (65 bike park, 5 bus lines, 1 train station within 800m);
Creation of bike and pedestrian routes;
Important green areas (41%green of the total area) bigger than the requirements and adoption of local plants to reduce water need (reduction of 55.6%; base case:355013 l/a - project case: 157538 l/a). In particular, the green zones are located at different levels of the area (ex. 53,93% of green roof);

C) Reduction of cooling demand → Reduction of heating island with green areas and external flooring with high solar reflectivity (65.3%);

G) Ecology of building materials → 27,92% of materials are recycled while the 44,33% of materials is local;

10. Monitoring of performance

System of control to monitor consumes.

References

1. www.arketipomagazine.it. [Online]
2. www.promozioneacciaio.it. [Online]
3. www.habitech.it. [Online]
4. www.infobuildenergia.it. [Online]
5. www.majowiecki.com. [Online]
6. www.frassinagodiciotto.com. [Online]
7. www.openproject.it. [Online]
8. www.windlab.ing.unifi.it. [Online]
9. www.ambienteregioneemilia.com. [Online]
10. ASQUINO, A. Azione del vento sugli edifici a torre: indagini sperimentali in galleria del vento e progetto strutturale della nuova sede Unipol di Bologna. Thesis, Supervisors: Prof. Ing. C. Borri, Prof. Ing. M. Orlando, Prof. Ing. P. Spinelli.

1. Scenario

Isozaki tower is one of the buildings belonging to a the wider requalification plan CityLife (CityLife srl - Generali Properties S.p.A., Allianz) that has redrawn the area of Milan trade fair. The plan includes private and public functions in a total surface area of 255000m². The project forecasts the realization of the following zones:

- Park of 168000m² (the 3rd biggest in the city);
- Museum of contemporary Art;
- Housing area;
- 3 towers as administration district (Isozaki tower, Zaha Hadid tower and Libeskind tower);
- Retail and services areas of 20000m²;
- 7000 car parks located in the basements;
- Walking and bike routes;
- Tube station (Line 5);

In addition, closed to the area, the new Fiera Milano Center of Congress (MIC PLUS) will rise.

2. Building description

General Description: The tower represents the tallest building in Milano and it is still in construction. The architects (Isozaki and Andrea Maffei) have designed the skyscraper looking at the "Column without ending" designed by Rumeno Costantin (1918): in fact, the tower is a repetition of a convex module for 8 times. The tower has the Gold LEED certificate (pre-certificate).

Goals: A) Connection with the context; B) Reduction of heating demand; C) Reduction of cooling demand; D) Maximization of daylighting; E) Protection from glare and sun radiation; G) Ecology of building materials; I) Integration with renewables; L) Optimization of operations.

Key aspects: Daylight planning and optimized lighting, Active façade, Photovoltaics, Tele heating, Optimization of operations

Data: Number of floors: 50 (46 offices, 2 lobby, 2 technical floor)
Number of floors above the ground: 3 (2 technical floors + 1floor car-parking: 611 cars+93motos)
Gross Floor Area (offices): 50000m²
Gross Floor Area (floor-type): 1080m²
Gross Floor Area (tower): 81615m²
Gross Floor Area (Parking+basement): 44485m²
Total height: 202m
Workplace: 3864

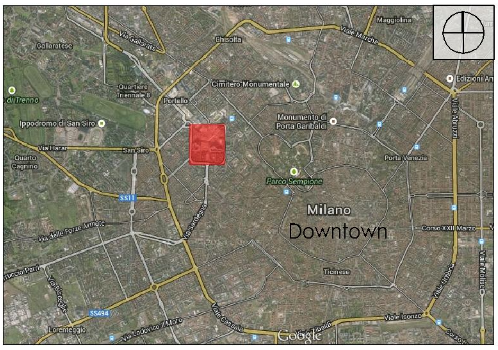
Time: Design period: 2007-2009
Construction: 2012-2015 (In Construction)

Experts: Architecture: Arata Isozaki + Andrea Maffei
Landscape planning: Open Project srl + Frassinagodiciotto
Statics: Maurizio Teora (PD), Luca Buzzoni (PM) + Arup Italia s.r.l.
Façade design: Mikkel Kragh, Mauricio Cardenas, Matteo Orlandi, Maria Meizoso, Carlos Prada
Building services (systems): Gianfranco Ariatta, Roberto Menghini, Riccardo Lucchese, Andrea Ambrosi / Ariatta Ingegneria dei sistemi s.r.l.
Building services (fire escape): Antincendio: ing. Salvatore Mistretta
Vertical connections: Jappsen Ingenieure, Francoforte
Lighting design: LPA - Light Planners Associates, Tokyo
Project management: J&A, Milano

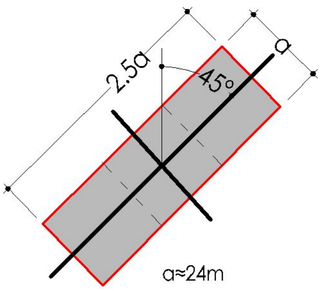
City Life area - Rendering

City Life area - Rendering and models [3]

Masterplan - Scale 1:7500



Map



- Office building
- Retail
- Housing
- Museum, Exposition building

Future Skyline [3]

3. Climate data

Latitude: 45.62° *Longitude:* 8.73° *Altitude:* 122

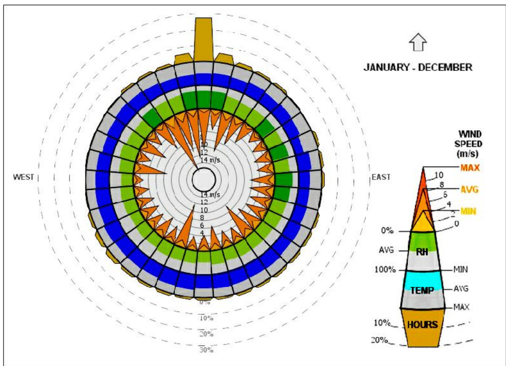
Description: Milano is located in the Po Valley and this position gives it a semi-continental climate.

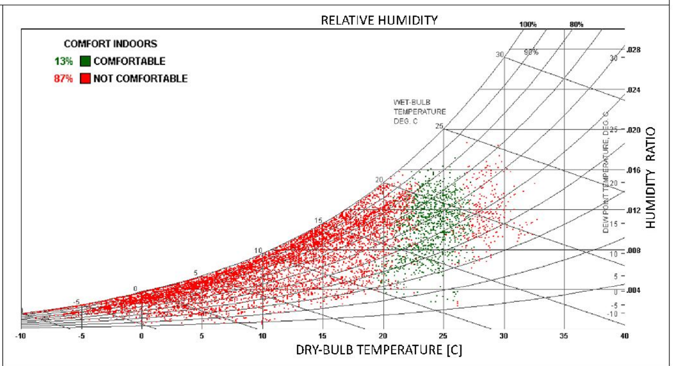
Winter: Quite cold.

Summer: Summers hot, humid and muggy.

Winds: Prevailing winds from North/West direction.

Wind directions and Psychrometric chart





4. Site location and site quality

Site Location: Largo Domodossola 1a, Milano (IT)

Site quality: The area is under construction and it will become a new zone in Milano with services, offices, museums, housing and green areas.

Nearby Buildings / Position and Morphology: The skyscraper is directly linked to the retail area (South/East) and the tube station (MM5) by a covered passage. The tower will place side by side to other two skyscrapers (North/West) becoming a new administrative centre. New residential areas will rise on North/East and South sides; while on the East part, a new pavilion for Fiera Milano will be built.

Vegetation / Position and Typology: The creation of high-rise buildings will permit a huge space for park.

5. Orientation and shape

Orientation: Axes rotated of an angle of 45°.

A) Connection with the context→	Creation of a public space (square) defined by the perimeters of the skyscrapers;
D) Maximization of daylighting→	Maximization of the surfaces disposed on North/West and South/East sides;
C) Reduction of cooling demand →	Longest axe is perpendicular to the direction of the prevailing winds increasing the wake in the leeward side.

Shape: Rectangle shape with a relation in plan 2.5a:a

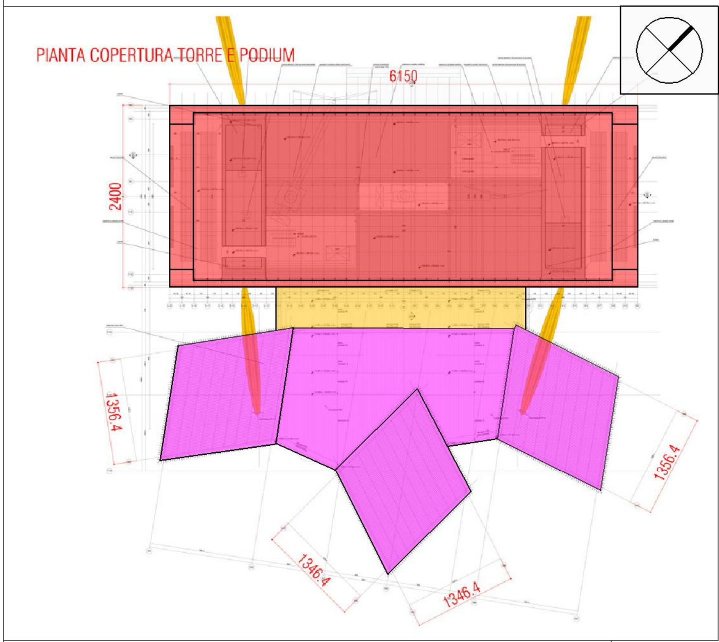
6. Internal layout

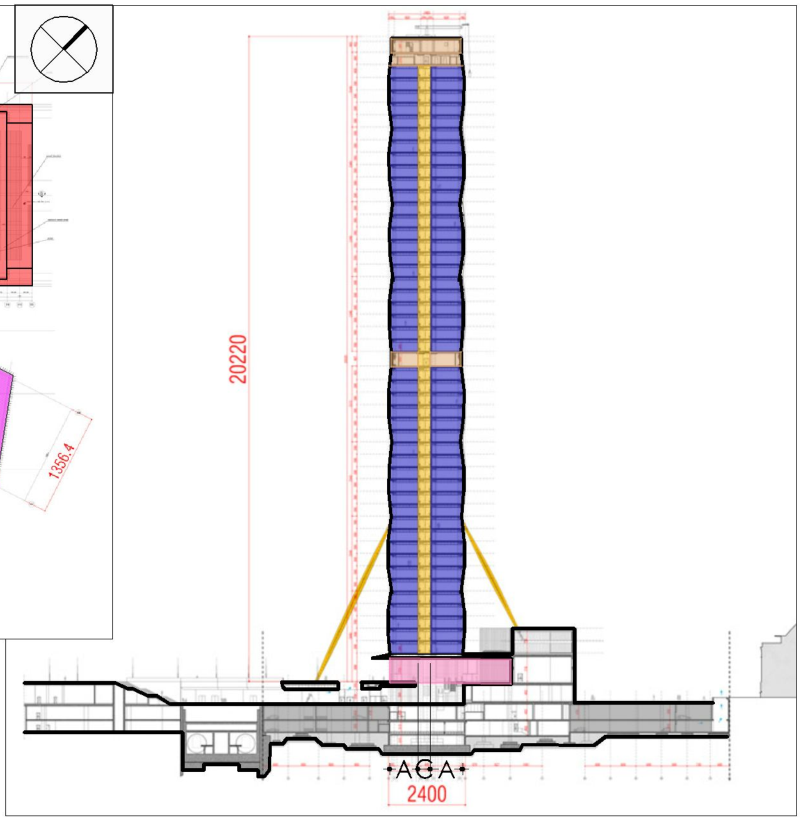
Office Spaces: Combi-office (open-space and cell offices) with high flexibility on North/East and South/West sides;

Meeting room/Conference room/Video conference: Lobby as open-space at the entrance (2floors height), while meeting rooms on East and West positions and in the central strip;

Services (break areas, toilets, technical spaces): Technical rooms are located in two floors in the basement as the car park (350 cars). Toilets and other services are grouped in the central strip at each level.

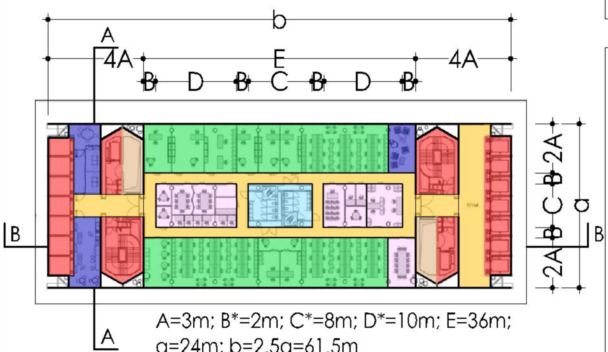
Connections: Vertical connections on East and West sides: 2 groups of staircase+lift and 2 groups of lifts (7+7). At the ground level, 2 escalators on core position and 4 lifts for the retail area. Double parallel strips of corridors as horizontal connections that bring at the lifts/staircase area. 4 corridors create the link between the two office blocks.





Roof - Scale 1:1000

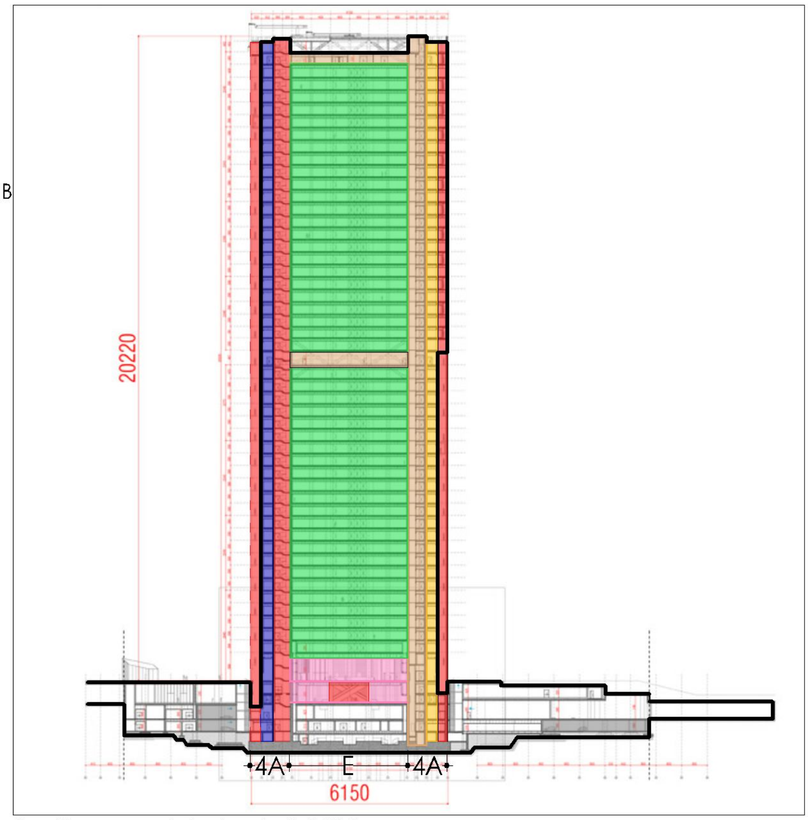
- Office Tower
- Connection
- Retail construction (Low-rise building)



A=3m; B*=2m; C*=8m; D*=10m; E=36m; a=24m; b=2.5a=61.5m

Floor type - Scale 1:1000

- Offices
- Break areas
- Vertical connections
- Technical spaces
- Horizontal Connections
- Toilets
- Meeting rooms, Conference rooms, etc.
- Entrance zone, reception, etc.
- Car park



Section A and B - Scale 1:2500

7. Structure and envelope composition

Structure: Concrete cores (C40/50) with middle steel belt-truss and top belt-truss (C60/75 S5 fiber reinforced). Columns (5+5 external+4 internal) with composite steel-concrete section in the lower floors, concrete section in the higher floors. Foundation with pile rafts (length>30m) and 4260m3 of concrete + 4 steel elements gold colored (height 40/60m).

Floors: Concrete slab (20cm) with lowered beams and raised floor. Height = 50cm

Facade: Curved curtain walls constitute the longest fronts, while curtain walls and sandwich panels with aluminum cladding constitute the shortest fronts.

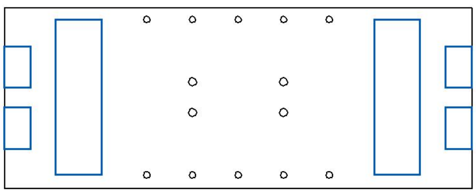
Long fronts:

- B) Reduction of heating demand + C) Reduction of cooling demand →Triple curved glass low iron with SHGC=32% on North/West facade, SHGC=26% on South/East front.
- D) Maximization of daylighting →Transparent on their entirety;
- E) Protection from glare and sun radiation→ Internal horizontal blinds made by aluminum;

Short front:

- B) Reduction of heating demand + C) Reduction of cooling demand → Stratified glass low iron with SHGC= 80% on South/East facade.

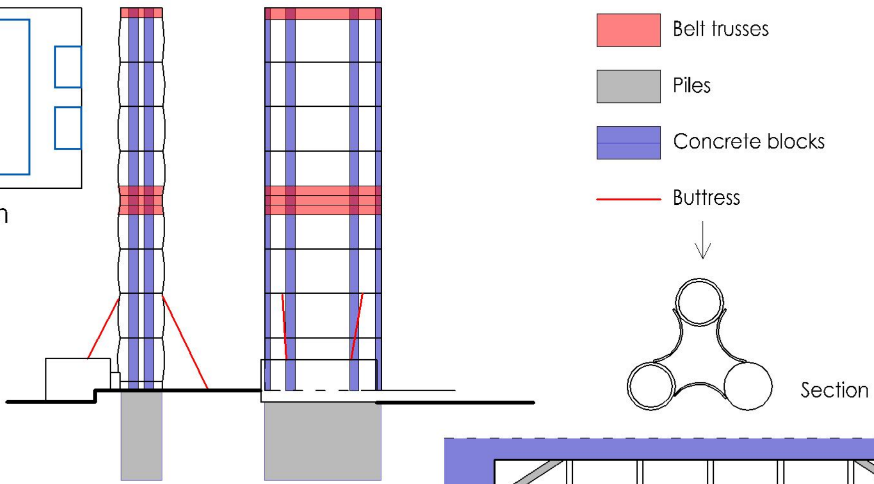
Roof: Flat opaque roof.

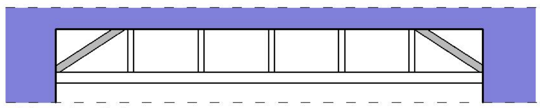


Structure sketch - Plan and section

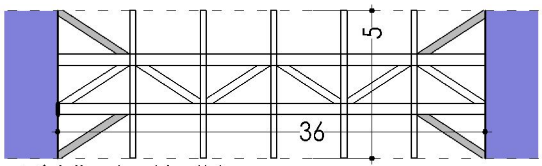
Mixed column

Concrete block

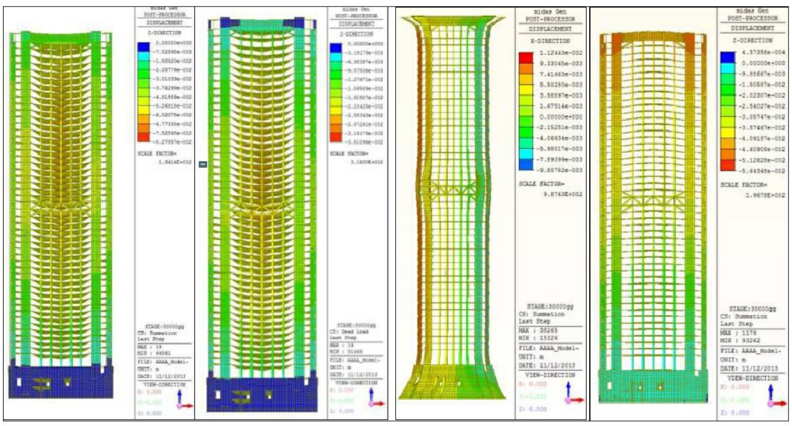




Top belt trusses

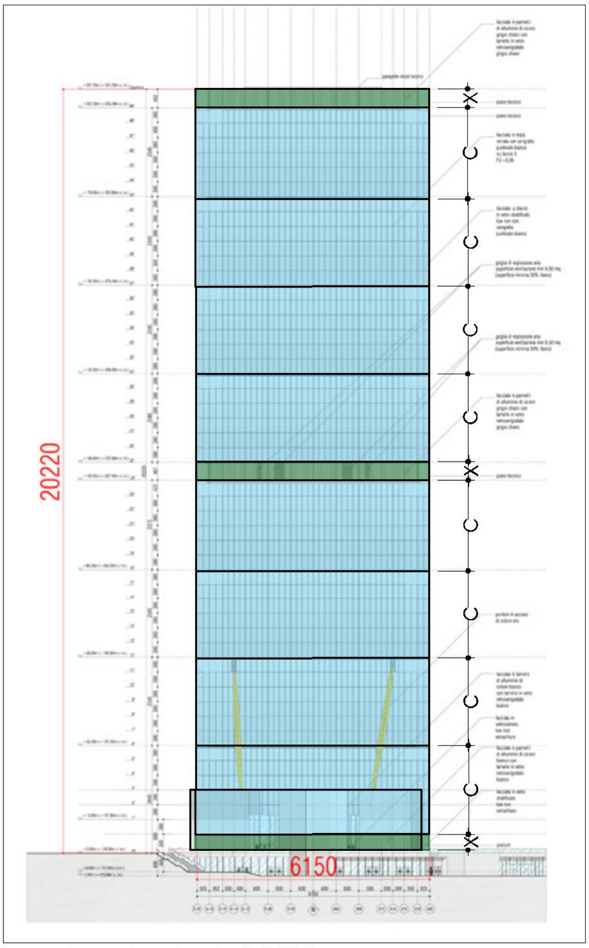


Middle steel belt trusses

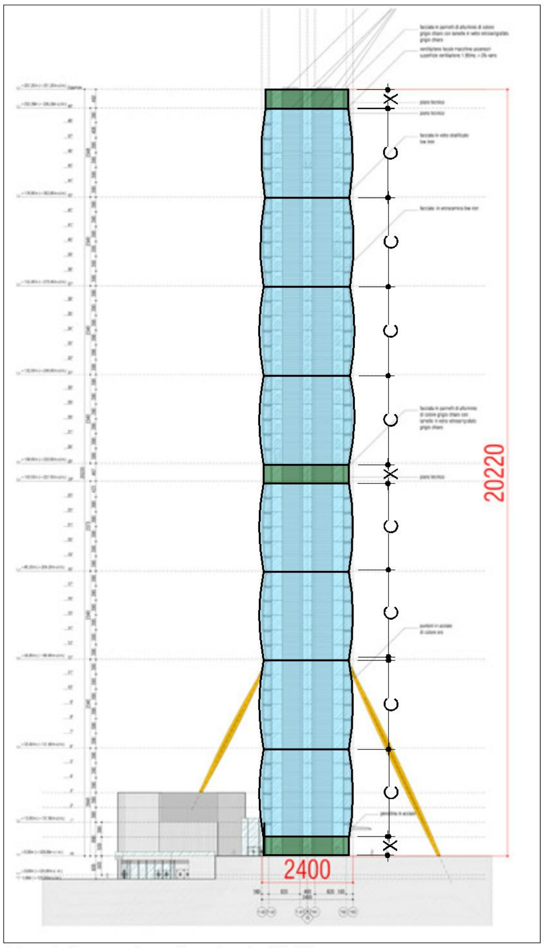


Structure[5] - Model - "1+ 2. Modello Visco-Elastico: Spostamenti verticali; 3+4. Modello Visco-Elastico: Ritiro, spostamenti orizzontali."

Construction site [1]



Long facade - Scale 1:2000

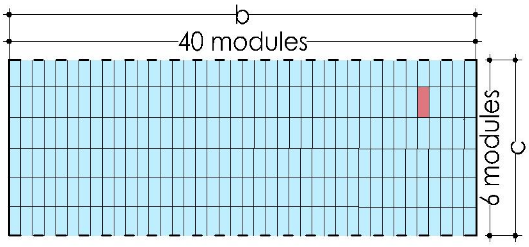


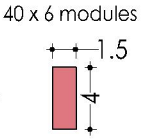
Short facade - Scale 1:2000

c

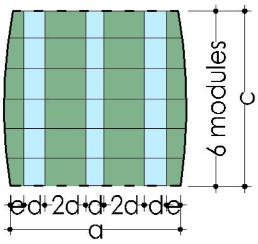
x

c*=24m;
x*=3,5m;





a=24m;
b=61.5m;
c*=24m;
d*=3m;
e*=1.8m



Facade sketch - Scale 1:1000

Curved wall - Transparent part

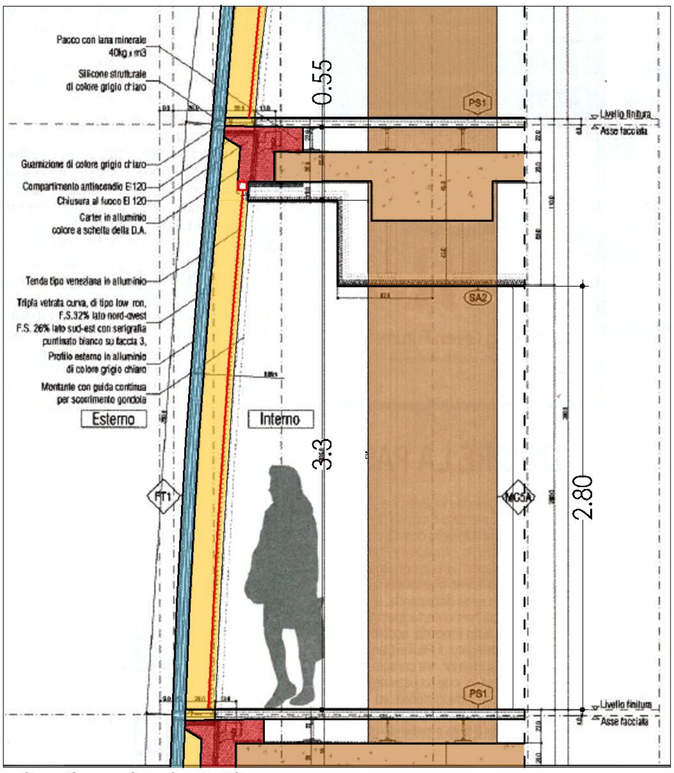
Opaque facade - Sandwich panel

Structure

Fire element and systems

Mullion

Blinds



Section - Scale 1:50

8. Energy concept and Systems

Heating/Cooling and Ventilation: Office buildings that will be used on a multi-tenant basis. Total cooling power: 6MW; Total thermal power: 5.4MW; Total electric power: 8.1MW including users' quota (2,8MW). The energy will be provided by superheated water (110°C) from the city tele heating net from the Figino incineration plant. Absorption refrigeration units are used for the production of cooling energy.

L) Optimization of operations → EMS Panorama® system to control the building and its consumes;

8. Environmental Strategies

CityLife is a wider project that will create a new area in Milano where the attention to the environment is fundamental.

A) Connection with the context →	External green area with local plants that create the 3rd biggest park in Milano; Promotion of low-emission car and electric cars with dedicated car parks (basement) close to the entrances; Creation of bike and pedestrian routes; Creation of a new tube line to improve the public transports;
C) Reduction of cooling demand →	Reduction of the heat island effect with the car parks located into the floors above the ground; Adoption of exterior materials with a high reflectance level;
I) Integration with renewables→	Passive and active solar strategies integrated into the building and adoption of tele heating.

10. Monitoring of performance

In construction

References

1. www.arketipomagazine.it. [Online]

2. www.ordinearchitetti.mi.it. [Online]

3. www.city-life.it. [Online]

4. www.ecsd.it. [Online]

5. MOLA, F. Isozaki tower (CityLife complex): a new office building in Milan. Technical-scientific seminar on Analysis and design of tall building structures, ECSD Srl.

6. www.issuu.com/studioiorio/docs/sio_general_booklet_2013. [Online]

7. Verticalità senza fine, IOARCH. Fare architettura in Italia, n.44, October 2012.

8. www.urbanfile.org. [Online]

Construction site
- Photos [8]

3.3 RESULTS AND DISCUSSION

3.3.1 GENERAL CONSIDERATIONS

The present analysis in addition to a panorama of various design solutions show a chronological development of the last 20 years (Table 3.5) of the concept of sustainability within the building that, looking at the future, aims to the EnergyPLUS. The examples go through the early cases where passive solutions were predominant to the latest examples where the exploitation of renewables is the leading goal and passive strategies are already ascertained.

Specifically, no one of the buildings presented are really NZEB, despite they are famous for their low-energy level according to the time they were built.

Many examples presented are located in Germany, which represents the leading country in the energy design and that by 2020 aims to reduce by 20% the primary energy consumption, by 40% the greenhouse gas emissions and to increase from 20% to 60% the share renewable energies [3]. In this country, the low-energy design is by now strengthened and large-scale plans are carried.

On the other side, Italy with its long-term of acceptance of projects, a confused and uncompleted legislation and its monumental and historical heritage, is in late on experimentation; it has few projects on big scale and new low-energy buildings appear isolated cases.

In addition, if the energy goal especially for low-rise buildings is consolidating and it is projecting to the zero aim (as in Germany), the same results are more difficult to reach for the high-rise type. This firstly occurs for the intrinsic fact that tall buildings have higher consumes more difficult to reduce and secondly, during the design phase, sustainable criteria are beside to structural problems, safety management aspects, etc. In this sense, Europe have less experience on such buildings comparing to Asia and USA. Table 3.6 shows that the tallest offices are located in China and USA.

1999	• IGUZZINI ILLUMINAZIONE (IT) • GSW HAUS (DE)
2002	• POLLMEIER (DE)
2005	• FEDERAL ENVIRONMENTAL AGENCY (DE)
2009	• ROPEMAKER (UK)
2012	• UNIPOL TOWER (IT)
2018	• ISOZAKI TOWER (IT)

Table 3.5: Chronological chart of case studies

1. **Burj Khalifa** (Dubai, United Arab Emirates, 2010, 828m)
2. **Taipei 101** (Taipei, Taiwan, 2004, 508m)
3. **Shanghai World Financial Center** (Shanghai, China, 2008, 492m, Mixed use)
4. **International Commerce Center** (Hong Kong, China, 2010, 484m, Mixed use)
5. **Petronas Towers** (Kuala Lumpur, Malaysia, 1998, 451,9m)
6. **Nanjing Greenland Financial Complex** (Nanjing, China, 2010, 450)
7. **Willis Tower** (Chicago, United States, 1974, 442,1m)
8. **KK100** (Shenzen, China, 2010, 441,8m, Mixed use)
9. **Guangzhou International Finance Center** (Guangzhou, China, 2010, 437,5m, Mixed use)
10. **Trump International Hotel & Tower** (Chicago, United States, 2009, 423,4m, Mixed use)

Table 3.6: World tallest office buildings in 2014 [4]

1. **Porta Nuova Garibaldi Towers** (Milano, 2011, 215m, Mixed use)
2. **Palazzo Regione Piemonte** (Torino, Under construction, 209m)
3. **Isozaki tower** (Milano, Under construction, 207m)
4. **San Paolo Bank Tower** (Torino, Under construction, 167,3m)
5. **Palazzo Lombardia** (Milano, 2010, 163m)

Table 3.7: Italian tallest office buildings in 2014 [4]

In fact, in these continents are rising the firsts "green" skyscrapers where the integration with renewables and the use of recycled materials appear fundamental (Figure 3.2 and Figure 3.3). The following part briefly describes some aspects of the sustainable design for offices extracted from the previous analysis.

A) Connection with the context;
B) Reduction of heating demand;
C) Reduction of cooling demand;
D) Maximization of daylighting;
E) Protection from glare and sun radiation;
F) Maximization of natural ventilation;
G) Ecology of building materials;
H) Protection from noise pollution;
I) Integration with renewables;
L) Optimization of operations.

Table 3.8: Lists of goals

Figure 3.2: The Hearst Tower, New York City (USA), 2006. The tower, designed by Norman Foster and by WSP Cantor Seinuk (structure), is a 46-storey tall (182m) with 80000m^2 of office space. The building received the 2006 "Emporis Skyscraper Award" as best skyscraper in the world completed that year. It is first green high-rise office LEED Gold in the city and the main sustainable aspects are:
- minimizing overheating with the envelope that has high performance low-emission glass with roller blinds to reduce glare and the building is also naturally overshadowed by the surrounding;
- diagrid structure uses 20% less steel and it is built using 85% of recycled steel; etc. [5]

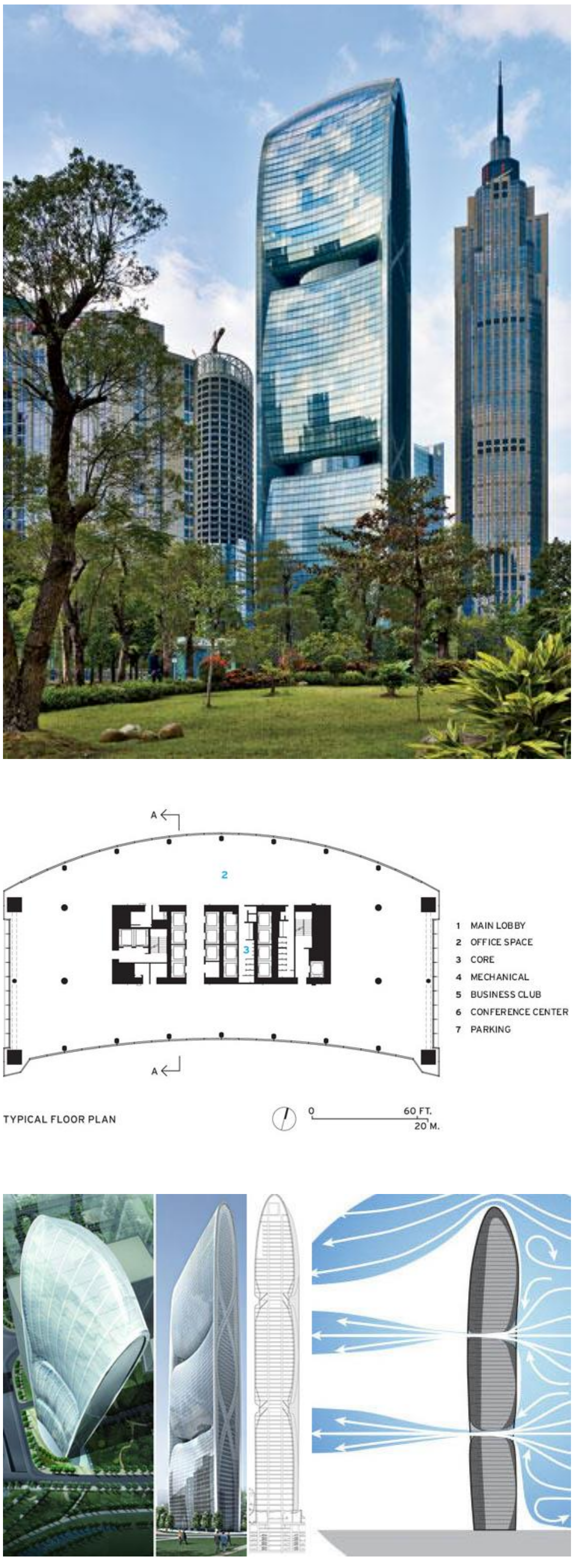


Figure 3.3: The Pearl River Tower, Guangzhou (China), 2011. It is a 71-story (309,7m) building designed by Skidmore, Owings & Merrill with AS+GG architects.
The building (212165 m^2) includes wind turbines and solar collectors, photovoltaic cells, raised floors ventilation, radiant heating and cooling ceilings.
It saved the 58% of energy of a similar stand-alone building. [6, 7]

3.3.2 EXTERNAL LAYOUT

The cases are located or in recent renovated areas (ex. Federal Environmental Agency, GSW Haus, Centro Leoni, Unipol Tower, Isozaki Tower) or in suburbs closed to the industrial zone as production support (ex. Pollmeier, Iguzzini Illuminazione) or in administration district center (ex. Ropemaker).

The external layout and the relative position of the building generally follow these requirements:

- position of the building to avoid shadows from the surroundings for a better control of the shades and of the relative system of shading devices (ex. all cases);
- avoid external car parks preferring the disposition on the basement to maximize the external green areas and to reduce the asphalt presence for the minimization of the heat island effect. This also permits to have more space to exploit as public zone (ex. Centro Leoni, GSW Haus, Ropemaker Place, Unipol Tower, Isozaki tower);
- adoption of paving materials with high reflectance coefficients to reduce overheating in summer (ex. Isozaki tower);
- maximization of green areas and adoption of local plants that have less water need (ex. Ropemaker Place, Unipol tower and Isozaki tower);
- disposition of vegetation as natural barrier to protect from prevalent winter winds using evergreen plants (positioned on North, North/East, North/West fronts) or fleeting trees (to shadow the South, East and West fronts). Despite, the use of vegetation for the exterior space of office buildings appears recurring either to shadow external car park (ex. Iguzzini) or to improve the outdoor microclimate rather than a real protection barrier for the building (as used in residential typology);
- promotion of: public transports through the creation either of new bus lines or tube lines (ex. Centro Leoni, Unipol tower, Isozaki tower); low-emission and electric cars trough specific parks dedicated (ex. Centro Leoni, Ropemaker Place, Unipol tower); new pedestrian and bike routes (ex. Centro Leoni, Ropemaker Place, Unipol tower, Isozaki tower).

Looking at the differences between low-rise and high-rise types, the following considerations can be made:

- <u>FOR THE LOW-RISE TYPE:</u>
  The footprint of the building reduces the outside free area available; anyway, the building can absorb the surrounding bringing to the interior (ex. into the atrium, Federal Environmental Agency and Centro Leoni). In addition, the shadow created by the building is quite contained and, if the exterior area is wide, it could be possible the adoption of horizontal geothermic pumps for heating and cooling (ex. Federal Environmental Agency);

- <u>FOR THE HIGH-RISE TYPE:</u>
  This category permits a bigger exterior area available to dedicate as public space. The block, generally, is totally conceived on itself even if it is possible the creation of a slab block of 2-3-storey that amplifies the base of the building (ex. Gsw Haus and Isozaki Tower) receiving, for example, either the main entrance or retail spaces, etc. In such case, the lower building is generally positioned along the perimeter of the area and has the function of connection with the context (ex. Gsw Haus). In addition, the aerodynamic shape that generally characterizes high-rise buildings, influences the microclimate in terms of comfort ventilation thanks the creation of vortex and pressure differences. For such reason, the position of outdoor public spaces is preferable in the leeward position (ex. GSW Haus).

3.3.3 ORIENTATION AND GEOMETRY

The solar radiation generally drives the orientation of the building more than the direction of winds. This because winds are less controllable, they can be deviated by the application of artificial and natural barriers and the effect on the energy performance is more uncertain.

Therefore, it is possible to exploit winds either through the rotation of the main axe on a perpendicular position to the prevailing ones (ex. Iguzzini Illuminazione and Gsw Haus); or applying an extra angle to increase the leeward combined with a contained depth of the building to permit a cross ventilation (ex. all examined cases).

North and South fronts are the best orientations for offices considering the solar radiation [2]. Despite this orientation can be changed either of a small angle (±15° from the North), without influencing the performance, or in order to meet a compromise with the prevailing wind directions or, for example, for geometrical restrictions related to the urban area.

- <u>FOR THE LOW-RISE TYPE:</u>

  The following geometries characterize the typical floor plan: square, circle, rectangle (mostly with an atrium), L, U, C or articulated (Figure 3.4).

  Specifically, the rectangle can be disposed with the main axe East/West to catch the best solar radiation. The square geometry, with workplaces along each sides, can privilege the rotation of axes of an angle of 45° from the North to maximize the fronts with North/South exposition. Despite all, this entails intermediate conditions (fronts are oriented North/East, North/West, South/East and South/West) with a consequent necessity of increasing the performance of the facades (especially in relation to the shading devices).

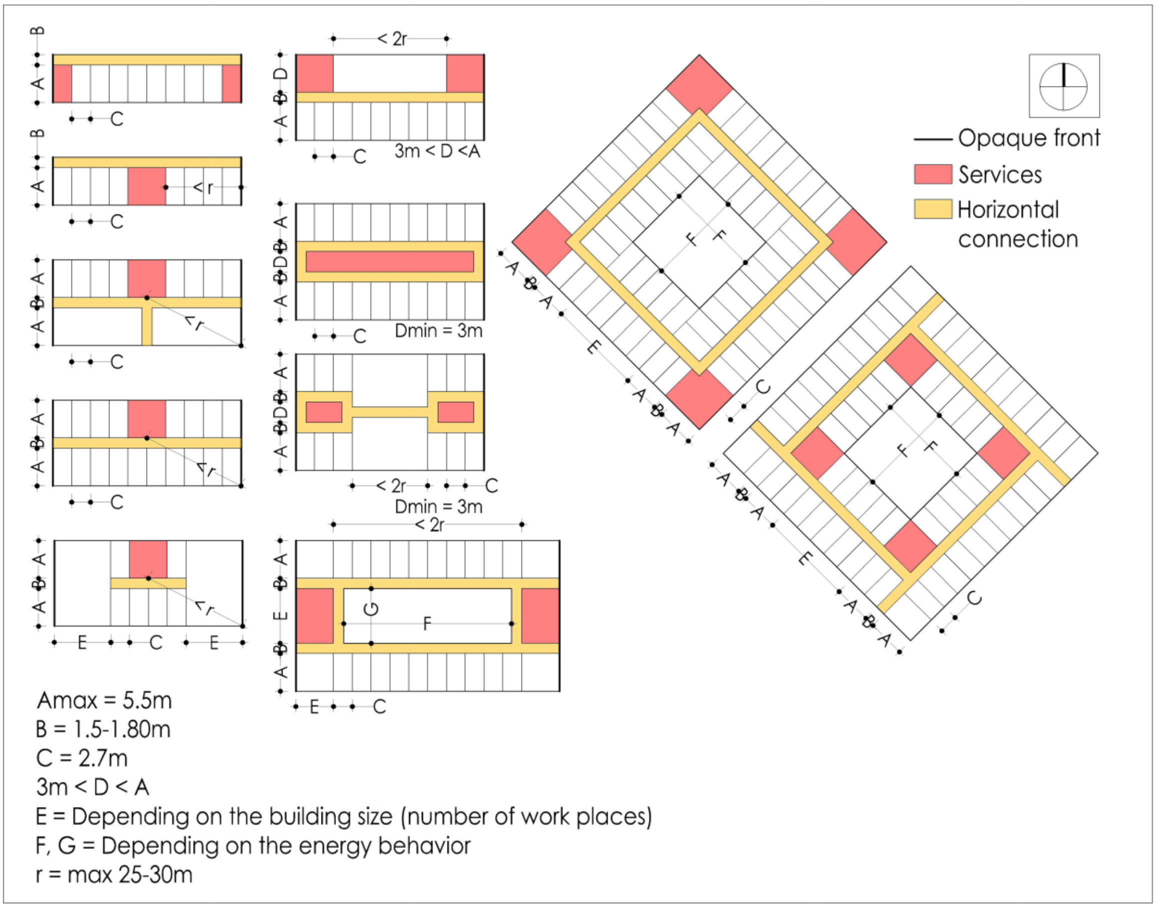


Figure 3.4: Low-rise buildings with a wide floor plan: internal layout according to the orientation [8]

[2] Such orientation permits a better control of the indoor conditions.

The articulated shape (ex. Federal Environmental Agency) can help to catch the best orientation for some parts of the building and meet other needs, for example, imposed by the relation with the context.

Despite all, even if in Italy, the rectangular shape is traditionally one of the most representative [9], in new low-rise buildings the presence of an atrium appears the most representative in Italy as in Europe. In fact, increasing the facade area, this solution permits the double facing of offices, the maximization of daylight and the increasing of natural ventilation (Paragraph 3.6);

- <u>FOR THE HIGH-RISE TYPE:</u>

  The direction of winds and their relation to the block is primary. This occurs firstly to reduce the impact of horizontal forces on the structure and secondly to exploit the ventilation. In such case, the building is oriented according to winds and the shape usually follows the wind dynamics preferring circle geometry of the floor plan (ex. Mary Axe, Figure 3.7), deforming the rectangle in a "boomerang geometry" (ex. GSW Haus), adopting round corners (Figure 3.6), until the twisted one for the skyscrapers (Figure 3.8).

  Even if the orientation of such buildings does not find the best disposition according to the solar radiation, huge transparent facades are common (ex. all high-rise examined cases).

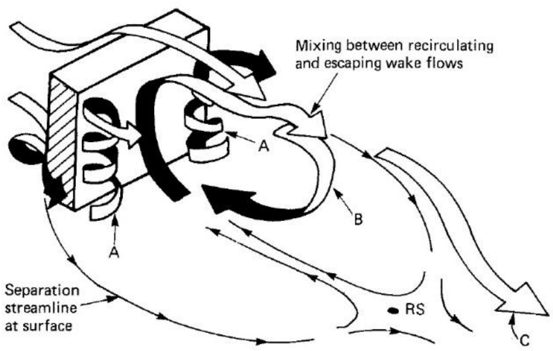


Figure 3.5: Wake circulation behind slab block (RS, rear stagnation point), Page 174 [10]

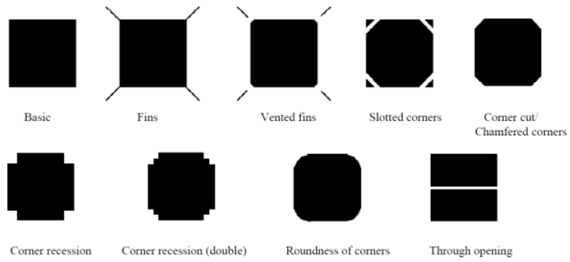


Figure 3.6: Aerodynamic variations of the corner geometry, Figure 1 [11]

Figure 3.7: Example of high-rise building with circle geometry, Mary axe, designer: Foster and Partners, London (UK), 2004

Figure 3.8: Example of twisted building, Chicago Spire, designer: Calatrava, Chicago (IL) [12]

3.3.4 INTERNAL LAYOUT

Looking at the floor type features, the following considerations are valid:

- lowered building depth (between 12m and 13m) to permit either cross ventilation and good level of daylight (ex. all examined cases). The relations between dimensions for the floor plan with a central corridor and double strips of offices, are the followings (Figure 3.9):

> Daylight inside the office: $\mathbf{A_{max} \le 5.5\text{-}6m}$
> Natural ventilation [13]:
> Horizontal ventilation with one opening: $\mathbf{A_{max} < 2C}$
> Horizontal ventilation with two or more openings: $\mathbf{A_{max} < 2.5C}$
> Cross ventilation: $\mathbf{(A+B+A)_{max} < 5C}$

- combi-office layout (ex. Centro Leoni, Ropemaker Place), where it is preferable disposing the cell-offices on North front (for a better control of the indoor comfort conditions); while open-offices on South side;[3]
- vertical connections, meeting rooms, café area, etc. can be preferably disposed to the extremes East and West (ex. Isozaki Tower) that can be mainly opaque (ex. Iguzzini Illuminazione) to reduce overheating in summer. Otherwise, they can be positioned on the North front. In such cases, they constitute buffer zones. However, if the geometry is linear, private offices and staircase blocks are placed side by side (ex. Federal Environmental Agency);
- small meeting rooms are generally positioned at every level relegating the more representatives to the ground floor close to the entrance (ex. Federal Environmental strategy) or to the upper floor (ex. Iguzzini);
- technical spaces are positioned either on the basement (ex. Federal Environmental Agency and Ropemaker Place) or in the last floors on top (ex. GSW Haus, Isozaki tower).

➢ FOR THE LOW-RISE TYPE:
The ground floor is the place with the main entrance, common spaces as café, meeting rooms, atrium, etc. The atrium appears as a semi-public space, opened or closed, often a sort of garden where plants and water improve the microclimate conditions of the offices overlooking (ex. Figure 3.10 and Iguzzini).

➢ FOR THE HIGH-RISE TYPE:
Ground and first floors can contain services (ex. café, hall) and thy can be characterized by the open space with double height to increase daylighting.

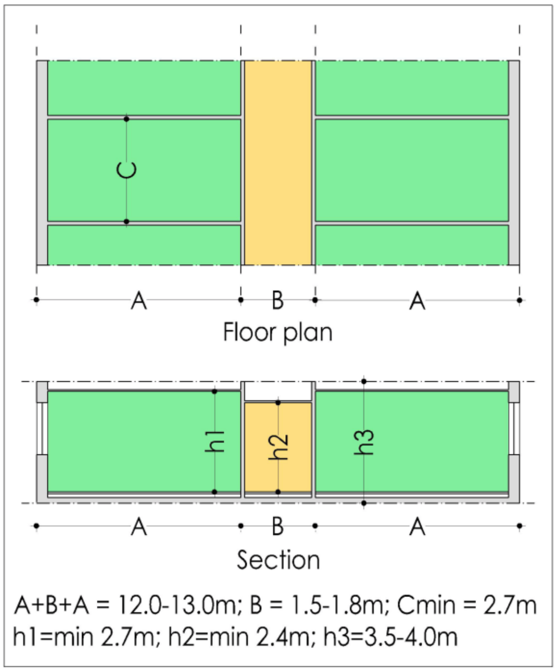


Figure 3.9: Design recommendations for office buildings

Figure 3.10: Federal Environmental Agency, atrium

[3] It is more difficult to reach good comfort levels in open-space where many people works. For this reason, the disposition on South front appears to be better for its easier way to control.

3.3.5 STRUCTURE AND ENVELOPE COMPOSITION

Looking at the structure and at the envelope composition, some considerations are listed below:

About the **structure**:

- all of the typical considerations made generally on structures are valid;
- wood, concrete, steel and mixed materials are used privileging the adoption of regional materials.

About the **floor slab**:

- floating floors (for a better distribution of cables) are adopted in all examples analyzed to meet the flexibility requirements;
- the solution of the exposed concrete ceiling (or even just a portion of it, close to the windows) appears one recurring solar passive strategy. It is economically convenient (saving the cost of the false ceiling) and the ceiling works as thermal mass supported by a systems of windows on facades that permit both the solar radiation and the ventilation to enter (ex. Pollmeier, Federal Environmental Agency and GSW Haus). This contributes to cool the building during summer nights and storage heat during winter. In such case, systems are located either close to the facade or into the corridors (with interior partitions with grills);
- another strategy is the adoption of a radiant false ceiling that, integrated with the geothermic system, cools and heats the spaces.

About the **facade**:

- high thermal insulation is adopted for both the opaque and the transparent parts to reduce the heating demand. The thickness of the insulation layer depends by the climate conditions and the system type. Glasses are triple or low-e especially on North;
- airthigness of the envelope has to be guarantee for a better control of the interior conditions and, on the other side, an appropriate ventilation has to be planned;
- Window-to-Wall Ratio according to the orientation to contain heating and cooling demands without renouncing to a see-contact with the outside.

  For instance, one strategy is the maximization of large transparent surfaces on North and South fronts where offices are disposed (with appropriate shading devices) reducing or eliminating windows on East and West sides (ex. iGuzzini, Unipol tower, Isozaki tower). Otherwise, if offices are distributed along each fronts, different size of windows can be chosen according to the orientation (ex. Pollmeier, Figure 3.11);
- different glasses according to the orientation varying their energy and lighting properties (U, SHGC and VT) as Isozaki tower;
- protection from solar radiation and glare through: the presence of overhang in the upper part of the window (ex. Centro Leoni); upper floors in overhang respect the ground one (ex. Pollmeier); adoption of shading devices (fixed/movable, internal/external, horizontal/vertical); morphology of the window that is sloped or rotated in a part to self-shading (ex. Ropemaker place);
- design of the facade with the division into imaginary horizontal and vertical strips with opaque and transparent parts.

  For the opaque portion, it is possible the application of PV (Figure 3.13 and Paragraph 5.4). For the transparent part, some parts are fixed, others are openable by the users and others are automatically controlled according to indoor/outdoor conditions (upper and lower part as in Iguzzini Illuminazione, lintel for Federal Environmental Agency, Figure 3.12). This last strategy contributes to guarantee natural ventilation, direct free cooling and is linked to the design of interior partitions;

From the considerations explained above, it is evident that the offices require a high automation level of the envelope connected with a control system of the indoor conditions. In fact, it appears necessary that the building transform itself according to the variation of the outdoor climate conditions operating in an active way. For example, shading devices activated to protect from overheating or openings for the night cooling.

About the **roof**:

- offices have generally flat roofs that could be either opaque allocating solar collectors or green (ex. Ropemaker Place) to improve the thermal indoor comfort;
- high thermal insulation level.

Figure 3.12: Grill for night cooling, Federal Environmental Agency, [15]

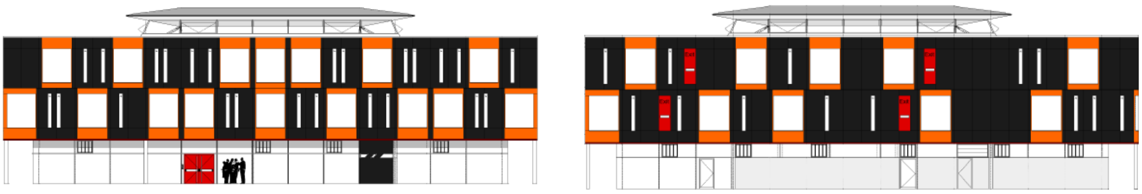


Figure 3.11: Example of different WWR, Pollmeier, North (left) and West (right) façades [14]

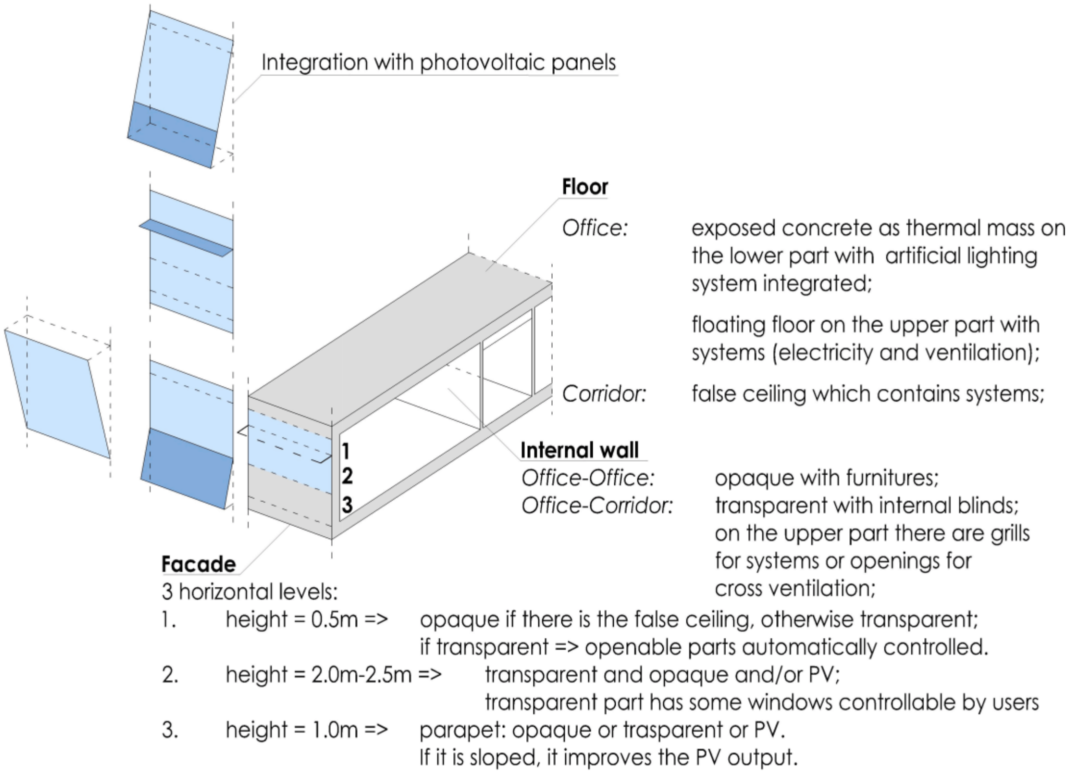


Figure 3.13: Design strategies for the envelope related to the South facade [8]

About the two main categories: low-rise buildings are characterizes by a wider range of technical solutions. This because buildings with a moderate height can be controlled easily and passive strategies for the maximization of natural ventilation and daylighting can be applied. On the other hand, the realization of tall buildings focuses overriding on the response of the structure to the wind action and transparences (often on the entire facades) become the main strategy applied thanks to efficient glasses.
The next Paragraph focuses on the different declination that some passive strategies have according to the two categories (low-rise and high-rise buildings).

3.3.6 PASSIVE STRATEGIES

Passive strategies have different declination according to the classification of low-rise buildings with a wide floor plan and high-rise buildings with a narrow floor plan.
For example, for the first category, the creation of an atrium (open or close that involves the whole building height) appears recurring and it strongly influences the energy behavior of the entire building. On the other hand, for the second class, the insertion of the sunspace represents a strategy that involves between 2 and 4-storeys (generally located at the first levels or distributing along the entire height).

3.3.6.1 LOW-RISE TYPE

The atrium appears as a semi-public space, opened or closed, often a sort of garden where plants and water improve the microclimate conditions. From the energy point of view, it can be used for daylighting the spaces overlooking, cooling, heating and ventilating the whole building. This is reached through the exploitation of the greenhouse effect, the cross ventilation and the chimney effect.
It represents a place with intermediate climate conditions between outside and inside, where the operative temperature has a range of 5K-10K of difference comparing to the outside [1].

However, the atrium can also present some critical aspects in relation to the overheating during summer period (especially if it is covered by a transparent roof), to the relevant thermal dispersions during winter and to the discomfort created by the air stratification.

Figure 3.14: Example of core atrium, Gotz Headquarters, designer: Weber e Geissler, Wurzburg (DE), 1995, Page 131 [16]

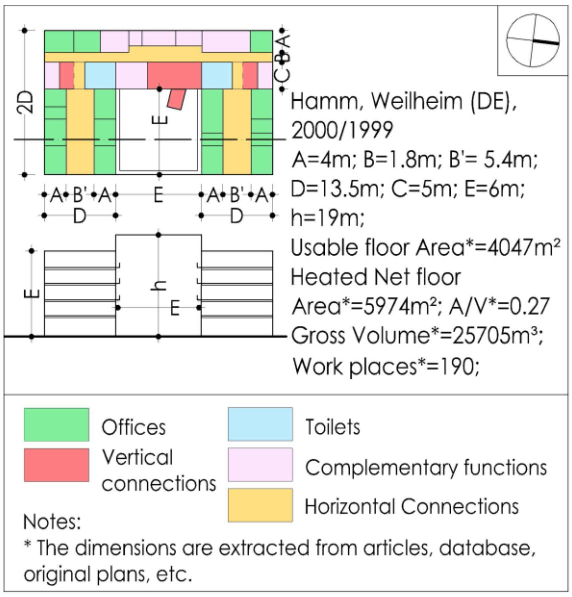


Figure 3.15: Example of decentralized atrium, Hamm, Weilheim (DE), 2000-1999, Figure [15] and sketch

It is important to define, during the design phase, the following aspects related to the atrium [17]:

- the position and the relation with the building (attached atrium, linear atrium, integrated atrium and core atrium, Figure 3.16);
- the geometry and the dimensions: the relation between the two dimensions influences the quality of the daylight (ex. the facades can generate shadows on each other) and of natural ventilation;
- the height and the relation with the building: if the atrium is higher, it is possible: to allocate vertical openings into the difference of heights for the ventilation; to slope the roof in order to improve the diffuse solar radiation (ex. Iguzzini Illuminazione);
- the choice between covering the atrium with a roof (and the consequent connotation as an interior space with a reduction of A/V ratio) or leaving as an exterior space (with the consequent growth of the A/V ratio);
- the morphology of the roof that can improve: the natural ventilation (ex. through the creation of chimneys or exploiting the effects generated by aerodynamic shapes) or the daylighting (ex. increasing the diffuse solar radiation through a sloped geometry) or can integrate PV modules;
- the type of envelope and the relation with the exterior one in order to guarantee ventilation and night cooling through a system of automatic openings;
- the automation level.

From the analyses, the buildings with a core atrium result of particular interest.
This configuration is ascribable to the following cases:

1) the building with a linear block (simple or double strips of function) has a longitudinal development which becomes too important that it closes on itself creating a central space (Figure 3.17);
2) the building has a triple body with the width of the central strip too deep. In such case the building requires an emptying of the central part in order to improve daylighting (Figure 3.18);
3) the building is totally conceived with a polar symmetry related to a central atrium (Figure 3.19).

The atrium, for the cases 1) and 2), has a rectangular geometry with one main dimension; while for the case 3), it is generally a square. The dimensions of the atrium are important. In fact, for instance, if the atrium has a rectangular geometry with a big difference between sides (with the shorter one contained), it is possible to obtain good ventilation disposing the long side perpendicularly to the wind directions and privileging a vertical development with openings on roof (air velocity increases). On the other hand, such geometry will not permit a good daylighting of the spaces overlooking at a lower level.
On contrary, if the atrium has big dimensions, daylighting is guarantee, but with less effective ventilation benefit.

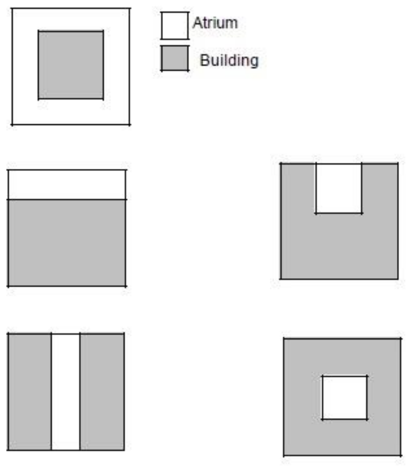


Figure 3.16: Types of atria [18]

In relation to the envelope, similar typological choices can be done for cases 1) and 2); while different considerations are valid for the case 3).

For the first two cases, the fronts of the buildings are generally disposed on the best orientation to capture the solar radiation. Therefore, the adoption of transparent facades, with a good system of shading devices, permits good level of daylighting and limits the overheating in summer. Hence, the technological solutions for the envelope consist, for example, in curtain walls with brise soleil or blinds.

On the other hand, for the case 3), the facades are not well oriented with problems of shading. In such cases, it is preferable to minimize the transparent parts or to adopt complex systems of the envelope as double skin facades.

For example, for the administration building Pollmeier, the fronts present a traditional different value of opaque/transparent, depending on the exposure. While, in the Gotz Headquarters (Figure 3.14 and 3.18), it is adopted a system of double skin facades naturally ventilated, which integrates fans for the repartition (through the cavity) of the heated air.

In addition, the atrium acts actively in combination with renewables. For instance, it can integrate photovoltaic modules into the transparent roof (the best angle and orientation of PV become the design criteria for the definition of the roof morphology) or thanks a ventilation strategy can be linked to the earth-to-air heat exchanger (ex. Pollmeier and Federal Environmental Agency).

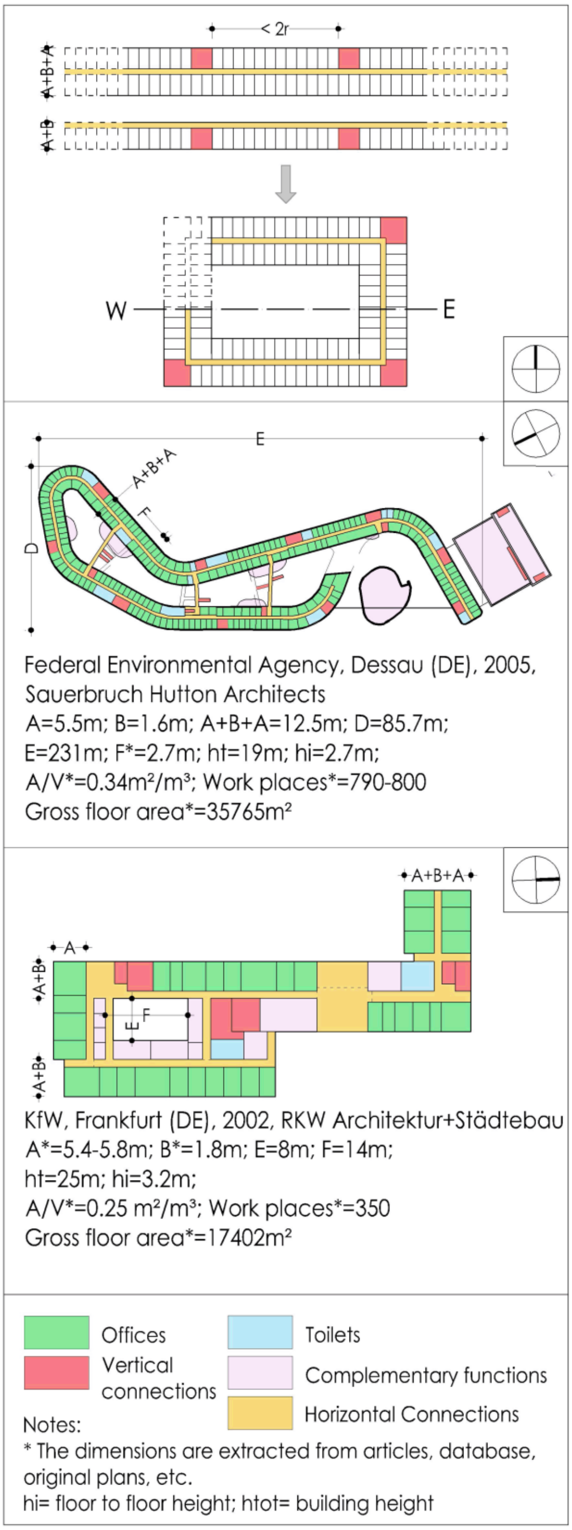


Figure 3.17: Summary of the case 1)

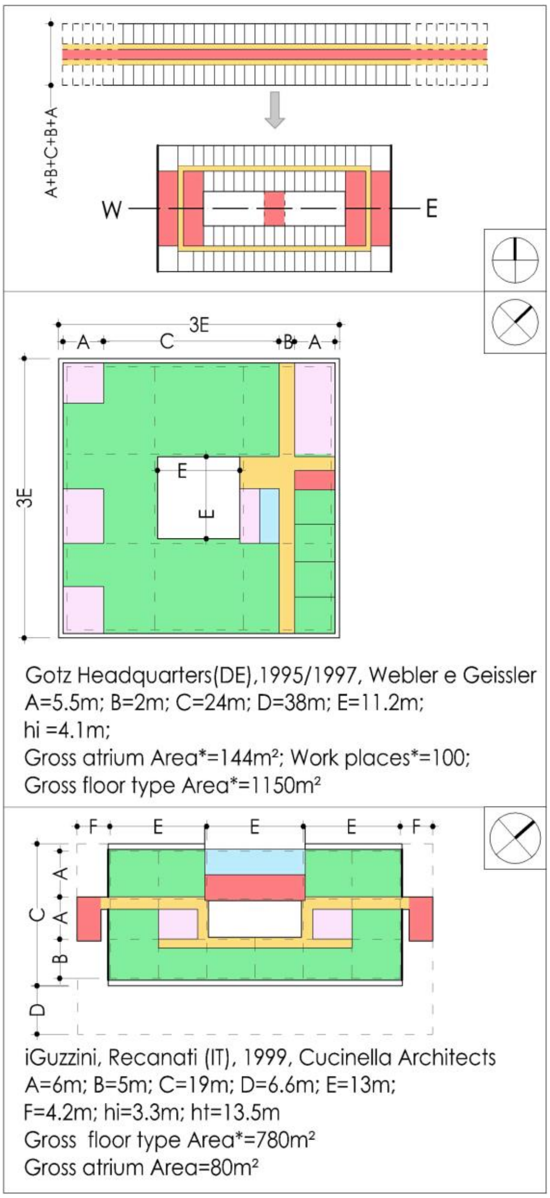


Figure 3.18: Summary of the case 2)

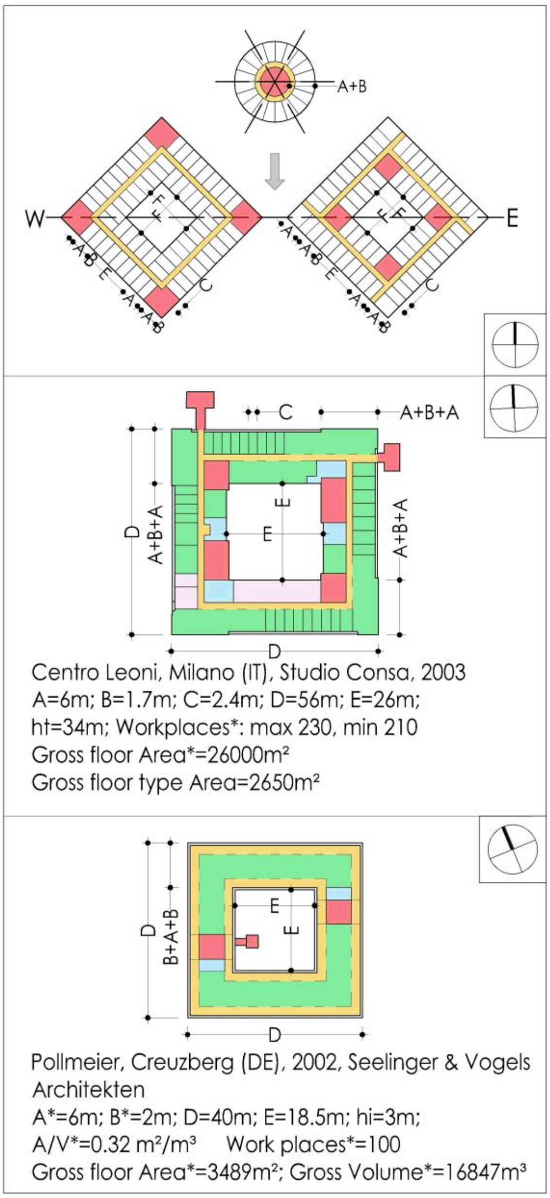


Figure 3.19: Summary of the case 3)

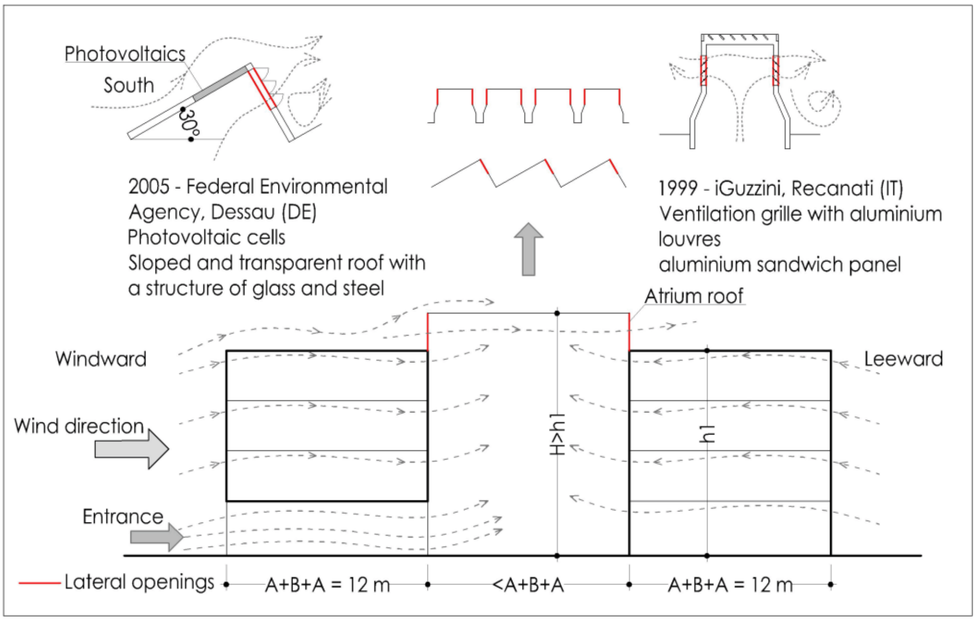


Figure 3.20: Morphology of the roof of the atrium

3.3.6.2 HIGH-RISE TYPE

High-rise buildings generally entail the following strategies:

- the presence of an atrium with 1-2-storey height that increases the daylight of the building core, usually close to the entrance (ex. Ropemaker Place) and having a function of hall/reception;
- sunspaces with a 1-4-storey height, that, if connected helicoidally and disposed along the perimeter, can privileging the circulation of air naturally within the building (chimney effect) as Mary Axe and Commerzbank (figures on right sides).
  In addition, to improve the microclimate, they can become a sort of winter gardens as for Commerzbank (Figure 3.22). Despite this, such solutions cannot solve completely the problem of the recirculation of air of such big buildings;
- the adoption of large transparencies to capture the solar radiation. Usually bigger fronts are totally transparent (WWR equal to 100%); while shorter fronts are mainly opaque (ex. Isozaki tower).
  If the facade is glazed on its entirety: on East, West and South fronts different types of double skin facades are common; while on North front, curtain walls are chosen. Specifically, double skin facades work differently according to the type (ex. box window type, shaft box type, corridor facade, multi-storey facade, etc.).
  For examples, the double skin facades of the Unipol tower have the passage of air trough horizontal corridors; while GSW Haus has facades with vertical air motion into the cavity, etc.
  Glazing are high performing with low U-value, low SHGC and high VT, in order to protect from heat losses in winter, to contain overheating in summer and to guarantee adequate level of indoor daylighting. In addition, transparencies are combined with sun shading devices either internal or disposed into the cavity of the double skin facade (ex. GSW Haus, Unipol tower, Isozaki tower).
  Alternatively, windows can be designed with a tilt angle to self-shading as in Ropemaker Place;
- contained depth of the building combined with the use of double skin facades (they works as buffer spaces) that permit natural ventilation of interior spaces.

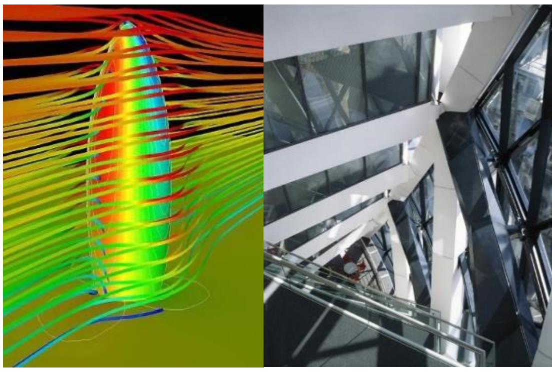


Figure 3.21: Mary Axe, London (UK), designed by Foster & Partners. Model with the wind forces dynamics and photo of the interior [19, 20]

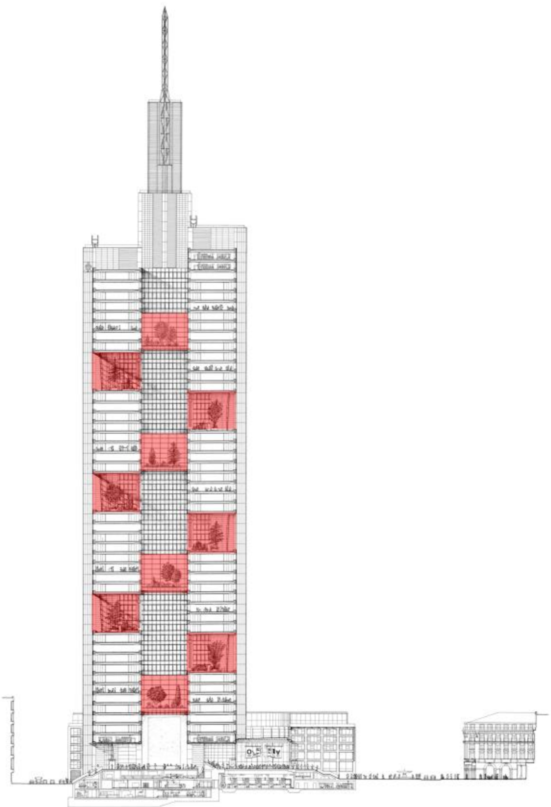


Figure 3.22: Commerzbank, designer: Fosters & Partners, Frankfurt (DE), 1997. In evidence sunspaces [21]

3.3.7 INTEGRATION WITH PHOTOVOLTAICS

The main recurring active strategies from the examples are the following:

- FOR THE LOW-RISE TYPE:
  The surface of the roof is wide and PV panels can be disposed (ex. Pollmeier and Federal Environmental Agency).
  The roof can be either flat allocating a mounting system (ex. Federal Environmental Agency) or sloped integrating PV as component (ex. Pollmeier). The first solution is easier to install and should be adopted especially in existing buildings; while the second one has high potential since PV become element of the envelope.
  The presence of the atrium with a roof can permit, with the appropriate morphology, also the integration of photovoltaics (ex. Federal Environmental Agency);

- FOR THE HIGH-RISE TYPE:
  PV systems can be integrated into the roof that is generally small and can be sloped to increase the surface available and the efficiency (ex. Unipol tower).
  Anyway, it is strongly recommended the integration into the south-facade where the area available is bigger (ex. Unipol tower).

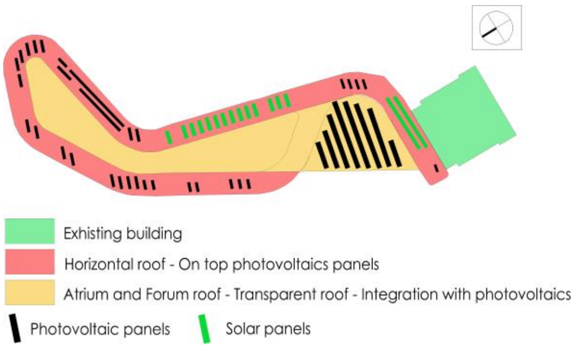


Figure 3.23: PV systems disposed on the roof of the Federal Environmental Agency

Figure 3.24: PV modules integrated into the roof of the atrium, Federal Environmental Agency

Figure 3.25: Example of PV integrated into the sloped roof and into façade, Unipol tower

Figure 3.26: Example of PV in the façade, Energy Base, Vienna (AU) [22]

TYPE	*DESCRIPTION*	*Low-rise buildings*				*High-rise buildings*			
		1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
ORIENTATION	N/S, E/W, NW/SE, NE/SW	NE/SW	NE/SW	NW/SE	N/S	N/S	N/S	E/W	NE/SW
BUILDING SHAPE	Linear								
	Tower					X	X	X	X
	Court	X	X	X	X				
GEOMETRY OF THE FLOOR-PLAN	Square	X			X		X		
	Rectangle			X		X			X
	Triangle								
	Trapezoid							X	
	Circle								
	C, L, U Shape								
	Articulated		X						
OFFICE LAYOUT	Cellular		X						
	Open-Office	X							
	Combi-Office			X	X	X	X	X	X
CONNECTIONS[4]	Vertical	E,W,c	N,S,E,W	E,W,N	N,E,W	N,c	S,E,W,c	E,W,c	E, W
	Horizontal	2r	1l	2l	1r	1l	-	1r	2l
STRUCTURE	Reinforced con.	X	X	X	X			X	
	Steel								
	Mixed					X	X	X	X
	Wood								
FLOOR	Concrete slab	X	X	X	X	X	X		X
	Mixed slab							X	
	Raised floor	X	X	X	X	X	X	X	X
FAÇADE	Trad. facade		X						
	Vent. facade	X		X	X			X	
	Curtain wall			X	X		X	X	X
	Double skin f.					X		X	
	SHADING DEVICES External	X		X	X		X		
	SHADING DEVICES Internal		X	X	X	X	X	X	X
	SHADING DEVICES Louvers (fixed)			X	X				
	SHADING DEVICES Blinds (movable)		X	X		X	X	X	X
	SHADING DEVICES Fabric	X			X				
ROOF	Flat	X	X	X	X	X	X		X
	Sloped							X	
	Curved					X			
	Opaque		X	X	X		X		X
	Transparent	X	X	X					
	Green	X					X		
PASSIVE SOLAR	Buffer zone	X	X	X	X	X	X		X
	Thermal mass	X		X	X	X			
NAT.VENTILATION & PASSIVE COOL.	Nat. vent.	X	X	X	X				
	Night cooling	X	X	X	X				
	Evapor. cooling		X						

[4] c=core; r=ring; l=linear

TYPE	***DESCRIPTION***	***Low-rise buildings***				***High-rise buildings***			
		1	***2***	***3***	***4***	***5***	***6***	***7***	***8***
HVAC	Heat pump	X	X		X				
	Fan coil system			X					
	VAV air system				X			X	X
	Biomass system	X					X		
	Heat recovery		X				X	X	
ACTIVE SOLAR (Photovoltaic)	NO BIPV		X				X		
	BIPV	X						X	
	Façade							X	
	Roof	X	X				X	X	
	Shading devices								

Table 3.9: Summary chart of buildings analyzed

REFERENCES

1. **BAUER, M., MÖSLE, P. and SCHWARZ, M.** *Green Building. Guidebook for Sustainable Architecture.* Berlin Heidelberg, Springer-Verlag, 2010.

2. **2009, Protocollo ITACA.** *Valutazione energetico - ambientale - edifici residenziali: nuova costruzione e recupero.* 3 Marzo 2009.

3. **FISCH, M. N., WILKEN, T. and STAEHR, C.** *EnergyPlus.* Leonberg, Univ. Prof. Dr. -Ing. M. Norbert Fisch, 2013, ISBN:978-3-00-041246-2.

4. **www.skyscraperpage.com.** [Online]

5. **www.fosterandpartners.com.** [Online]

6. **www.archrecord.construction.com.** [Online]

7. **www.openbuildings.com.** [Online]

8. **MICELI, S.** *Architectural Design for NZEB Office Buildings.* Prague, Conference Proceedings: Young Researchers in Sustainable Building, YRSB13, June 2013, ISBN:9788024750194.

9. **FABRIZIO, E, GUGLIELMINO, D and MONETTI, V.** *Italian benchmark building models: The office building.* Sydney, Conference Proceedings: 12th Conference of International Building Performance Simulation Association, 14-16 November 2011.

10. **COOK, N. J.** *The Designer's guide to wind loading of building structures. Part 1.* Garston, Watford, Building Research Establishment, 1985.

11. **AMIN, J. A. and K., AHUJA A.** *Aerodynamic modifications of the shape of the buildings: A review of the state of the art.* Asian Journal of Civil Engineering (Building and Housing), Vol. 11, n. 4, Pagg. 433-450, 2010.

12. **www.archrecord.construction.com/news/daily/archives.** [Online]

13. **GROSSO, M.** *Il raffrescamento passivo degli edifici.* Rimini, Maggioli Editore, 1997.

14. **www.zub-systems.de.** [Online]

15. **www.enob.de.** [Online]

16. **DETAIL, Solar architecture.** *Administartion building in Wurzburg.* DETAIL, Solar architecture, n.3, 1997.

17. **BAZZOCCHI, F., DI NASO, V. and MICELI, S.** *Toward NZEB Office Buildings.* Milano, Conference Proceedings: 39th World Congress on Housing Science, IAHS, Poliscript, vol. 2, pp. 135-141, 17-20 September, 2013, ISBN:9788864930206.

18. **EASE**, Guidebook. *Sunspaces and Atria.* Education of Architects in Solar Energy and Environment, Section 2.2.

19. **www.guardian.co.uk.** [Online]

20. **www.fosterandpartners.com.** [Online]

21. **www.pinterest.com.** [Online]

22. **www.solarwatt.de.** [Online]

23. **www.itaca.org.** [Online]

4. ENERGY PERFORMANCE OF THREE BASE CASES

CONTENTS

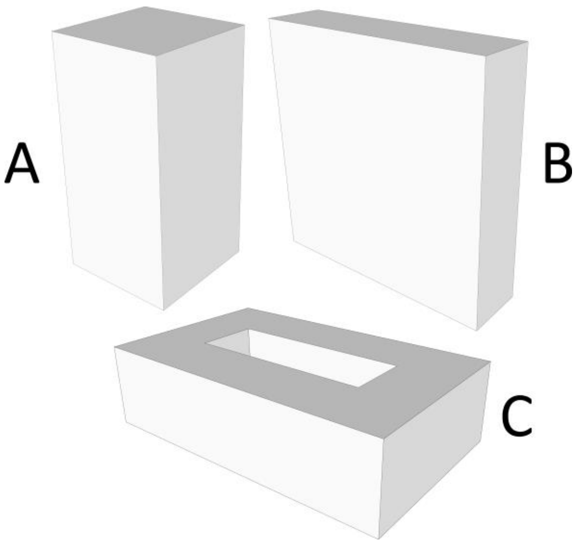


Figure 4.1: Base cases: A, B and C

INTRODUCTION

The present chapter shows the energy performance of three office buildings, as base cases (Figure 4.1), located in five Italian cities.
The base cases have different shapes, but equal volume, gross area, number of workers, building features, etc. Specifically, the cases A and B represent high-rise buildings (they differ for the geometry of the floor plan); the case C is a low-rise building with a core atrium (it represents the main recurring shape for its category, Chapter 3).
The chapter has the following purposes:
- identification of the cities that characterize the diversity of the Italian climate;
- definition of the cases representative of the office typology (they constitute the "base" for further improvements, Figure 4.2);
- determination of the influences that different shapes and systems have on the energy demand of the building.

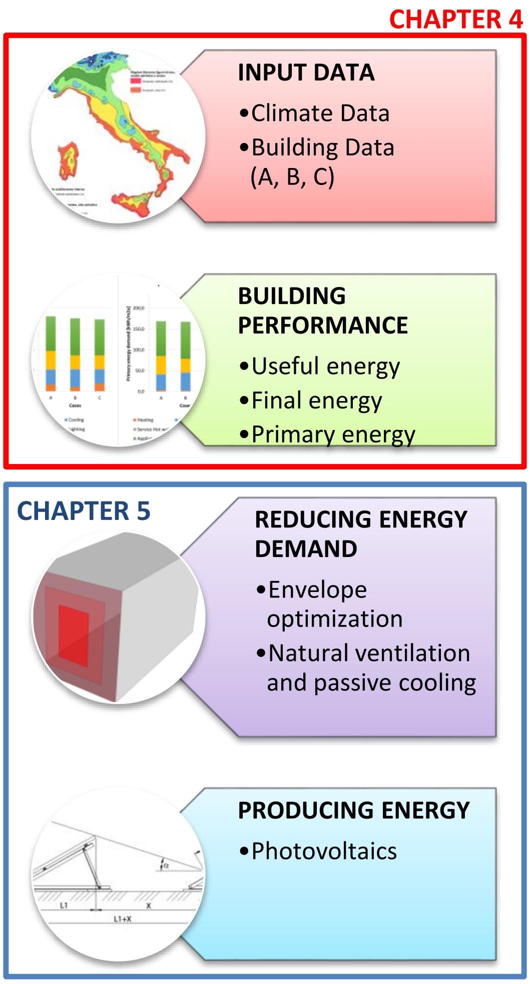


Figure 4.2: Summary Chart

4.1 CLIMATE CHARACTERIZATIONS BY LOCATION

Italy has a temperate climate[1] strongly influenced by the presence of Mediterranean; in fact, the proximity to the sea and the presence of mountains create different climate conditions such as it is possible to divide the territory in different climatic zones (from Figure 4.3 to Figure 4.5). Starting from the knowledge that climatic variables (temperature, wind, solar energy, moisture, etc.) affect the energy performance of the building depending by the time, five cities are selected for the models as representatives of the Italian climate.

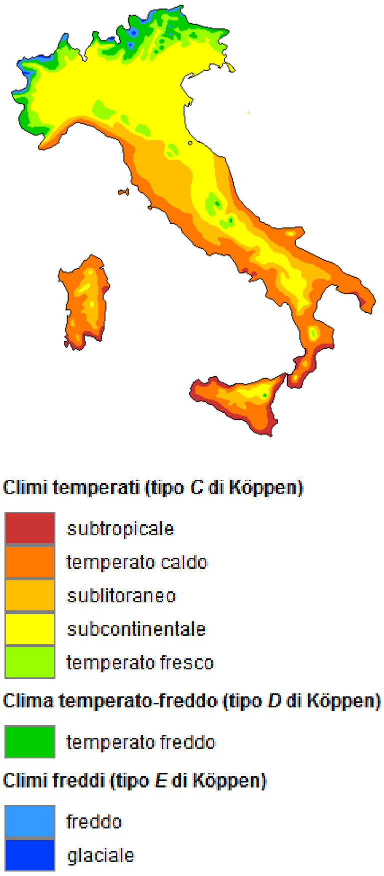


Figure 4.3: Köppen-Geiger climate classification for the Italian climate, Page 470 **[1]**

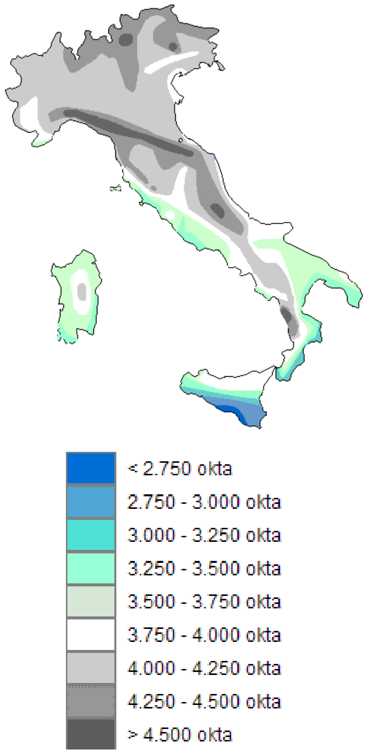


Figure 4.4: Map of the average annual cloudiness[2] in Italy, **[2]**

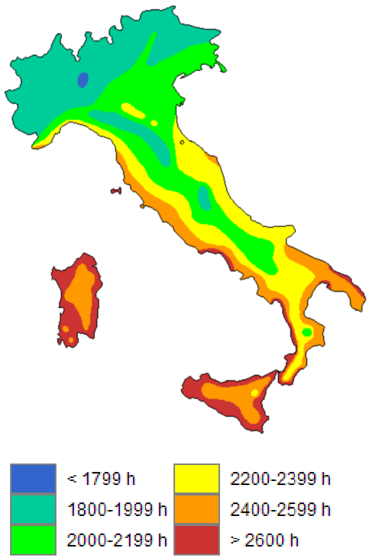


Figure 4.5: Map of yearly sunshine hours in Italy, Page 28 **[3]**

[1] Climate is classified according to the geographic distribution and to the scale (macroclimate, meso climate, topo climate, and microclimate).
M. Grosso defines the climate as "*la media delle condizioni meteorologiche di una località, di una zona, di una regione o di un intero continente, effettuata per un periodo di tempo sufficiente a evidenziare condizioni di tendenza stabili delle variabili atmosferiche*" [18].

[2] The sky conditions can be estimated in terms of how many eighths of the sky are covered in cloud. Okta is the unit of measurement used to describe the amount of cloud that cover a location. The value goes from 0 oktas (completely clear sky) to 8 oktas (completely overcast sky).

The locations are selected following the classifications described in D.P.R. n. 412/1993 [4] and in the ENEA Report[3] [5]. This is made because the national regulation (D.P.R. n.412/1993) presents a classification of the Italian territory only based on the heating period; while ENEA suggests a classification based on the cooling one. This second approach appears important to take into account since *"the spread of the summer air conditioning systems, with the consequence increase of the energy consumptions, renders necessary to proceed…to the definition of summer climatic zones"*[4].

Specifically, the national regulation subdivides the territory in 6 winter climatic zones (from A to F, Table 4.1) according to the Heating Degree-Days (HDD); while ENEA proposes a classification in 7 summer climatic zones (from A to G, Table 4.2) according to a summer index of climatic severity (V_c)[5].

ZONE	HDD [Kd]	HEATING PERIOD
A	< 600	1st December / 15th March
B	600-900	1st December / 31st March
C	900-1400	15th November / 31st March
D	1400-2100	15th November / 15th April
E	2100-3000	15th October /15th April
F	>3000	No limit

Table 4.1: Climatic classes considering the heating period - D.P.R. n.412/1993 **[4]**

	CLASSE						
	A	**B**	**C**	**D**	**E**	**F**	**G**
Range vettore climatico ridotto standard	< 1,493	1,493÷1,643	1,643÷1,744	1,744÷1,826	1,826÷1,898	1,898÷1,968	≥ 1,968
Valore centrale di C (*)	0,015	0,100	0,200	0,293	0,391	0,493	0,586

(*) L'indice di severità *C* è stato valutato riferendosi al modulo del vettore climatico ridotto standard traslato $\left|\vec{V}_C\right|_{std} - k(\mu)\left|\vec{V}_{C,ref}\right|_{std}$ con un valore medio rilevato per $-k(\mu)\left|\vec{V}_{C,ref}\right|_{std} = -1,468$

Table 4.2: Climatic classes considering the cooling period - ENEA Report **[5]**

CLASSE	COMUNI		POPOLAZIONE	
A	1348	16,7%	2.491.416	4,1%
B	1934	23,9%	7.581.426	12,6%
C	2412	29,8%	16.572.634	27,5%
D	1338	16,5%	13.642.109	22,6%
E	480	5,9%	9.470.466	15,7%
F	393	4,9%	6.011.219	10,0%
G	189	2,3%	4.582.057	7,6%
	8094	100%	60.351.327	100%

Table 4.3: Summer classes with the percentage of cities and the percentage of population **[5]**

Therefore, in order to select five Italian cities (Table 4.4), it is considered:

- both winter (D.P.R. n.412/1993) and summer (ENEA Report) classifications as indicators of the importance of the heating and cooling periods;
- classes both with the major number of people (Table 4.3) and with the higher summer index.

[3] Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile (ENEA).
[4] Pag. 3 [5]
[5] The Severity Climatic Index depends by the air temperature, the specific humidity and the solar radiation of a specific location and it is calculated following the method described in the ENEA Report.

EXAMPLES OF CITIES	CLASSIFICATION: KÖPPEN-GEIGER	CLASSIFICATION: D.P.R. n.412/1993	CLASSIFICATION: ENEA Report	CLIMATE	REFERENCE CITY
Sestriere Brusson, Mazzin Chamois, Livigno	Tundra (Et) Cold Continental (Dfc) Humid Continental (Dfb)	E	A	COLD	-
L'Aquila, Sondrio Potenza	Oceanic (Cfb) Mild Mediterranean (Csb)	E	B		
Milano, Torino, Venezia	Humid subtropical (Cfa)	E	C	COLD WINTER HOT SUMMER	MILANO
Bologna, **Firenze**		D	D	MILD	FIRENZE
Roma, Pescara	Mediterranean (Csa)	D	E		ROMA
Ragusa, Taranto **Napoli**		C	F G	HOT	NAPOLI
Palermo, Reggio Calabr. Messina, Salerno		B	F G		PALERMO

Table 4.4: Comparison between climate classifications and identification of the reference cities

The cities considered are the following (Figure 4.6):

- Milano (MI);
- Firenze (FI);
- Roma (RM);
- Napoli (NA);
- Palermo (PA).

Sheets from n.1 to n.5 show the climate characterization. They have same structure with the description of:

- the macroclimate;
- the typical winter and summer conditions in relation to the zone;
- the climate of the city. In this section, there are some graphics related to the annual average temperature; the solar radiation range, the illumination range[6], the wind velocity range and the psychometric chart. Specifically the results followed the ASRHAE Standard 55-2004 using the PMV model[7].

Specifically, information are extracted from the software "Climate consultant 5.5 BETA" while weather data came from the ASHRAE International Weather for Energy Calculation (IWEC) [6] and from UNI10349:1995 [7].

Figure 4.6: Identification of the cities selected on the territory

[6] For the city of Firenze, that graphic is not available.
[7] **PMV** = Predicted Mean Vote is the average comfort vote which uses seven point thermal sensation scale from -3 to +3 where 0 represents the ideal value of thermal neutrality. The PMV range (-0,5; +0,5) means that conditions are within the comfort zone.

ZONE: COLD WINTER & HOT SUMMER — Sheet n.1

DESCRIPTION

Subcontinental climate.
The cities considered have generally 2100<HHD<3000 and $1.643<V_c<1.744$ and they are characterized by cold winters and a warm/hot summers.
It encloses the Pianura Padana, Veneta and Friulana, the Northern Adriatic coast and some area of the Peninsular.

WINTER

It is cold with possible snowfall.
Average of the colder months:
1-2 months with average temperature 0-3 °C

SUMMER

There is a gap between winter and summer of 20°C.
Average of the warmer months:
2-3 months with an average temperature > 20°C

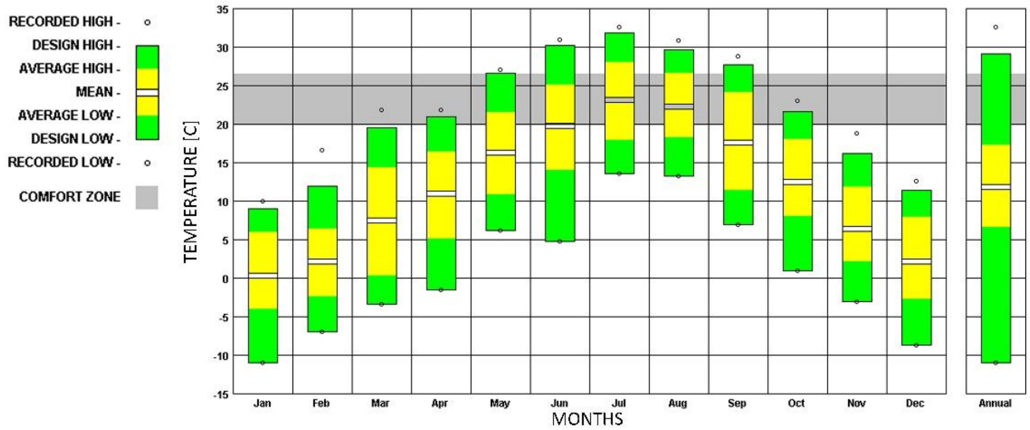
CITY

MILANO - Classification: E (D.P.R. 412/1993) /C (Enea Report)

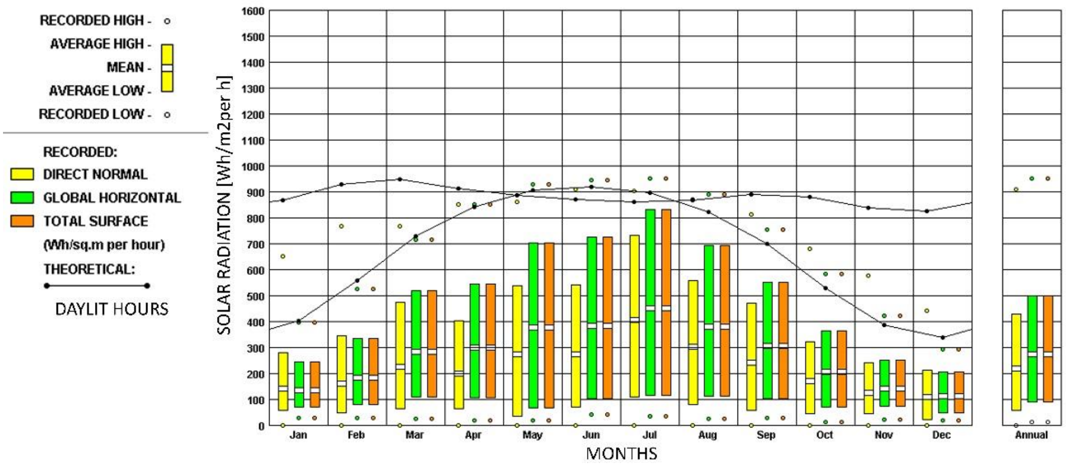
Altitude	Latitude	Longitude	HDD	V_c	Heating period
122	45.62°	8.73°	2404	1.789	15th October /15th April

Milano is located in the Po Valley and this position gives it a semi-continental climate. The winters are quite cold and the summers hot, humid and muggy. Precipitation is moderately high and it is possible the presence of fog. According to the psychometric chart, the 13% of hours during the year are in comfort zone this occurs especially for the low air temperature and for the relative humidity.

AVERAGE TEMPERATURE

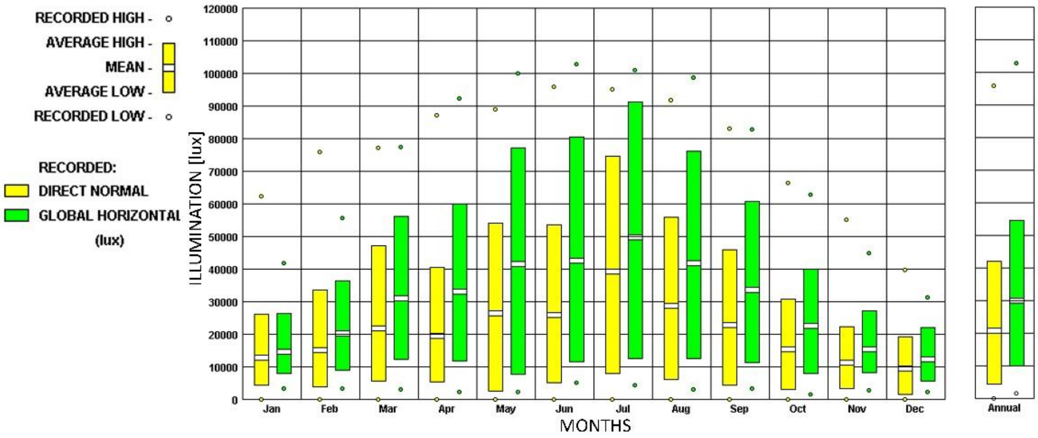


SOLAR RADIATION RANGE

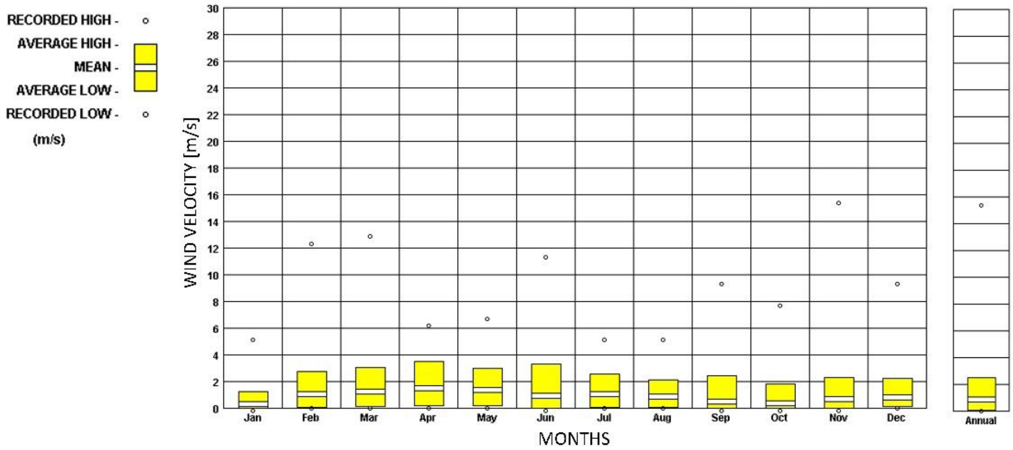


ZONE: COLD WINTER & HOT SUMMER Sheet n.1

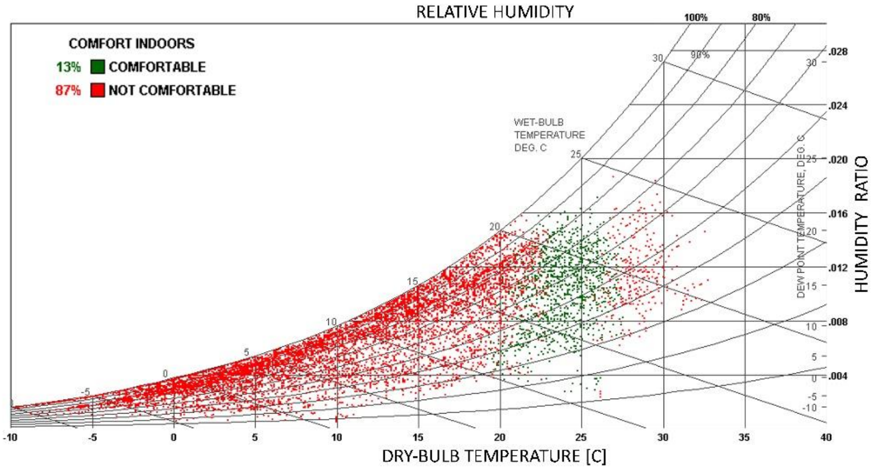
ILLUMINATION RANGE



WIND VELOCITY RANGE



PSYCHROMETRIC CHART



ZONE: MILD — Sheet n.2

DESCRIPTION	Temperate and sub-coastal climate. The cities considered have generally 1400<HHD<2100 and $1.643<V_c<1.826$ and they are characterized by a moderately cold winter and hot summer. Typical of the Liguria at low altitude and of the hilly areas of Preappennino Tusco-Umbro-Marchigiano.
WINTER	It is not particularly rigid. *Average of the colder months:* 2-3 months with average temperature < 10°C
SUMMER	There is gap between winter and summer of 20°C. *Average of the warmer months:* 3-4 months with an average temperature > 20°C

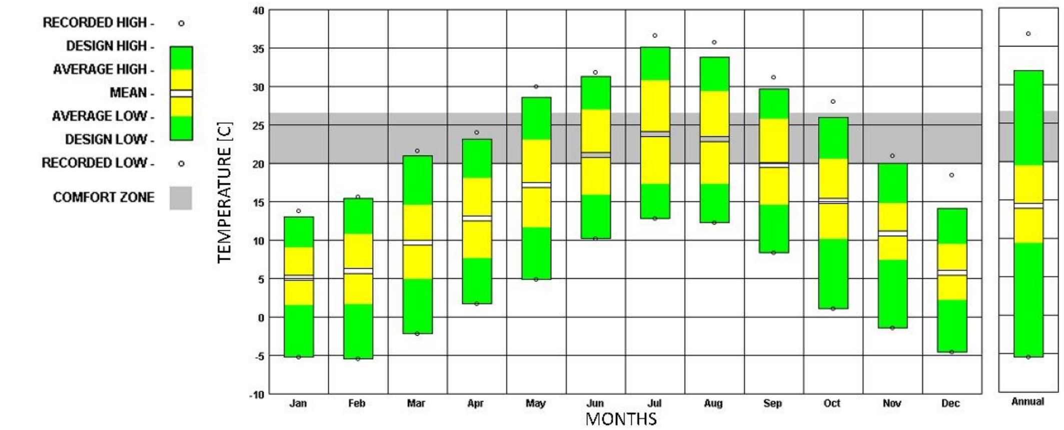
CITY

FIRENZE - Classification: D (D.P.R. 412/1993) /D (Enea Report)

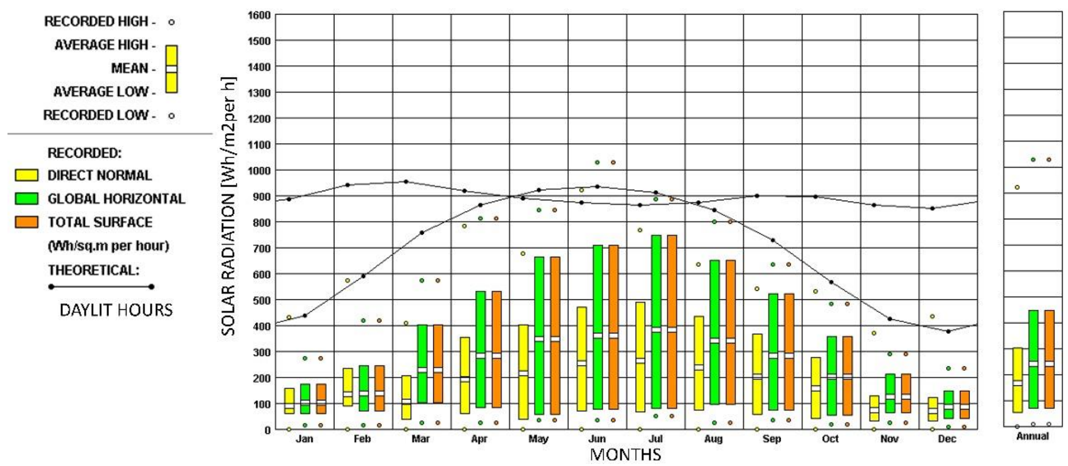
Altitude	Latitude	Longitude	HDD	V_c	Heating period
38	43.8°	11.2°	1821	1.79	1st November / 15th April

Firenze has a temperate climate with warm summers with sweltering episodes and moderately cold and humid winters. According to the psychometric chart, only the 12% of hours during the year are in comfort zone this occurs especially for the low and hot air temperature and for the humidity.

AVERAGE TEMPERATURE

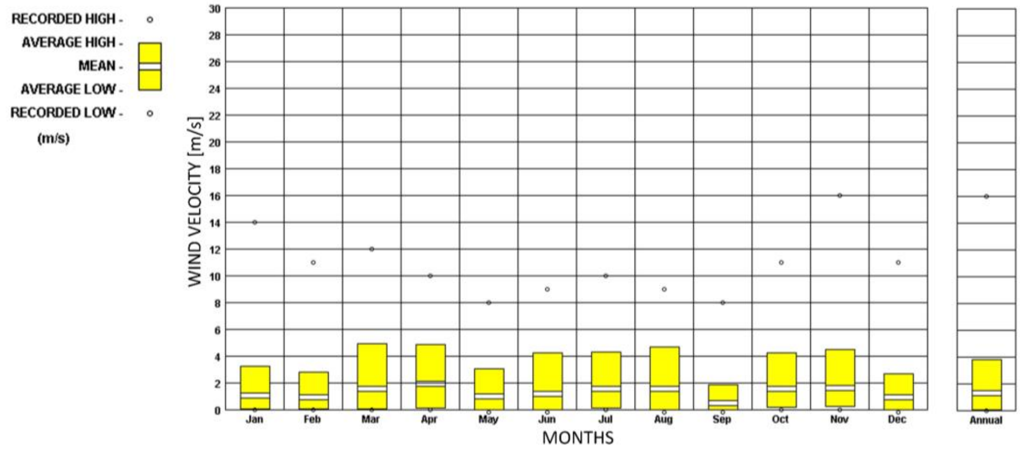


SOLAR RADIATION RANGE

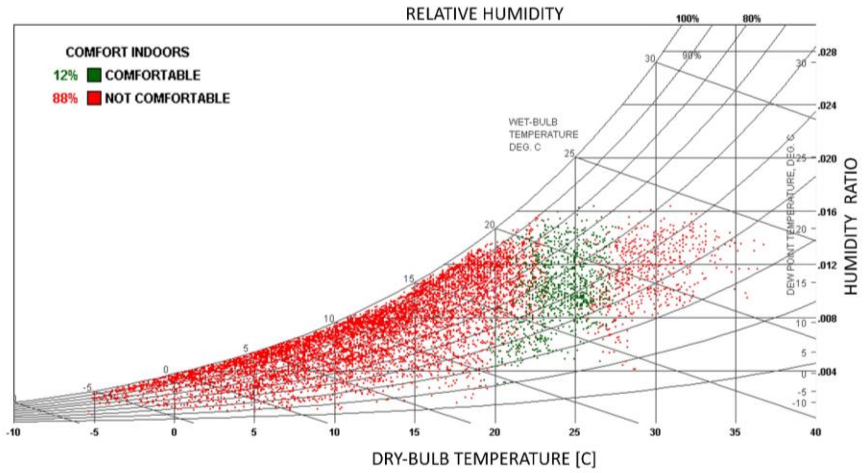


ZONE: MILD Sheet n.2

WIND VELOCITY RANGE



PSYCHROMETRIC CHART



ZONE: MILD	**Sheet n.3**
DESCRIPTION	Temperate Mediterranean climate with hot summer (Csa) The cities considered have generally 1400<HHD<2100 and $1.826<V_c<1.898$ and they are characterized by a mild winter and a warm summer. It is typical of the cities along the Peninsula.
WINTER	It is not particularly rigid. *Average of the coldest month:* 2-3 months with average temperature of 5°C
SUMMER	*Average of the hottest month:* 3-4 months with an average temperature > 20°C

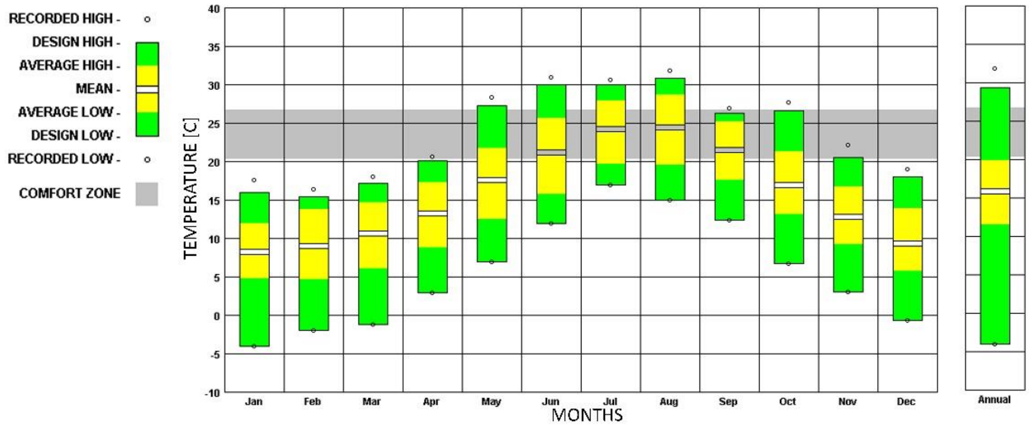
CITY

ROMA - Classification: D (D.P.R. 412/1993) **/E** (Enea Report)

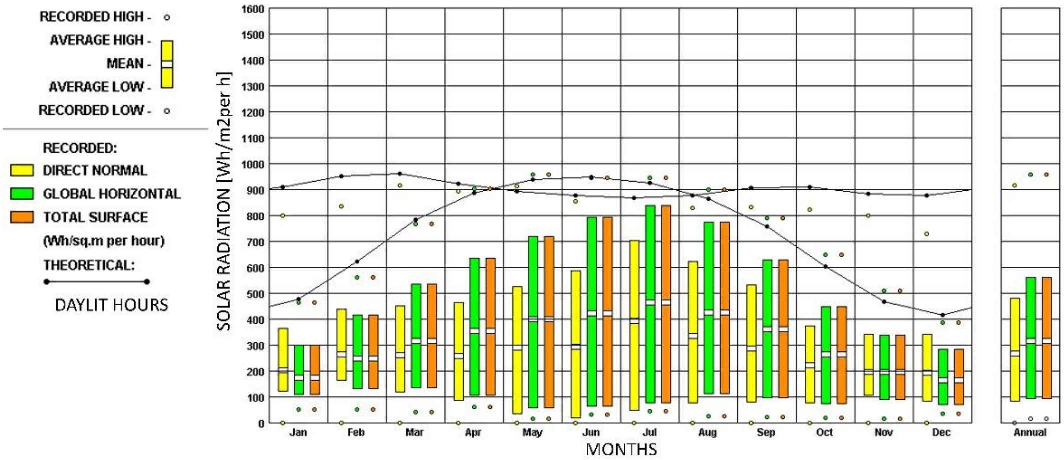
Altitude	Latitude	Longitude	HDD	V_c	Heating period
3	41.8°	12.23°	1415	1.886	1st November / 15th April

Roma has a Mediterranean climate. The wettest seasons are spring and autumn, the summer is hot and potentially drought, while winter is generally mild and rainy.
According to the psychometric chart, the 18% of hours during the year.

AVERAGE TEMPERATURE

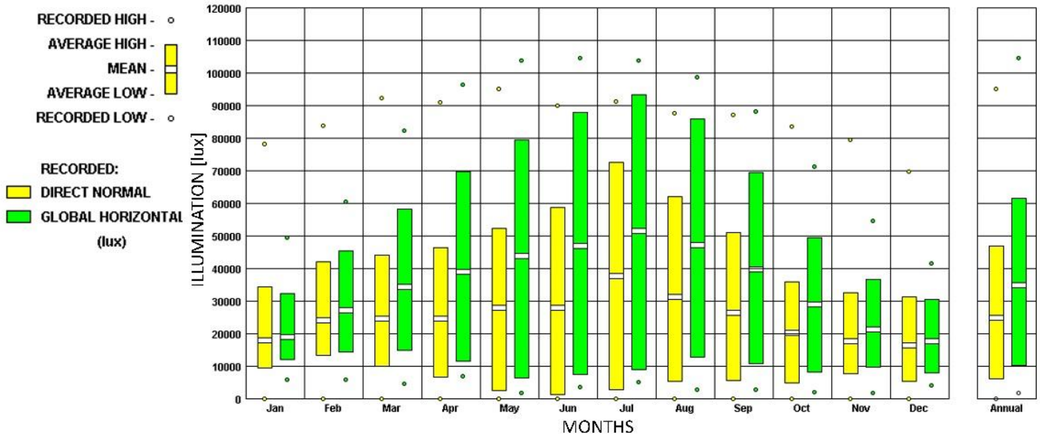


SOLAR RADIATION RANGE

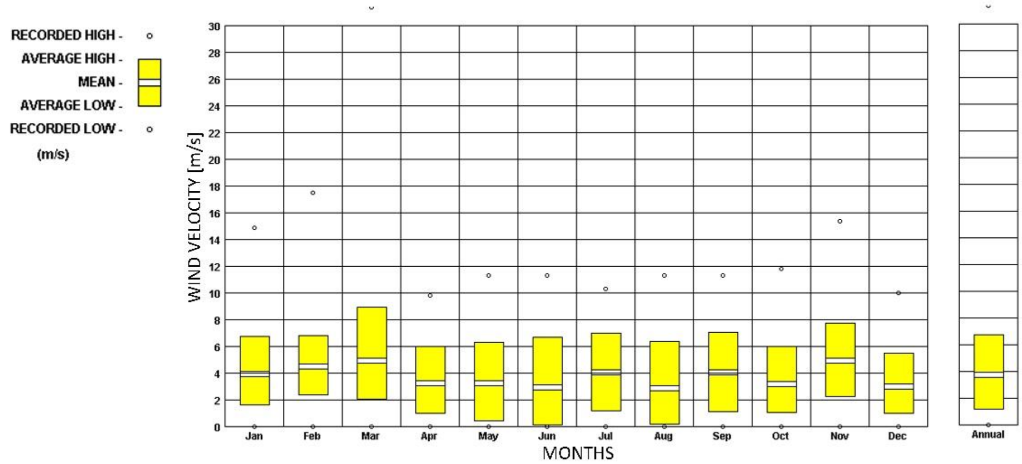


ZONE: MILD — Sheet n.3

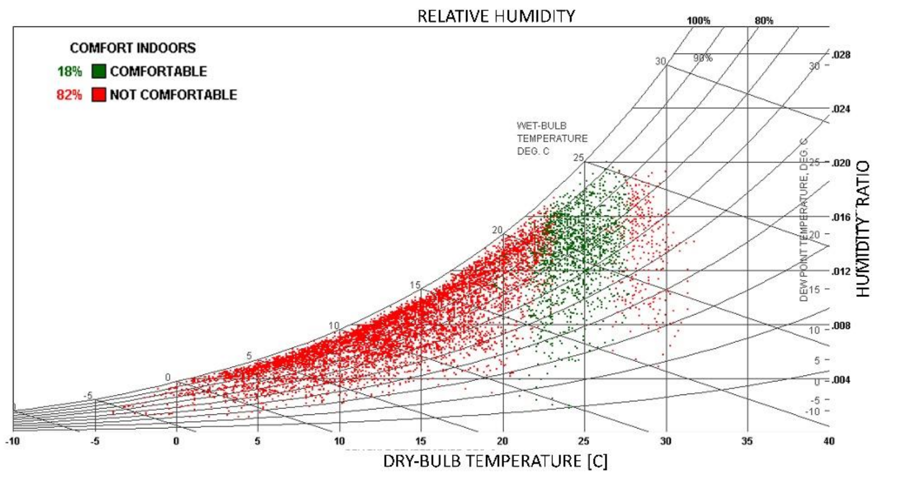
ILLUMINATION RANGE



WIND VELOCITY RANGE



PSYCHROMETRIC CHART



ZONE: HOT — Sheet n.4

DESCRIPTION

Temperate Mediterranean climate with hot summer (Csa)
The cities considered have generally 900<HHD<1400 and V_c>1.968 and they are characterized by a mild winter and hot summer.
It involves the warmer areas of some coastal areas: coast in the South, the islands, the coastal strip from Liguria to Calabria, the southern end of the Adriatic and Ionian area.

WINTER

It is not cold also for the sea influence.
Average of the colder months:
3 months with average temperature <10°C

SUMMER

It is hot and humid.
Average of the warmer months:
4 months with an average temperature > 20°C

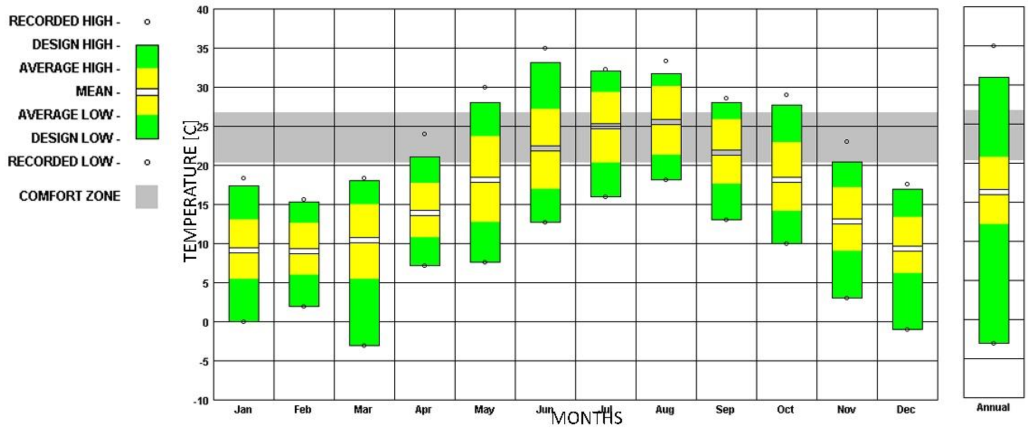
CITY

NAPOLI - Classification: C (D.P.R. 412/1993) /G (Enea Report)

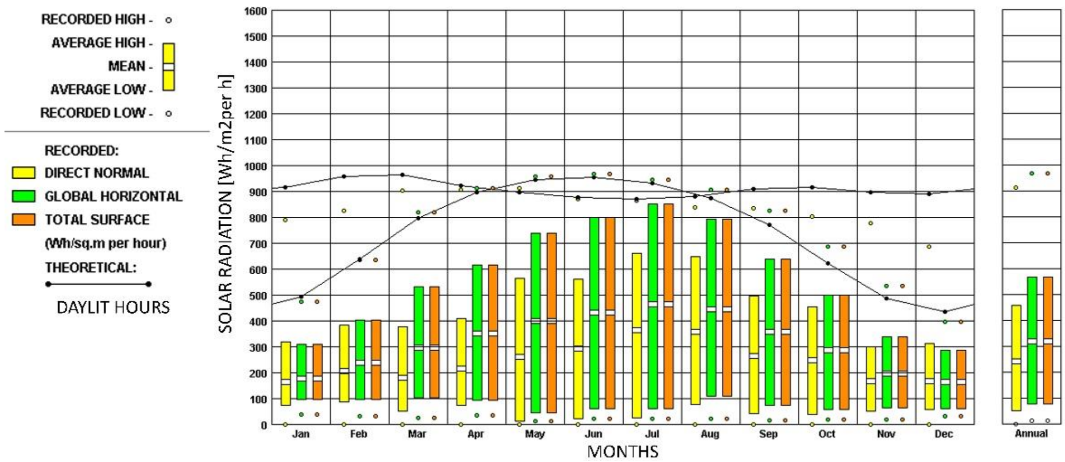
Altitude	Latitude	Longitude	HDD	V_c	Heating period
72	40.85°	14.3°	1034	1.994	15th November/31st March

Napoli has mild, rainy winters and hot, dry summers, also affected by the sea breeze.
According to the psychometric chart, the 17% of hours during the year are in comfort zone.
This occurs especially for the mild air temperature while discomfort is caused by hot air.

AVERAGE TEMPERATURE

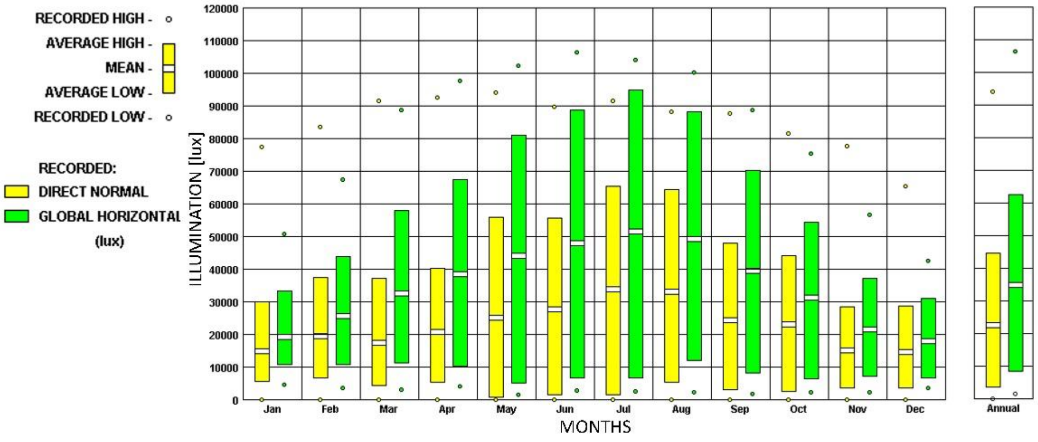


SOLAR RADIATION RANGE

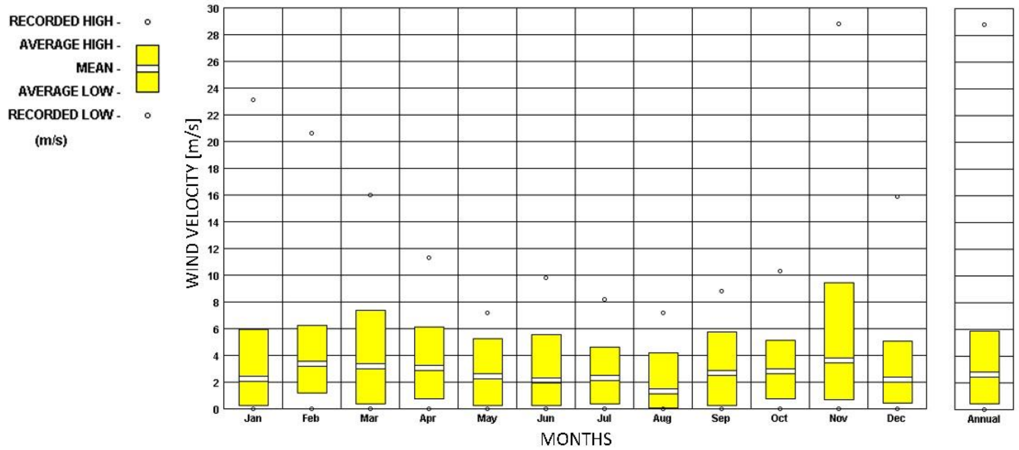


ZONE: HOT Sheet n.4

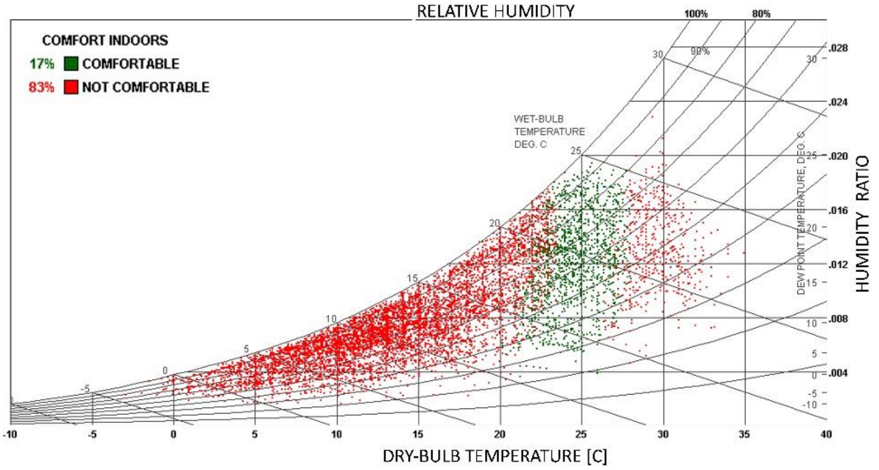
ILLUMINATION RANGE



WIND VELOCITY RANGE



PSYCHROMETRIC CHART



ZONE: HOT — Sheet n.5

DESCRIPTION

Temperate Mediterranean climate with summer drought (Csa).
The cities considered have generally 600<HHD<900 and 1.898<V_c<1.968 and they are characterized by a mild winter and a hot summer.
It involves the warmer areas of restricted coastal area: coast in the South, the islands, the coastal strip from Liguria to Calabria, the southern end of the Adriatic and Ionian area.

WINTER

It is not cold also for the sea influence.
Average of the colder months:
4 months with average temperature <15°C

SUMMER

It is hot and arid.
Average of the warmer months:
5 months with an average temperature > 20°C

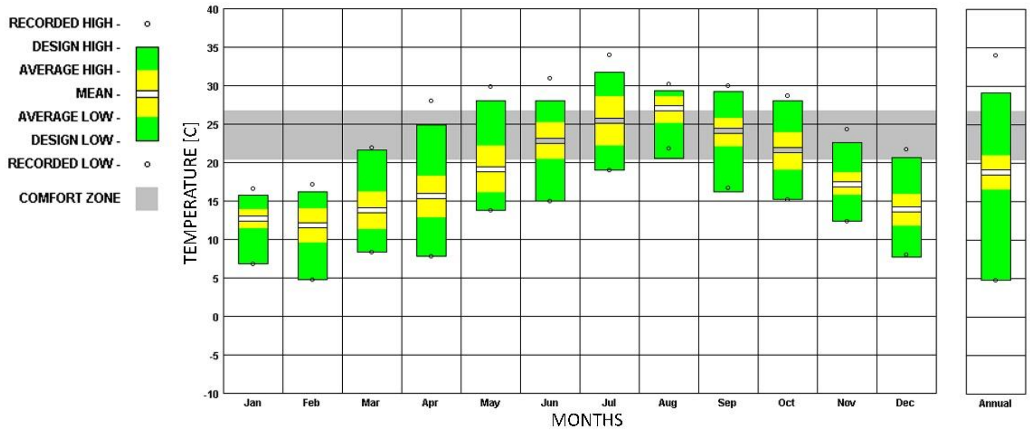
CITY

PALERMO - Classification: B (D.P.R. 412/1993) /F (Enea Report)

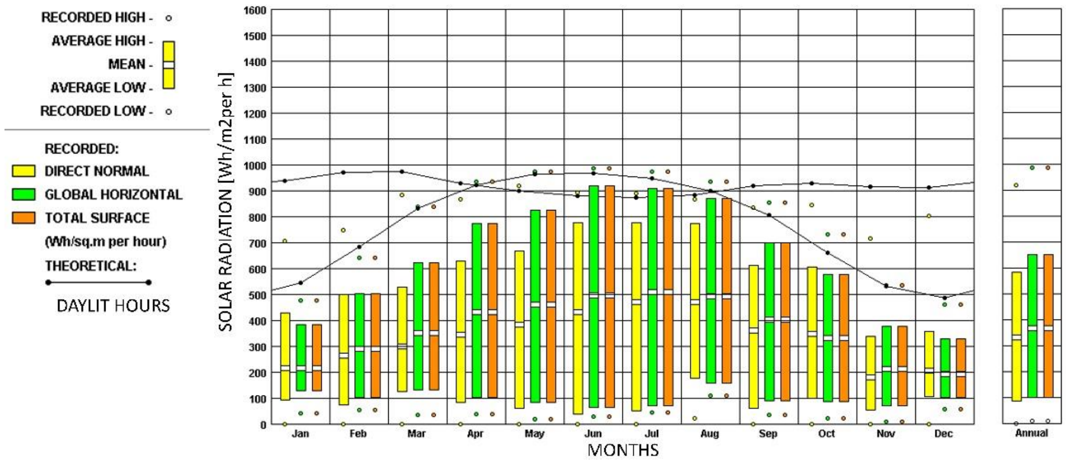
Altitude	Latitude	Longitude	HDD	V_c	Heating period
34	38.18°	13.1°	751	1.92	1st December / 31st March

Palermo has a temperate climate with dry, warm and hot summer; while winters are cool and rainy. The intermediate seasons have moderate temperatures.
According to the psychometric chart, the 28% of hours during the year are in comfort zone.
The overheating predominantly causes the discomfort.

AVERAGE TEMPERATURE

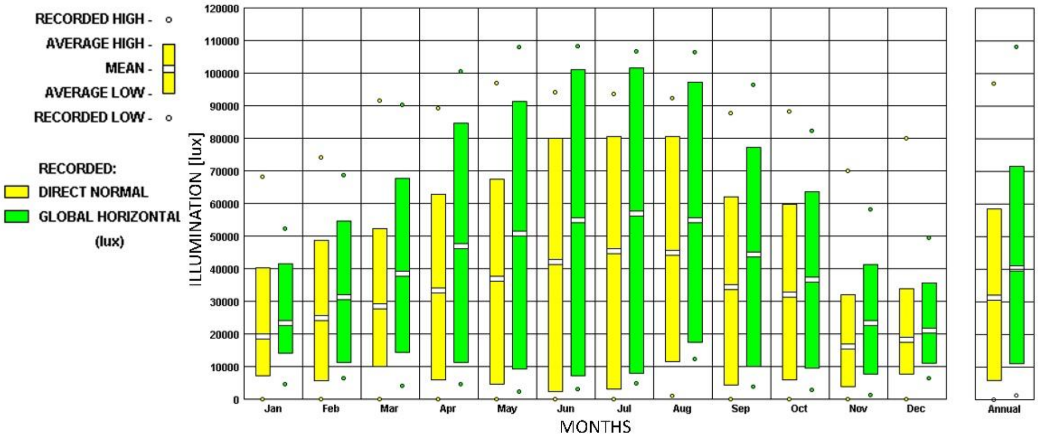


SOLAR RADIATION RANGE

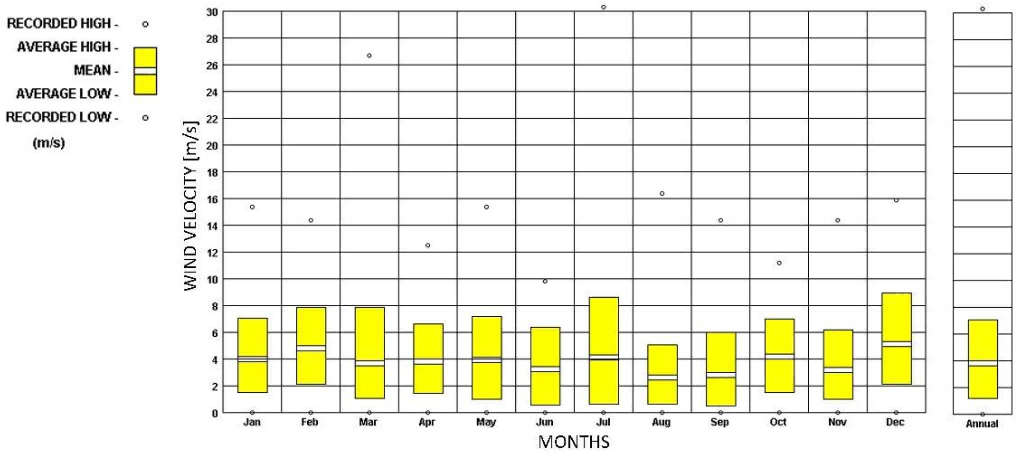


ZONE: HOT **Sheet n.5**

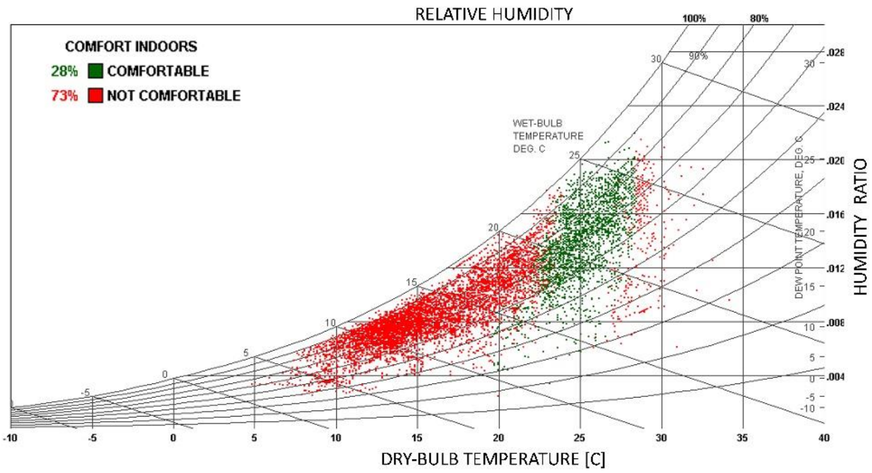
ILLUMINATION RANGE



WIND VELOCITY RANGE



PSYCHROMETRIC CHART



4.2 BUILDING FEATURES OF BASE MODELS

This paragraph presents the features of the base cases whose the energy performances will be calculated for the five cities previously presented.

At this step, the base cases, which only differ for the shape, have same building features independently by the location as also same indoor comfort conditions, etc. The results obtained (Paragraph 4.3) will constitute the first term for the later comparison with the results of energy efficient cases where some design parameters are optimized (Chapter 5).

4.2.1 GEOMETRY AND INTERNAL LAYOUT

From the analyses of the state of art and of the case studies (Chapter 3), it has been possible the identification of three different recurring buildings. The first two cases (A and B) are high-rise buildings with a different geometry of the floor plan; while the third case (C) is a low-rise building with a core atrium (Figure 4.1 and Figure 4.7). Specifically:

1. **CASE A:** 12-storey tower with a polar symmetry of the floor plan and with a central core of services;
2. **CASE B:** 12-storey building with a linear shape and services grouped in the center;
3. **CASE C:** 4-storey building with a core atrium and services disposed on extremes.

The characteristics (Table 4.5) that the three blocks have in common are the following:

- volume (V);
- total Area (A_T);
- number of workers (N_w);
- building type (Paragraph 4.2.2);
- indoor comfort conditions, internal loads and occupancy type (Paragraphs 4.2.3, 4.2.4, 4.2.5);
- systems type (Paragraph 4.2.6).

Despite, they differ for:

- geometry of the floor plan (square, rectangle, atrium);
- dimensions of the floor plan;
- number of storey (N_L);
- A/V ratio.

Each floor plan is identical to the others for every model and the floor-to-floor height is univocally defined and equal to 4m.

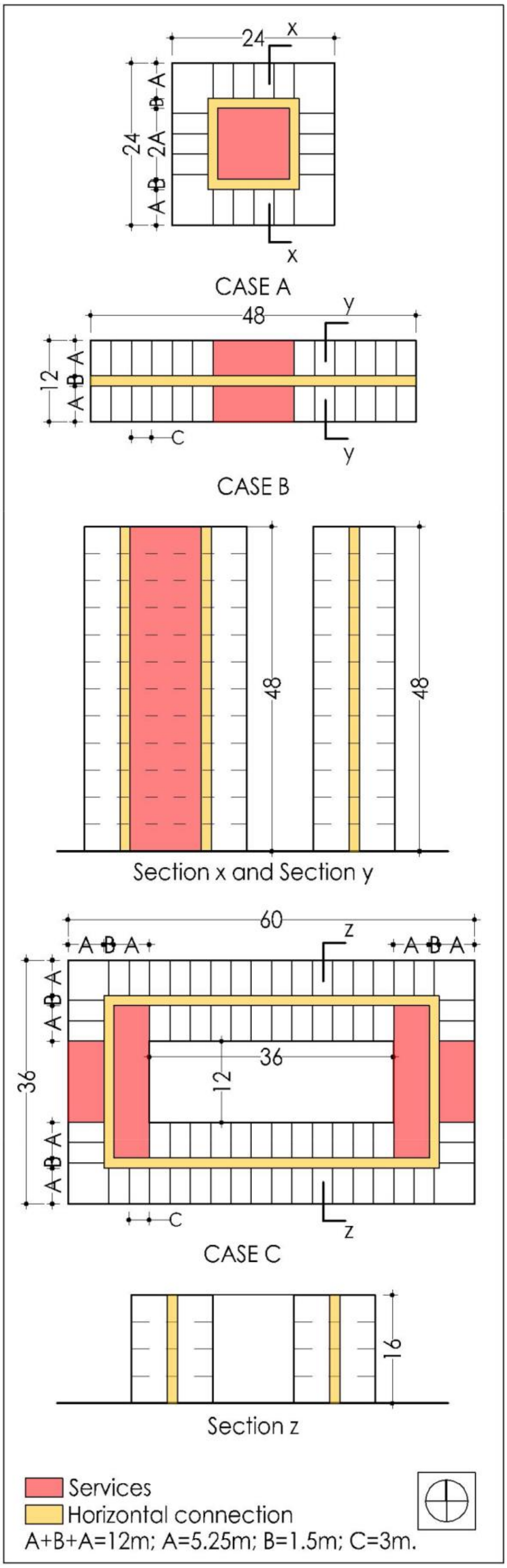
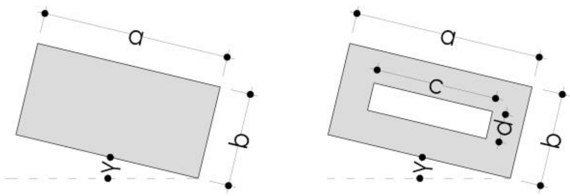


Figure 4.7: Geometry definition for the three base models

The number of stories (they shares the cases into the macro-classification of low-rise and high-rise buildings) and the dimensions of the floor plan are assumed in order to make a comparison between different configurations with the same volume.
The design of the three buildings is based on the following considerations:

- the dimensions are extracted from the case studies analyzed (Paragraph 3.3.4), where, as example, 12m is the medium depth of a building with a double strip of cellular offices and a central corridor;
- Table 4.6 shows the area adopted for the design of the models (1 worker has 15.5m^2).

In addition, two main macro-categories are individuated (office zones and service zones) corresponding to different functions and different indoor comfort conditions (Paragraph 4.2.3).
All the base models are oriented with an azimuth angle (γ) equal to 0° privileging the most suitable orientation of office spaces that is North/South [8].



a,b,c,d Dimensions of the floor plan
γ Azimut angle

Figure 4.8: General sketch of the floor plan

	CASE	A	B	C
FLOOR PLAN	Aspect ratio	a:b = 1	a:b = 4	a:b = 1.6 c:d = 3
	a [m]	24	48	60
	b [m]	24	12	36
	c [m]	-	-	36
	d [m]	-	-	12
	A_{fp} [m^2]	576	576	1728
BUILDING	N_L	12	12	4
	H_{tot} [m]	48	48	16
	A_T [m^2]	6912	6912	6912
	V [m^3]	27648	27648	27648
	N_W	446	446	446
	A/V ratio	0.21	0.25	0.29

a,b,c,d Dimensions of the floor plan (Figure4.8)
A_{fp} Gross area of the floor plan
N_L Number of levels
H_{tot} Total height of the building
A_T Total gross area of the building
V Volume of the building
N_W Number of workers

Table 4.5: Geometry characterization of the base models

SPACE REQUIREMENTS FOR OFFICE WORK	SPACE WITH HIGH STANDARD LEVEL [m^2/pers]	SPACE WITH LOW STANDARD LEVEL [m^2/pers]	SPACE ADOPTED [m^2/pers]	MACRO ZONES [m^2/pers]
Work station area	10	5	**7.5**	**OFFICES 10.8**
Area for the access to the workstation: internal circulation (+10%)	10+1 = 11	5+0.5 = 5.5	7.5+0.8 = 8.3	
Area for special services: meeting rooms, showing rooms, etc. (+2.5m^2 to 0)	11+2.5 = 13.5	5.5+0 = 5.5	8.3+2.5 = 10.8	
Circulation (+15%)	13.5+2 = 15.5	5.5+0.8 = 6.3	10.8+1.6 = 12.4	**SERVICES 4.8**
Area for services that support the office zones: archive, break areas, toilets, etc. (+3.3m^2 to 2.2m^2)	15.5+3.3 = 18.8	6.3+2.2 = 8.5	12.4+3.1 = 15.5	
Average area for person	**18.8**	**8.5**	**15.5**	

Table 4.6: Space definition for each worker for the early dimensioning of the cases and identification of two macro-categories that reflect two different thermal zones. The data related to the space standards are extracted from literature, Page 123 [9].

4.2.2 BUILDING ENVELOPE

The three cases are multi-storey offices with reinforced concrete structure.

At this step, the envelope composition is univocally determined for all locations (Table 4.7). Specifically, the opaque facade (Figure 4.10) is composed as following: "Poroton" block + thermal insulation layer + aluminum mullions and ceramic tiles with clips on edge.

The WWR is 20% on each façade, according to the limit $\mathbf{Area_{window} \geq 1/8 \cdot Area_{room}}$ imposed by national regulations. The size of the window is, for example, 1.2m·2m (Figure 4.9)[8].

The glazing is a double glass with the following composition: 6mm Pyrolitic Clear glass + 16mm Argon + 4.4·2mm Clear glass with PVB interlayer. Its properties are: LSG[9]=1.12; SHGC=0.63; VT=0.71; U=1.7W/m²K.

In addition, no shading systems are considered at the present step.

The internal partitions have two layers of plasterboard within the insulation material (ex. wall proposed by Knauf). The internal partitions that divide spaces with different functions (ex. walls between service and office zones) double the thickness of the insulation layer (Figure 4.11).

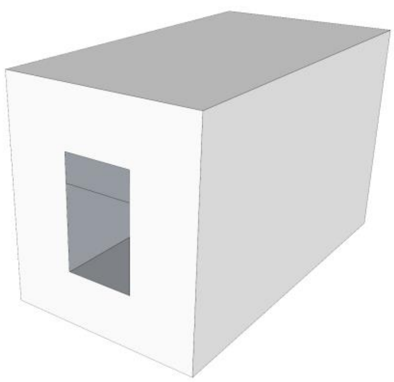


Figure 4.9: Example of one cell-office with WWR equal to 20%

CITY	THERMAL TRANSMITTANCE [W/m²K]			
	U_{wall}	$U_{wall,limit}$	U_{win}	$U_{win,limit}$
Milano	**0.31**	0.34	**1.7**	1.7
Firenze		0.36		1.9
Roma		0.36		1.9
Napoli		0.40		2.1
Palermo		0.48		2.7

Table 4.7: Comparison between thermal transmittance adopted for the envelope of the base cases (U_{wall} and U_{win}) and the limit values imposed by national regulation ($U_{wall,limit}$ and $U_{win,limit}$) **[10]**

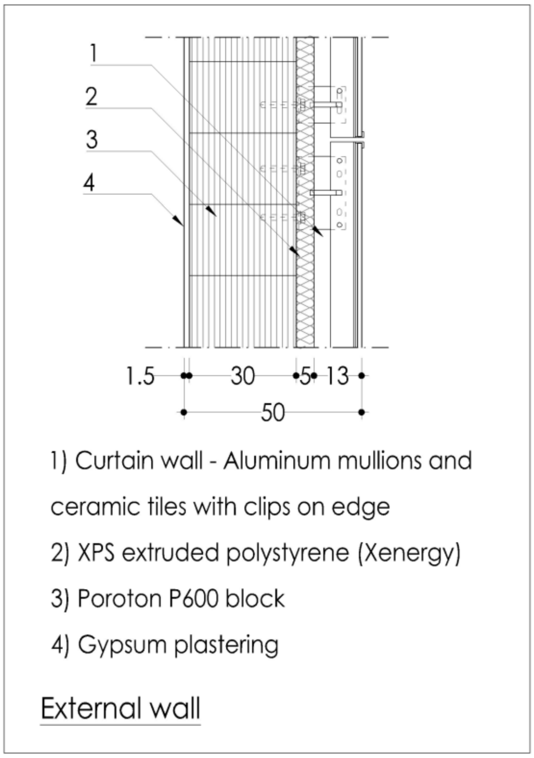


Figure 4.10: Wall composition

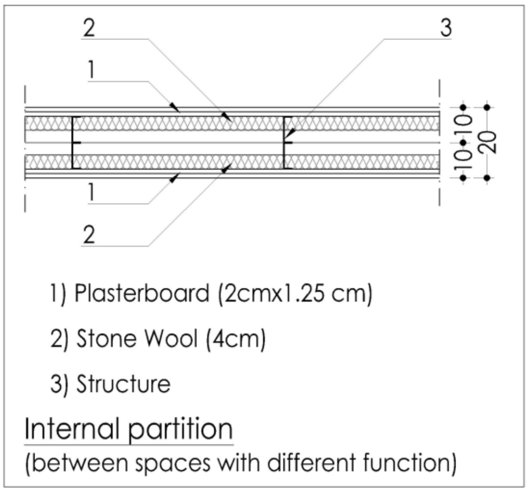


Figure 4.11: Internal partition composition

[8] The transparent part can be composed by a lower window (1.20m·1.50m) and an upper vasistas (1.20m·0.50m).

[9] LSG = Light to Solar Gain ratio is the Visible Transmittance (VT) divided by the Solar Heat Gain Coefficient (SHGC). Higher ratio entails more spectrally selective glazing.

4.2.3 ZONING AND INDOOR COMFORT

Different thermal zones are defined for the models. There are two macro- zones (Table 4.8):

- *OFFICE ZONES (OZ):* They enclose office spaces, meeting rooms, etc. In such areas high comfort conditions are necessary (as example lighting = 500lux) and appliances loads are relevant for the computer usage;
- *SERVICE ZONES (SZ):* They enclose vertical connections, toilets, services, accessories spaces, etc. In these areas, for example, lighting is reduced at 150lux and appliances loads are definitely less.

The area of the zones is equal for all cases considering the total area of the building; otherwise, there is a difference between them considering the area of the floor plan.

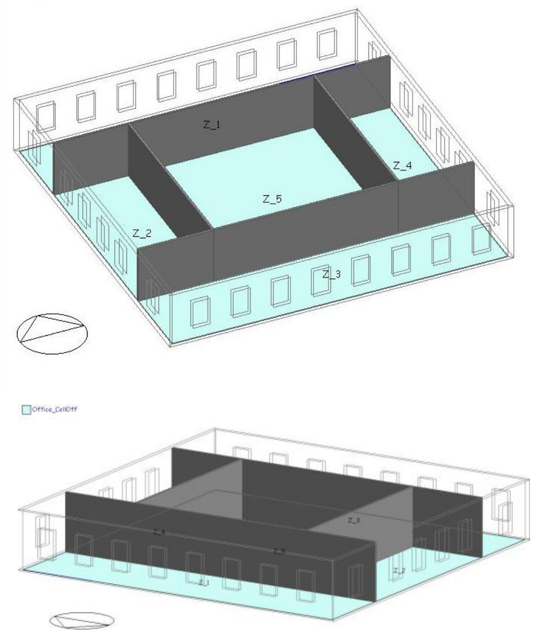


Figure 4.12: Model of the floor plan with the thermal zones - Case A

ITEM	
Thermal comfort[10]	Winter = 20°C Summer = 26°C (Set point T: Winter = 18°C; Summer = 26°C)
Visual comfort[11]	Office zone: 500 lux Service zone: 150 lux

Table 4.8: Indoor comfort conditions

Figures 4.12 and 4.13 show the thermal zones; while Table 4.8 presents the summary of the indoor comfort conditions in relation to the thermal zones.

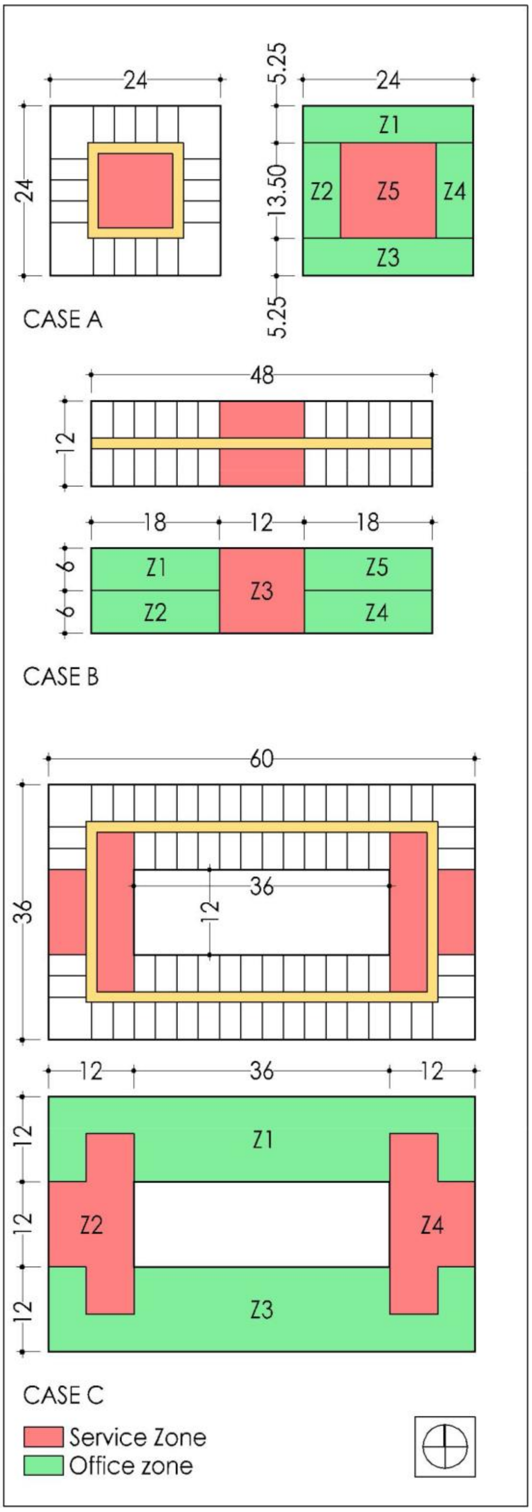


Figure 4.13: Thermal zones according the three cases

[10] D.P.R. 412/93 winter and UNI10339:1995 summer

[11] UNI12464-1:2004

4.2.4 OCCUPANCY TYPE

For all of models, the occupant densities and hours of occupation are assumed climate independent. Opening hours and occupation of spaces are set as in Table 4.9. The closing time is on Sunday and the holidays considered are the following:

8th, 24th-26th December
10th-12th (Easter), 25th April
1st May
2nd June
1st-15th August

The metabolic rate[12] is 120W/per for a person who is sitting and work or read (office work) [11, 12]. About the occupancy density, the value is 0.06per/m^2 for office zones and is reduced at 0.03per/m^2 for services while the air-changing rate is 11l/s·per. About service hot water, a value of 0.21l/m^{2}day is considered [11, 13].

4.2.5 INTERNAL LOADS

Internal loads for appliances are determined considering computers, printers and servers located in the office zones and without considering the location of a specific space clearly dedicated (ex. computer room).

Appliances electrical loads are for the offices zones 15W/m^2; while for service ones are 3W/m^2 according to UNITS 11300, page 22 [14]. The average lighting distribution power is 11.8W/m^2 in office areas and it is reduced at 5.4W/m^2 in service zones according to Table 3-2[13], Page 34 [8].

4.2.6 BUILDING SERVICE SYSTEMS

Two different type of systems are considered in order to know the influence they can have on the primary energy demand of the cases.
The systems are:

- **SYSTEM 1**: it consists in a condensing gas boiler for heating and service hot water and an air conditioning system for cooling. The sources are gas and electricity;
- **SYSTEM 2**: it is a reversible heat pump (Heat pump + Compression Chiller) for cooling, heating and service hot water. The sources are electricity and renewables (air or ground or water).

Fan coils provide the mechanical ventilation for both cases.
"System 1" represents a solution typically adopted in Italian offices especially in the past building, while "System 2" appears more recent.

ITEM	
Occupancy density [per/m^2]	Office Zone: 0.06
	Service Zone: 0.03
Air changing rate [l/s·per]	11
Service hot water [l/m^{2}d]	0.21
Metabolic rate [W/per]	120
Winter Clo factor[14] [clo]	1
Summer Clo factor [clo]	0.5
Work time [h]	8-19
Work days [d]	5
Appliances loads [W/m^2]	Office Zone: 15 Service Zone: 3
Lighting loads [W/m^2]	Office Zone: 11.8 Service Zone: 5.4

Table 4.9: Summary of the occupancy configuration and of internal loads

[12] Metabolic rate [W/m^2 or W/per or met], or human body heat or power production. It is often measured in the unit "met" where 1 met = 58W/m^2.
[13] Room type:
Office light computer usage →1.1W/ft^2≈11.8W/m^2
Corridor → 0.5 W/ft^2≈5.4W/m^2.
[14] Insulation of cloths expressed in "clo" unit where 1clo=0.155 m^{2}K/W.

4.3 RESULTS AND DISCUSSION

The energy software calculates the energy demand (Q_u) of the base cases. Before showing the results, it is important to clarify some definitions.

4.3.1 THREE FORMS OF ENERGY

There are three forms of energy (Figure 4.14):

- **USEFUL ENERGY (Q_u):** it is the energy used for heating, ventilation, lighting, etc. and it meets the user need for hot water, refrigerating, cooking, washing, etc.
- **FINAL ENERGY (Q_f):** it is the energy fed to the building continuously or intermittently and it is generally recorded by meters (electricity, gas) or in terms of volume (wood, coal);
- **PRIMARY ENERGY (Q_p)**[15]: "*is calculated as the sum of the primary energy expenditure costs and the final energy used for heating, cooling and electricity. The expenditure costs include the cost of handling from the depository of the fuel resource to the user's building (final energy)*" page 26, [15].

Q_p could be calculated multiplying the final energy demand for the PE-factors[16] of fuels.
The PE-factors, in this thesis, have the following values:

- gas equal to 1.36 [16];
- electricity from the national grid 2.18 [17];
- electricity from renewable sources 0.

In the present thesis, "energy efficient" building means lower primary energy demand.

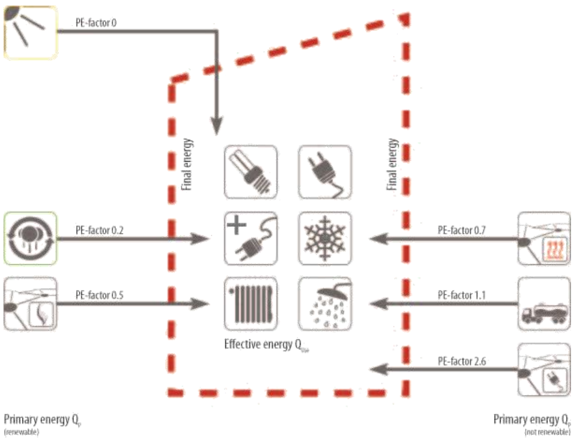


Figure 4.14: Primary Energy factors, final energy and useful energy, Page 28 **[15]**

Tabella 1. Valori limite per il fabbisogno annuo di energia primaria per la climatizzazione invernale per metro quadrato di superficie utile dell'edificio espresso in kWh/m² anno

Rapporto di forma dell'edificio S/V	Zona climatica									
	A	B		C		D		E		F
	fino a 600 GG	a 601 GG	a 900 GG	a 901 GG	a 1400 GG	a 1401 GG	a 2100 GG	a 2101 GG	a 3000 GG	oltre 3000 GG
≤0,2	10	10	15	15	25	25	40	40	55	55
≥0,9	45	45	60	60	85	85	110	110	145	145

I valori limite riportati in tabella 1 sono espressi in funzione della zona climatica, così come individuata all'art. 2 del D.P.R. 26/08/1993, n. 412, e del rapporto di forma dell'edificio S/V, dove:
a) S, espressa in metri quadrati, è la superficie che delimita verso l'esterno (ovvero verso ambienti non dotati di impianto di riscaldamento) il volume riscaldato V;
b) V è il volume lordo, espresso in metri cubi, delle parti di edificio riscaldate, definito dalle superfici che lo delimitano.
Per valori di S/V compresi nell'intervallo 0,2-0,9 e, analogamente, per gradi giorno (GG) intermedi ai limiti delle zone climatiche riportati in tabella si procede mediante interpolazione lineare.

Table 4.10: Primary energy demand for heating. Limits according to the climatic zone and the A/V ratio imposed by D.Lgs. 192/2005.

[15] **Primary energy demand as described into the national regulation: $EP=EP_i+EP_{acs}+EP_e+EP_{ill}$** [kWh/m²a or kWh/m³a]. Where:
EP_i = Primary Energy Index for the heating period;
EP_{acs} = Primary Energy Index for service hot water
EP_e = Primary Energy Index for the cooling period;
EP_{ill} = Primary Energy Index for lighting.
[16] They reflect the quality of the energy generation and distribution.

4.3.2 YEARLY USEFUL ENERGY DEMAND

Among the five cities, the highest heating and cooling demands are respectively in Milano and Palermo for all the three base cases (from Figure 4.15 to Figure 4.17). Specifically:

- from Milano to Palermo, heating demand decreases of 93% to 97%; while cooling demand increases of 53% to 56%;
- in Florence, there is a balance between heating and cooling for the case A; while there is an imbalance for the case B and C;
- in Roma, there is a predominance of cooling demand for cases A and B; while for the case C also heating is important;
- in Napoli and Palermo, cooling demand is predominant for all the three cases.

According to the variation of the building shape, it is possible to observe how B increases cooling demand and reduces heating while C increases heating demand and reduces cooling demand, comparing to the results of the case A.

4.3.3 FINAL ENERGY DEMAND

Useful energy demand will be covered by building service systems. Considering the performance efficiency of the reference systems, the final energy demand in each city could be calculated as follows:

$$Q_f = \frac{Q_U}{\eta} \; or \; \frac{Q_U}{COP} \; or \; \frac{Q_U}{SPF}$$

Q_U	Yearly Useful Energy Demand [kWh/m²a];
η	Efficiency of system;
COP	Coefficient of performance;
SPF	Seasonal Performance Factor.

Equation 4.1: Final Energy Demand

In this thesis:

- **SYSTEM 1**: for space heating **η=0.9** and for cooling space **SPF=2**. Lighting and appliances are directly grid connected;
- **SYSTEM 2**: **COP_h[17]=3** for the heating space and service hot water systems; while for cooling space is **COP_c=2**. Lighting and appliances are directly grid connected.

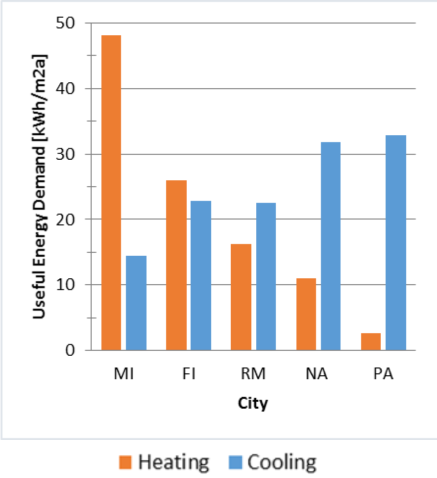


Figure 4.15: Useful energy demand - Case A - All cities

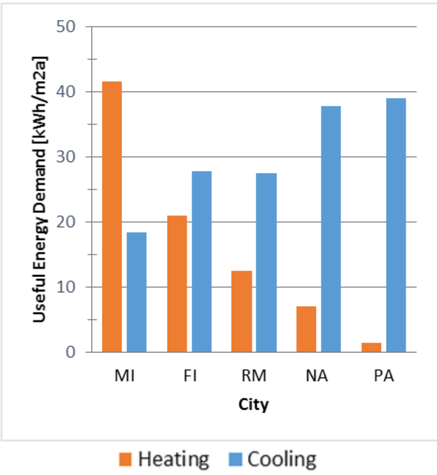


Figure 4.16: Useful energy demand - Case B - All cities

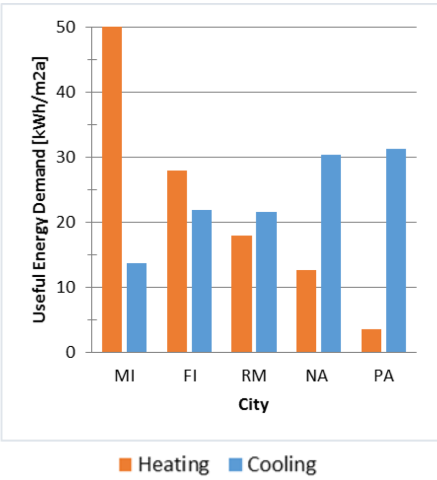


Figure 4.17: Useful energy demand - Case C - All cities

[17] COP values (for heating and cooling spaces) are assumed equal and constant for all cities. Specifically, for geothermic and water heat pumps, COP can be considered quite constant; while for air heat pump, COP depends by the exterior climate conditions, so the values would change depending by the city.

4.3.4 PRIMARY ENERGY DEMAND

The primary energy demand is calculated with the following equation:

$$Q_P = Q_f \cdot PE$$

Q_f	Final Energy Demand [kWh/m^{2}a];
PE	Primary Energy factors.

Equation 4.2: Primary Energy Demand

Where PE-factors are defined in the previous paragraph (Paragraph 4.3.1).

Figures from 4.18 to 4.23 show the results in terms of Primary Energy demand of the buildings when it is applied "System 1".

It is possible to make the following considerations:

- as expected, electricity is the most important energy need and it depends by appliances, lighting and cooling demands. For example, in Milano they represent the 67% of the total energy (Figure 4.18);
- the energy demand for service hot water is constant for all cities and cases. Its influence on the energy performance is not so significant (ex. it represents the 1% in Figure 4.18). This result differs, for instance, from the residential typology where service hot water demand assumes more importance;
- the energy demand for appliances (Q_P≈85kWh/m^{2}a) is independent from the location and the building shape. This occurs for the initial definition of the thermal zones that are equal for the three cases;
- lighting demand depends by the location and the building shape. Specifically, it decreases from Milano to Palermo and from the case A to the C. It constitutes, for example, the 23% of the total energy demand in Milano (Figure 4.18).
  In these results, lighting demand is lower than appliances. This appears different from the results of the studies made by the Turin research group (Chapter 2) where lighting and appliances have almost the same importance. This occurs since, in the base cases, an on/off control system for lighting is inserted in order to reduce them;
- Palermo has the lowest primary energy demand for all the cases (ex. 168.6kWh/m^{2}a for A and 159.7kWh/m^{2}a for C) while Milano has the hugest (ex. 224.2kWh/m^{2}a for A and 219.6kWh/m^{2}a for C).

Focusing on the three cases, it is possible to observe:

- **Milano (MI):** choosing B entails a Q_P reduction of 4% (≈10kWh/m^{2}a) if compared to the A case, of 2% (≈5kWh/m^{2}a) if compared to C case. This occurs because the rectangle shape have a large façade with windows south oriented and it permits the increasing of heat gains;
- **Firenze (FI):** preferring B means to save the 4% (≈7kWh/m^{2}a) comparing to the case A, and 1% comparing to the C;
- **Roma (RM):** B and C cases are more recommended than A. Choosing C permits to save the 4% of Q_P comparing to A (≈6.6kWh/m^{2}a). Between A and B there is a difference of 3%;
- **Napoli (NA):** C is preferable with Q_P demand reduction of 4% (≈6.6kWh/m^{2}a) comparing to A;
- **Palermo (PA):** between the energy demands of A and B cases, there is a difference of 1%. It is preferable the C case with a Q_P lower of 5% (≈10kWh/m^{2}a).

From the previous considerations, the influence of the shape on the primary energy demand is at maximum between 4% and 5% (max. 10kWh/m^{2}a).

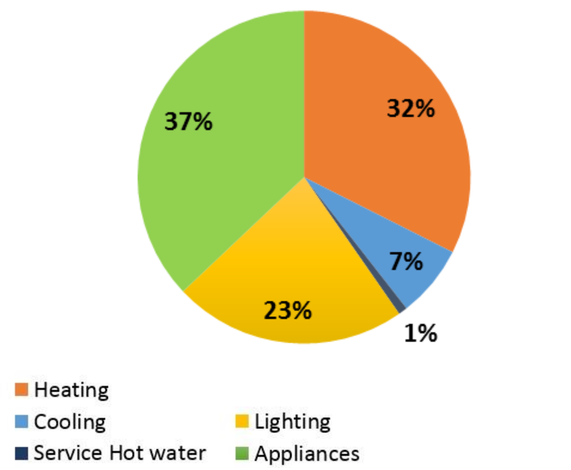


Figure 4.18: Primary energy demand percentages - Case A - Milano - "System 1"

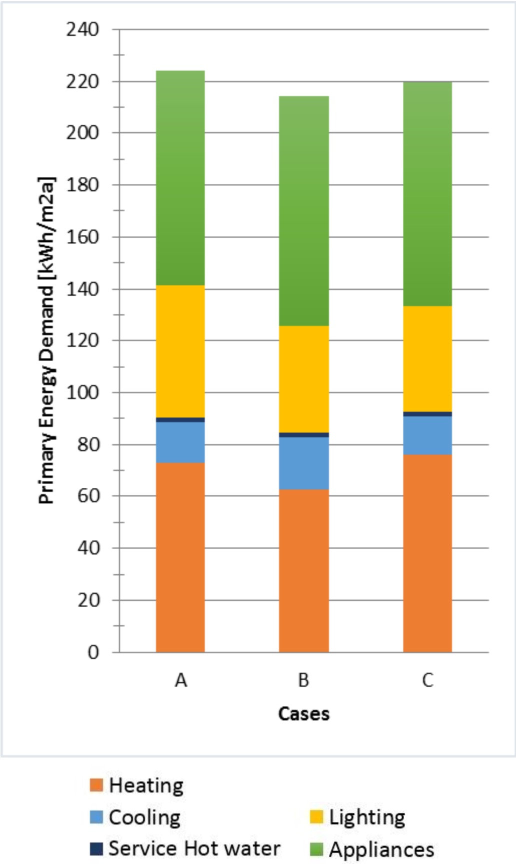


Figure 4.19: Primary energy demand - All cases - Milano - "System 1"

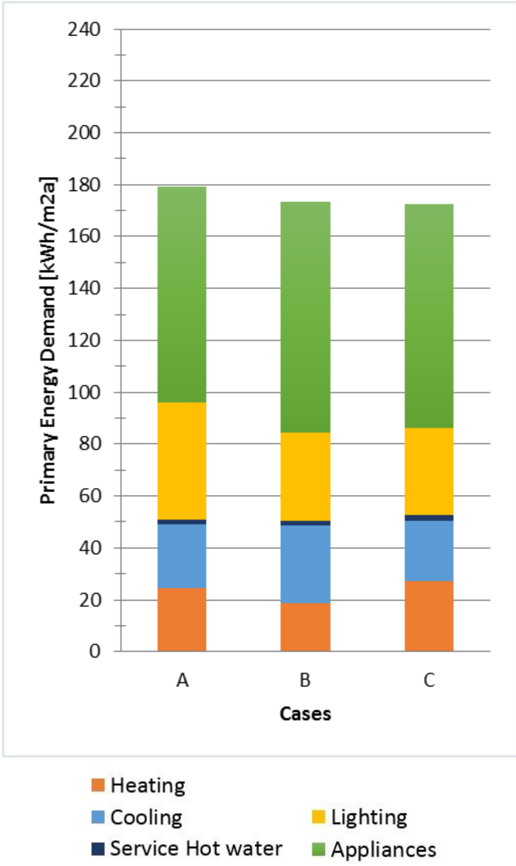


Figure 4.21: Primary energy demand - All cases - Roma - "System 1"

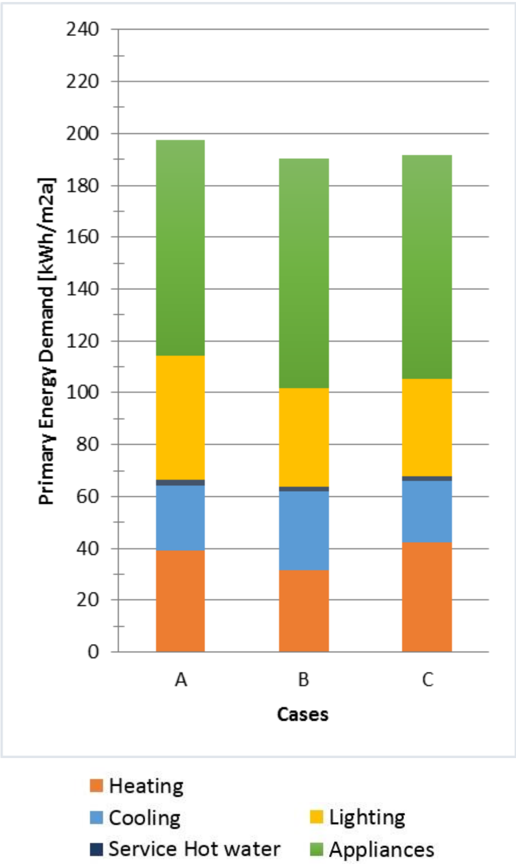


Figure 4.20: Primary energy demand - All cases - Firenze - "System 1"

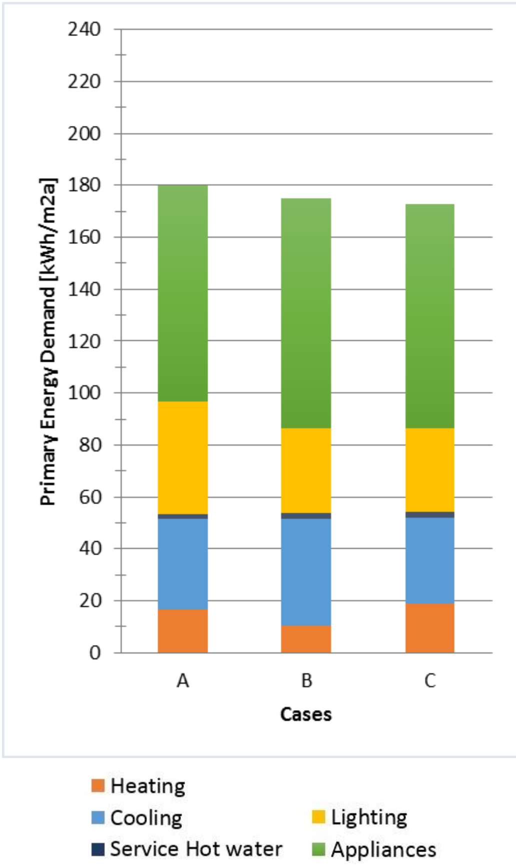


Figure 4.22: Primary energy demand - All cases - Napoli - "System 1"

Figures from 4.24 to 4.28, present the results when "System 2" is applied to all base cases and cities.

It is possible to observe, making a comparison between the Q_P demands of "System 1" and "System 2" (from Figure 4.29 to Figure 4.37), that the second type of system entails a reduction of the heating demand for all cases.

In fact, the adoption of a heat pump permits a major energy saving that is bigger for a cold city (ex. Figure 4.31) and is lower for a hot city.

As example, in Milano Q_P is reduced of the 17% (≈39kWh/m^{2}a) comparing to the case where System 1 is adopted.

In addition, it is also possible to observe that with the application of "System 2", the influence of the shape is further reduced according to the general reduction of the heating demand.

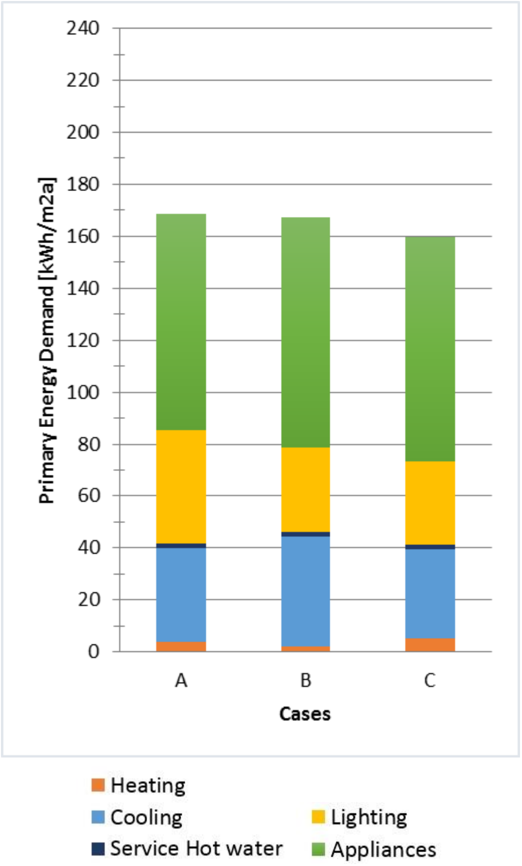


Figure 4.23: Primary energy demand - All cases - Palermo - "System 1"

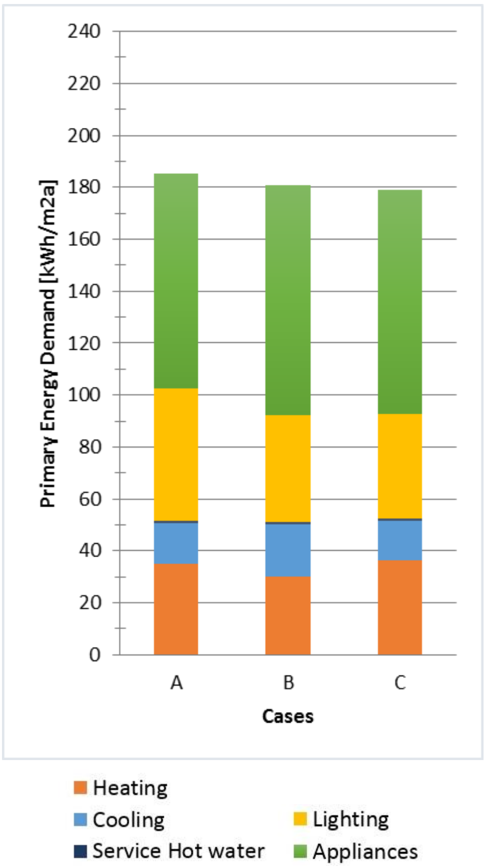


Figure 4.24: Primary energy demand - All cases - Milano - "System 2"

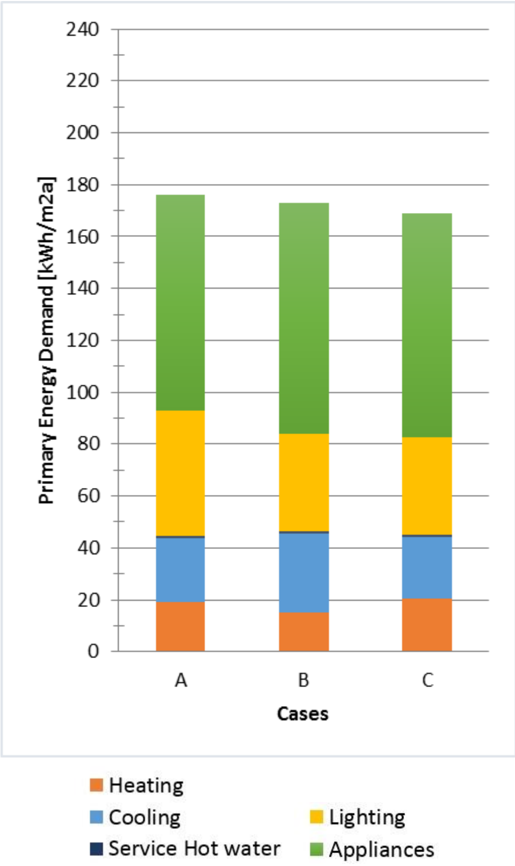


Figure 4.25: Primary energy demand - All cases - Firenze - “System 2”

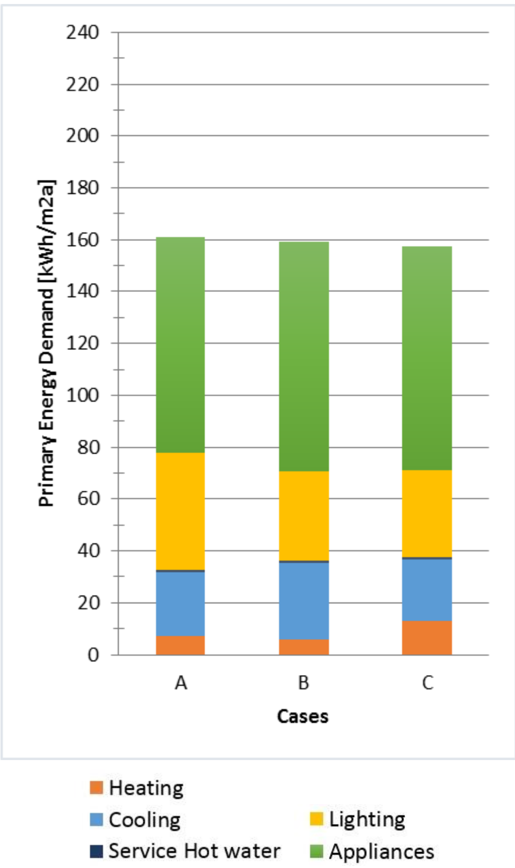


Figure 4.26: Primary energy demand - All cases - Roma - “System 2”

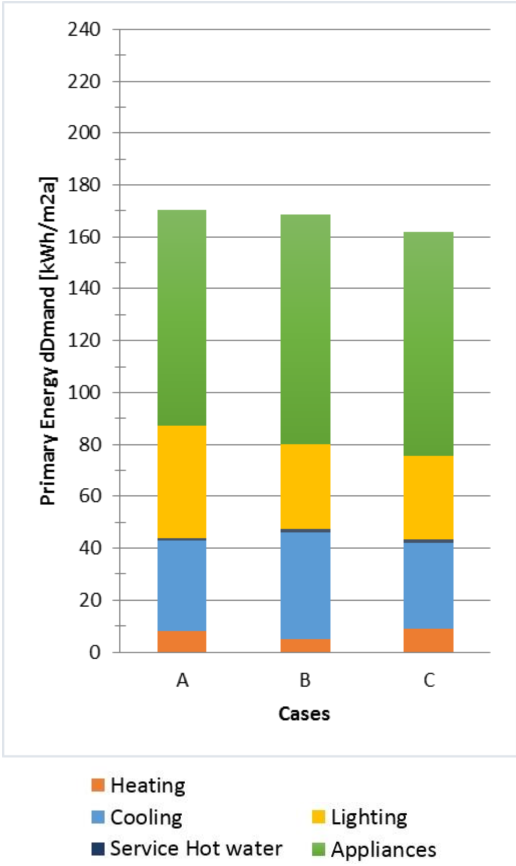


Figure 4.27: Primary Energy Demand - All cases - Napoli - “System 2”

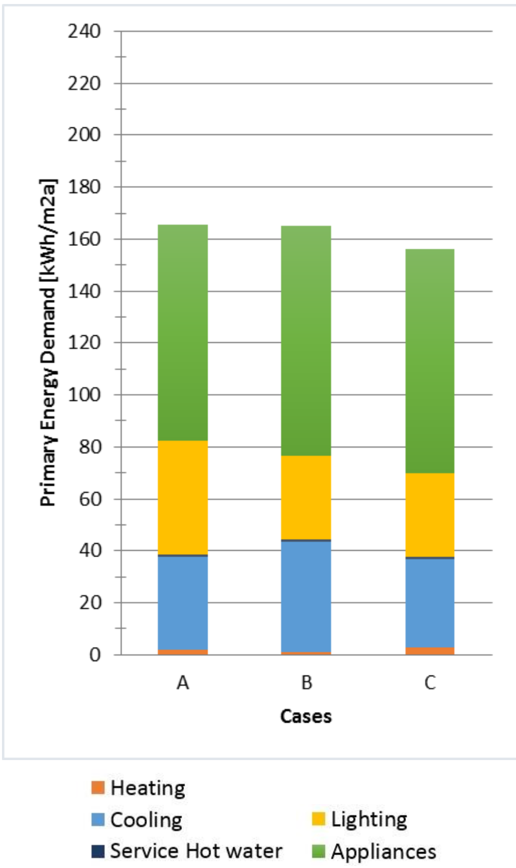


Figure 4.28: Primary energy demand - All cases - Palermo - “System 2”

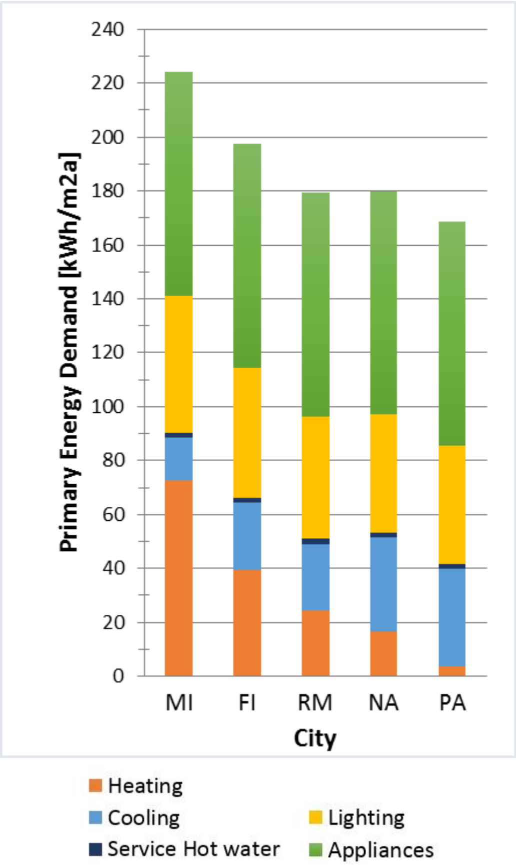


Figure 4.29: Primary energy demand - Case A - All cities - "System 1"

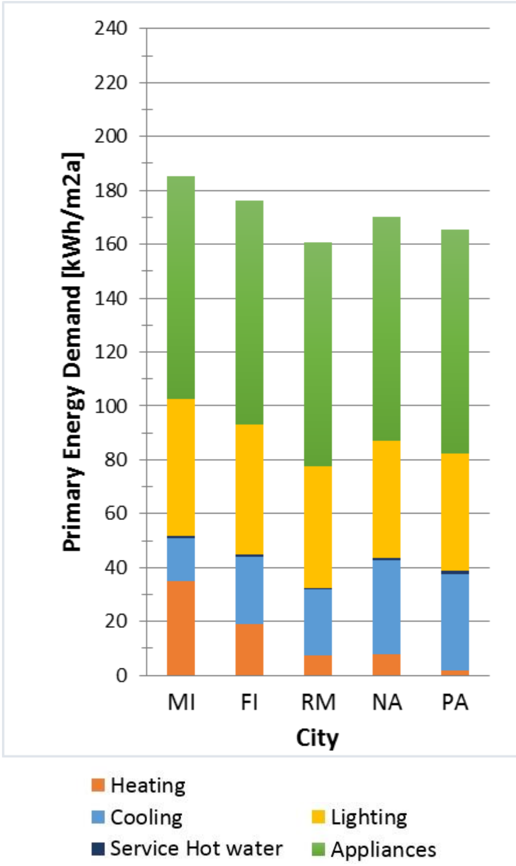


Figure 4.30: Primary energy demand - Case A - All cities - "System 2"

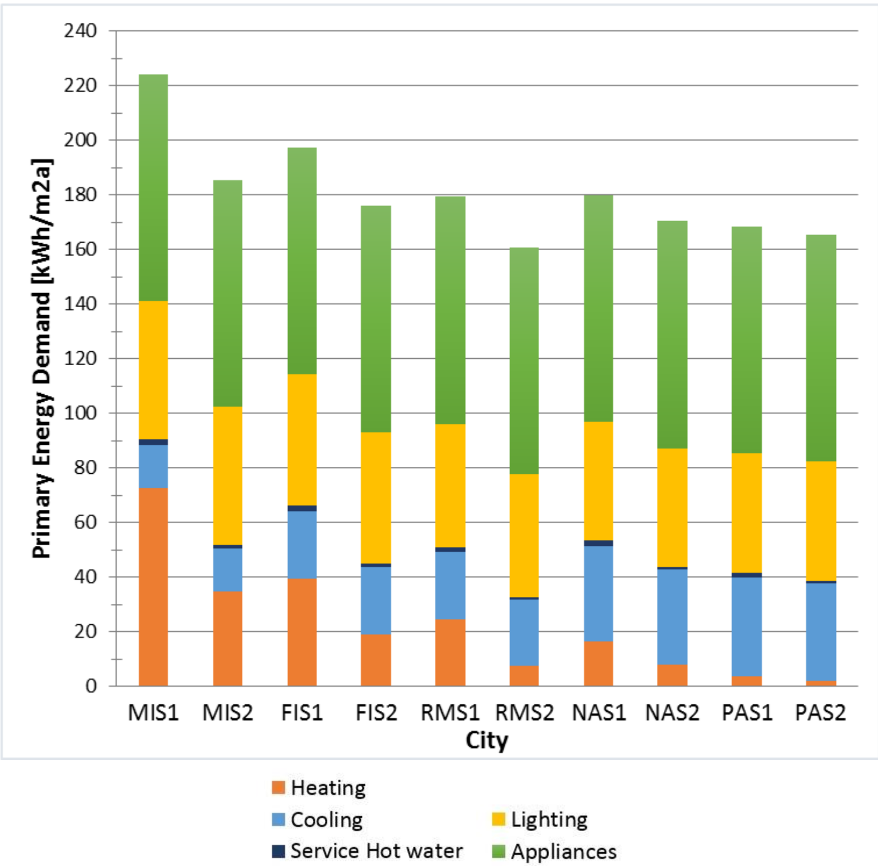


Figure 4.31: Comparison between Primary energy demands - Case A - All cities - "System 1" and "System 2"

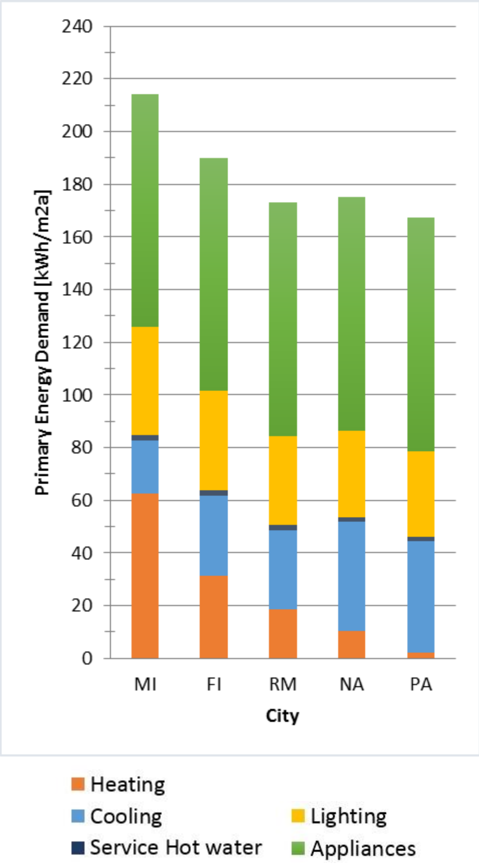


Figure 4.32: Primary energy demand - Case B - All cities - “System 1”

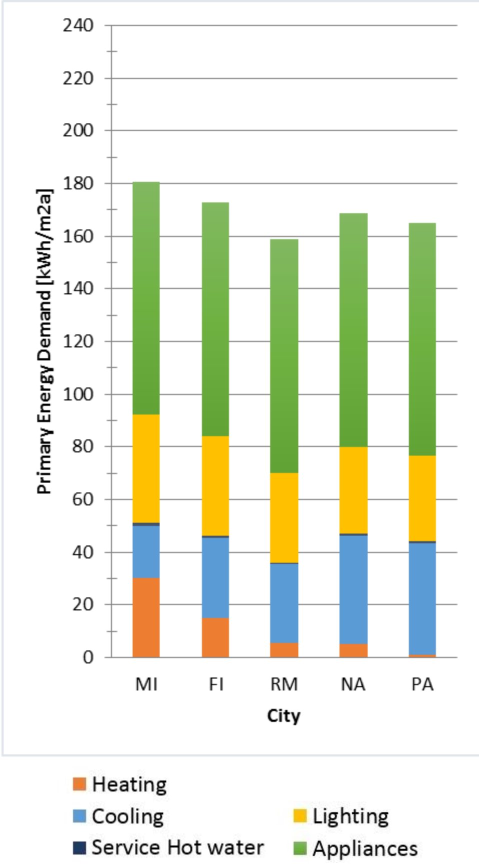


Figure 4.33: Primary energy demand - Case B - All cities - “System 2”

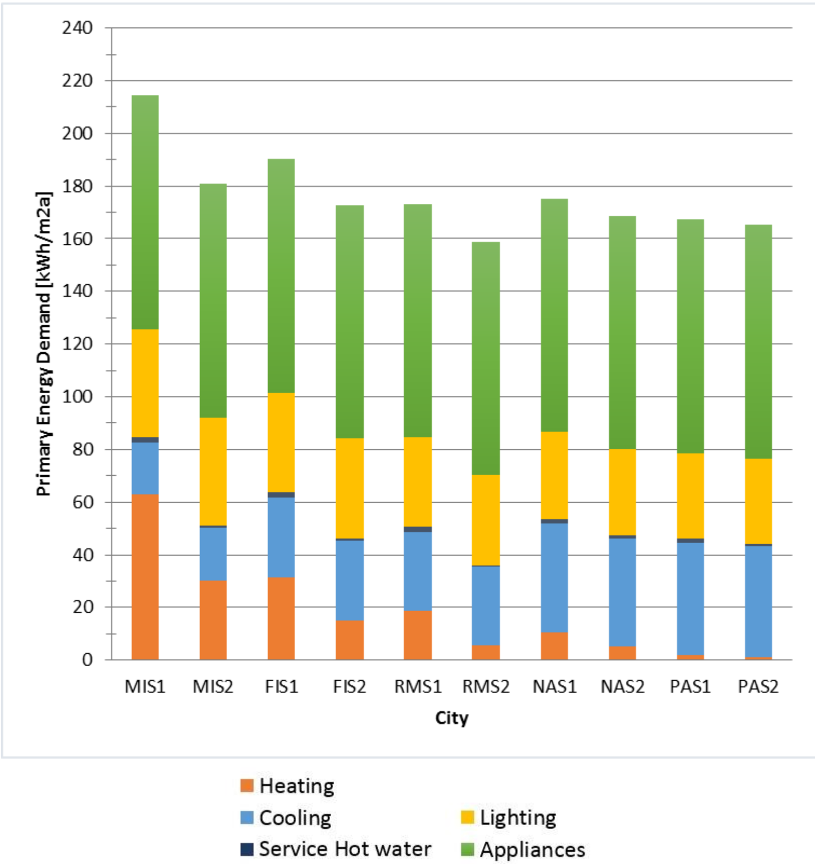


Figure 4.34: Comparison between Primary energy demands - Case B - All cities - “System 1” and “System 2”

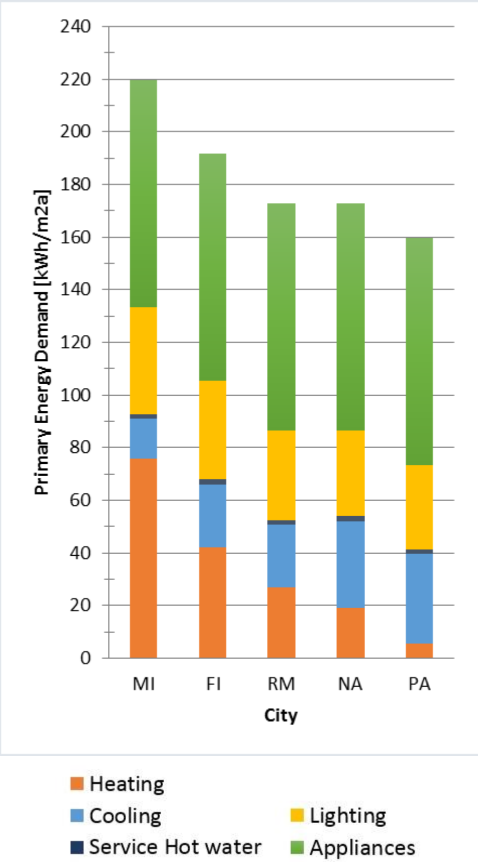


Figure 4.35: Primary energy demand - Case C - All cities - “System 1”

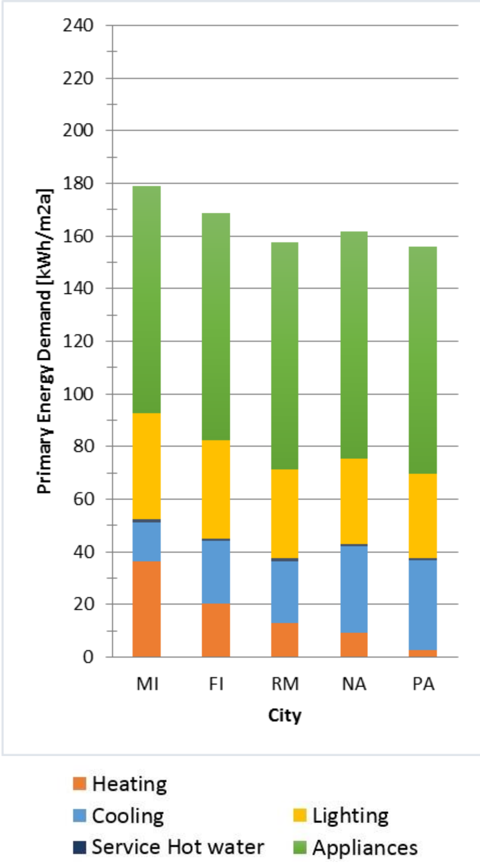


Figure 4.36: Primary energy demand - Case B - All cities - “System 2”

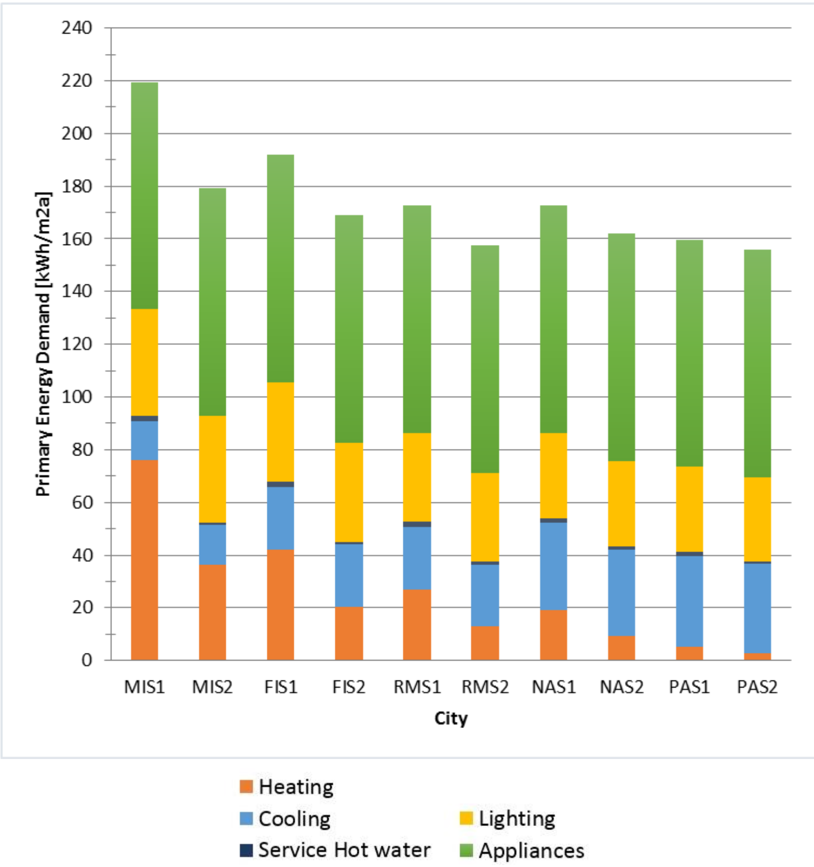


Figure 4.37: Comparison between Primary energy demands - Case C - All cities - “System 1” and “System 2”

REFERENCES

1. **PINNA, M.** *L'atmosfera e il clima.* Torino, UTET, 1978.

2. **www.scia.isprambiente.it**. [Online]

3. **PINNA, M.** *Contributi di climatologia.* Roma, Società geografica italiana, 1985.

4. **D.P.R. 26/08/1993, n.412.** *Regolamento recante norme per la progettazione, l'installazione, l'esercizio e la manutenzione degli impianti termici degli edifici ai fini del contenimento dei consumi di energia, in attuazione dell'art. 4, comma 4, della legge 9 gennaio 1991, n.10.*

5. **TERRINONI, L., SIGNORETTI, P. e LATAURO, D.** *Indice di severità climatica: classificazione dei comuni italiani ai fini della climatizzazione estiva degli edifici.* ENEA Report RdS/2012/107, 2012.

6. **http://apps1.eere.energy.gov/buildings/energyplus/cfm/weather_data3.cfm [Online]**

7. **UNI10349:1994.** *Heating and cooling of buildings. Climatic Data.*

8. **ASHRAE**. *Advanced Energy Design Guide for Small to Medium Office Buildings. Achieving 50% Energy Saving Toward a Net Zero Energy Building.* 2011.

9. **ARREDI, M.P.** *Edilizia per uffici. Progettare metodi tecniche norme realizzazioni.* Torino, UTET, 2004.

10. **D.Lgs. 29/12/2006, n.311.** *Disposizioni correttive ed integrative al decreto legislativo 19 agosto 2005, n. 192, recante attuazione della direttiva 2002/91/CE, relativa al rendimento energetico nell'edilizia.* Gazzetta Ufficiale n. 26, 1 febbraio 2007, Supplemento ordinario n. 26/L.

11. **ROLLINO, L.** *Fabbisogni energetici per edifici caratterizzanti il terziario in Italia: aspetti termici ed illuminotecnici.* Torino, PhD thesis, Supervisors: C. Aghemo , A. Pellegrino, 2012.

12. **ABDEL-GWAD, M.** *Designing Energy Office Buildings in Hot Arid Climate.* Braunschweig, PhD thesis, Supervisors: Univ. Prof. Dr. -Ing. M. N. Fisch, Prof. P. Krusche, Der Andere Verlag, 2011.

13. **UNI10339:1995.** *Impianti aeraulici a fini di benessere. Generalità, classificazione e requisiti.* 1995.

14. **UNITS11300-1:2008.** *Prestazioni energetiche degli edifici.*

15. **FISCH, M. N., WILKEN, T. and STAEHR, C.** *EnergyPlus.* Leonberg, Univ. Prof. Dr. -Ing. M. Norbert Fisch, 2013, ISBN:978-3-00-041246-2.

16. **UNI EN 15603:2008.** *Prestazione energetica degli edifici. Consumo energetico globale e definizione dei metodi di valutazione energetica.*

17. **CTI 9:2012.** *Prestazioni Energetiche degli Edifici: Calcolo della Quota di Energia Rinnovabile.*

18. **GROSSO, M.** *Il raffrescamento passivo degli edifici.* Rimini, Maggioli Editore, 1997.

5. PARAMETRIC STUDIES AND STRATEGIES FOR RENEWABLE ENERGY SUPPLY

CONTENTS

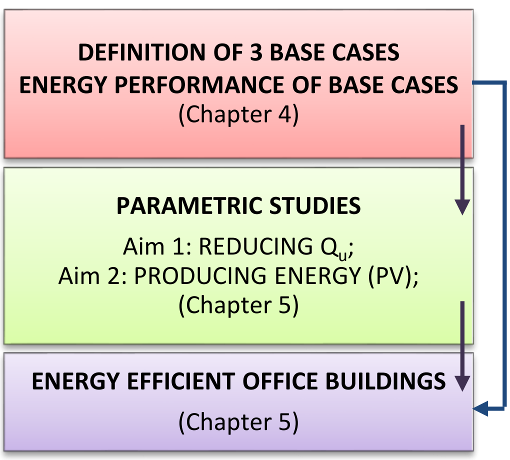


Figure 5.1: Chart of the energy analysis

INTRODUCTION

The present chapter investigates some design strategies that have been significant in Chapter 3. A parametric study occurs in order to reduce the useful energy demand (Q_u) of the building and some investigations are made on the use of renewable energy. Finally, there is the presentation of a summary of the results through the proposition of some examples of energy efficient buildings. The three base cases (A, B, C) considered in Chapter 4 are the subjects of this last part (Figure 5.1). In fact, the parameters optimized are applied to one of the base cases in order to propose examples of energy efficient office buildings. The examples are one for each city.

Specifically, energy analyses varying some architectural parameters are carried on to control the influence of the design choices on the energy performance that becomes an indicator.

Parametric studies involve the following main parts:

- envelope optimization;
- strategies for the reduction of the cooling demand;
- potential of BIPV.

The first part presents the study of the optimum thickness of the insulation material in relation to the costs and the optimum window design looking at the WWR, the glazing type and the application of shading devices.

The second section investigates the possibility to reduce cooling demand through hybrid ventilation during summer nights and midseason.

The third part explores some possibilities to cover the remaining electricity needs of the building thanks the integration of PV into the envelope. It is underlined how the geometry influences the performance of the PV systems.

5.1 OPTIMAL THERMAL INSULATION THICKNESS

After the definition of the composition of the external wall (in terms of disposition of layers, material properties, layer thickness, etc.); the heat transmission losses could be further reduced increasing the thickness of the insulation layer (δ_M).[1] This entails an increasing of the investment costs.

Therefore, the paragraph shows the calculation of the optimal thickness of the insulation layer to meet a balance between the growth of the initial investment cost for the increased thickness and the consequent minor cost for heating and cooling through systems [1, 2].

Specifically, heat transmission losses of the external wall, considering the heating period (Q_{th}) and the service life time of the insulation material (N is 30 years), are calculated as Equation 5.1. Heat transmission gains of the external wall during the cooling period (Q_{tc}) are calculated similarly (Equation 5.3).

The way to determine the optimum thickness of the insulation material consists in minimizing the operating expense of systems. In fact, heat transmissions of the external wall has to be covered by mechanical systems (heating and cooling) to preserve indoor comfort conditions. In such way, the cost (f) is the sum of the real costs of space heating during winter period (C_{th}), of space cooling during summer period (C_{tc}) and the initial investment cost of the insulation material (it is the sum of the cost of the material and the labor cost).

For example, the cost of space heating could be calculated as Equation 5.2. In the same way, the calculation for the cooling period is made (Equation 5.3).

$$
\begin{aligned}
N \cdot Q_{th} &= N \cdot \sum_{t_h} q_{th} = \\
&= N \cdot \sum_{t_h} A_{wall} \cdot U_{wall} \cdot \Delta T_h = \\
&= N \cdot A_{wall} \cdot U_{wall} \cdot \sum_{t_h} (t_i - t_e) = \\
&= N \cdot A_{wall} \cdot U_{wall} \cdot HDD \cdot 0.024
\end{aligned}
$$

Equation 5.1: Heat transmission losses of the external wall during the heating period and the service life time of the insulation layer

N	Life time of thermal insulation [a]
Q_{th}	Heat transmission losses of opaque external wall during the heating period [kWh/a]
q_{th}	Hourly heat transmission losses of opaque external wall [kW]
t_h	Heating period [h]
A_{wall}	Area of the external wall [m^2]
U_{wall}	Heat transfer coefficient of external wall [W/m^{2}K]
ΔT_h	Difference of temperatures between indoor and outdoor air during heating period [K]
HDD[2]	Heating Degree Days [Kd/a]
0.024	=0.001·24 → 0.001 = value to convert from W to kW; 24 = value to convert HDD from Kd/a to Kh/a

$$
C_{th} = \frac{N \cdot Q_{th}}{\eta_h} \cdot C_{fh}
$$

Equation 5.2: Energy costs of space heating

C_{th}	Energy costs of space heating to cover heat transmission losses of opaque external wall [€]
Q_{th}	Heat transmission losses of opaque external wall [kWh/a]
N	Life time of thermal insulation [a]
η_h	Efficiency of heating system
C_{fh}	Fuel price of space heating [€/kWh]

[1] Heat transmission losses in buildings generally occur through external walls, windows, ceilings, floors and air infiltrations. In this paragraph, only heat transmission losses through the external wall are considered [2].

[2] HDD are defined in D.P.R. 412/1993 as the sum of the differences between the indoor and the outdoor temperatures ($=\sum T_i - T_o$). The indoor temperature (T_i) is considered equal to 20°C [18].

HEATING PERIOD

$$\boldsymbol{N \cdot Q_{th}} = N \cdot A_{wall} \cdot U_{wall} \cdot HDD \cdot 0.024$$

(Heat transmission losses of the external wall during the life time of the insulation material)

↓

COOLING PERIOD

$$\boldsymbol{N \cdot Q_{tc}} = N \cdot A_{wall} \cdot U_{wall} \cdot CDD \cdot 0.024$$

(Heat transmission gains of the external wall during the life time of the insulation material)

↓

ENERGY COST

$$\boldsymbol{f: C_{th} + C_{tc} + C_i}$$

Where:

$$C_{th} = \frac{N \cdot Q_{th}}{\eta_h} \cdot C_{fh}$$

$$C_{tc} = \frac{N \cdot Q_{tc}}{\eta_c} \cdot C_{fc}$$

$$C_i = C_M \cdot A_{wall} \cdot \delta_M + C_L$$

$$K = \frac{\alpha \cdot C_{fh}}{\eta_h} + \frac{\beta \cdot C_{fc}}{\eta_c}$$

$$\boldsymbol{f: C_{th} + C_{tc} + C_i =}$$

$$\boldsymbol{\frac{N \cdot K \cdot A_{wall} \cdot \lambda_M}{R_{wo} \cdot \lambda_M + \delta_M} + C_M \cdot A_{wall} \cdot \delta_M + C_L}$$

↓

MINIMUM OF $f \rightarrow \delta_M$ Optimum

$$\boldsymbol{\frac{df}{d\delta_M} = 0}$$

Equation 5.3: Mathematical problem for the optimization of the thickness of the thermal insulation material **[1]**

N	Life time of thermal insulation [a]
Q_{th}	Heat transmission losses of external wall during the heating period [kWh/a]
Q_{tc}	Heat transmission gains of external wall during the cooling period [kWh/a]
A_{wall}	Area of the external wall [m^2]
U_{wall}	Heat transfer coefficient of external wall [W/m^{2}K]
C_{th}	Energy costs of space heating to cover heat transmission losses of opaque external wall [€]
C_{tc}	Energy costs of space cooling to cover heat transmission losses of opaque external wall [€]
C_i	Investment for thermal insulation layer [€]
C_{fh}	Fuel price of space heating [€/kWh]
C_{fc}	Fuel price of space cooling [€/kWh]
C_M	Price of insulation material [€/m^3]
C_L	Labor cost [€/m^3]
η_h	Efficiency of heating system
η_c	Efficiency of cooling system
δ_M	Insulation thickness [m]
λ_M	Heat conductivity of insulation material [W/mK]
R_{wo}	Total thermal resistance of the external wall except the thermal insulation layer [m^{2}K/W]
α	0.024·HDD
β	0.024·CDD
HDD	Heating Degree Days [Kd/a]
CDD	Cooling Degree Days [Kd/a]

While HDD are scheduled for all cities in Italy; CDD need to be calculated.

For this purpose, the daily perceived temperatures are adopted instead the daily outdoor temperatures [3].

The perceived temperature, called also in literature “Humidex” or “humidity index”, takes into account both outdoor temperatures and relative humidity (Equation 5.4). Such temperature is firstly calculated on hourly basis and then the average daily value is made [3].

The results are listed in Table 5.1, Figure 5.2 and 5.3.

For instance, Figure 5.2 and 5.3 shows how in Milano and Palermo, during summer months, the temperatures are perceived higher (H>T) for the high humidity. Table 5.1 shows how, in Milano summer is more humid than in Firenze in fact CDD_{MI}>CDD_{FI}.

$$H = T + \frac{5}{9} \cdot \left(6.11 \cdot \frac{RH}{100} \cdot 10^{\frac{7.5 \cdot T}{237.7+T}} - 10\right)$$

$$H_{med} = \sum H/24 \,; \quad CDD = \sum H_{med} - T_i$$

Equation 5.4: CDD calculation **[3]**

T	Hourly temperature [°C]
RH	Hourly relative humidity [%] [4]
H	Hourly perceived temperature [°C]
H_{med}	Daily perceived temperature [°C]
T_i=26°C	Interior design temperature [°C] [5]
CDD	Cooling Degree Days [Kd/a]

CITY	HDD [Kd/a]	CDD [Kd/a]
MILANO	2404	298
FIRENZE	1821	224
ROMA	1415	297
NAPOLI	1034	559
PALERMO	751	545

Table 5.1: HDD and CDD for Italian cities

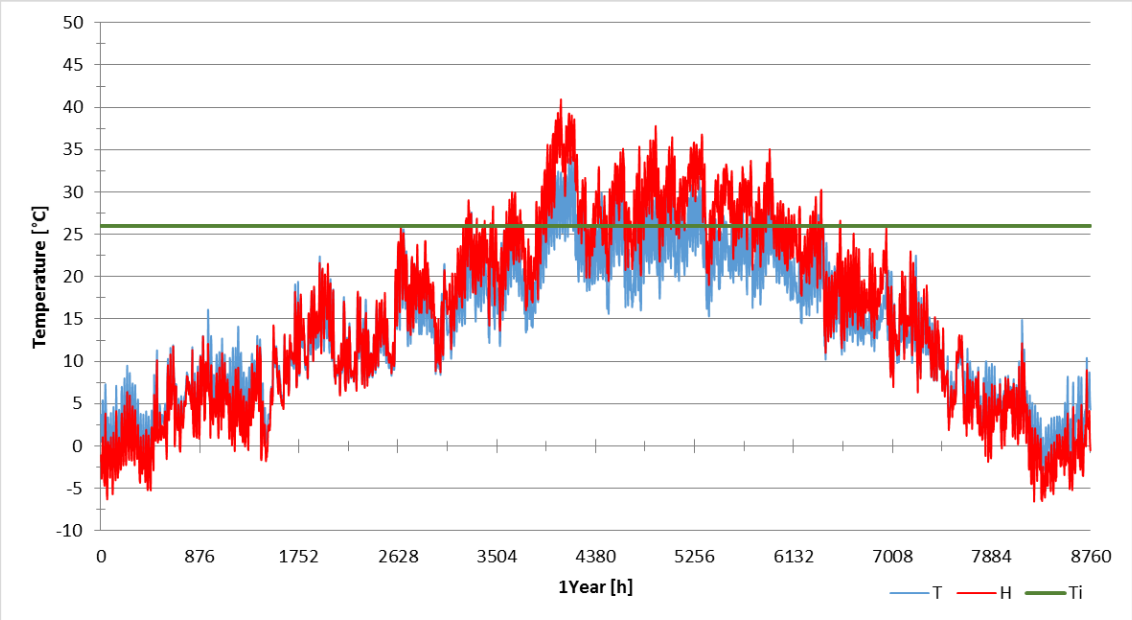


Figure 5.2: Milano - Hourly outdoor temperature and hourly perceived temperature trends

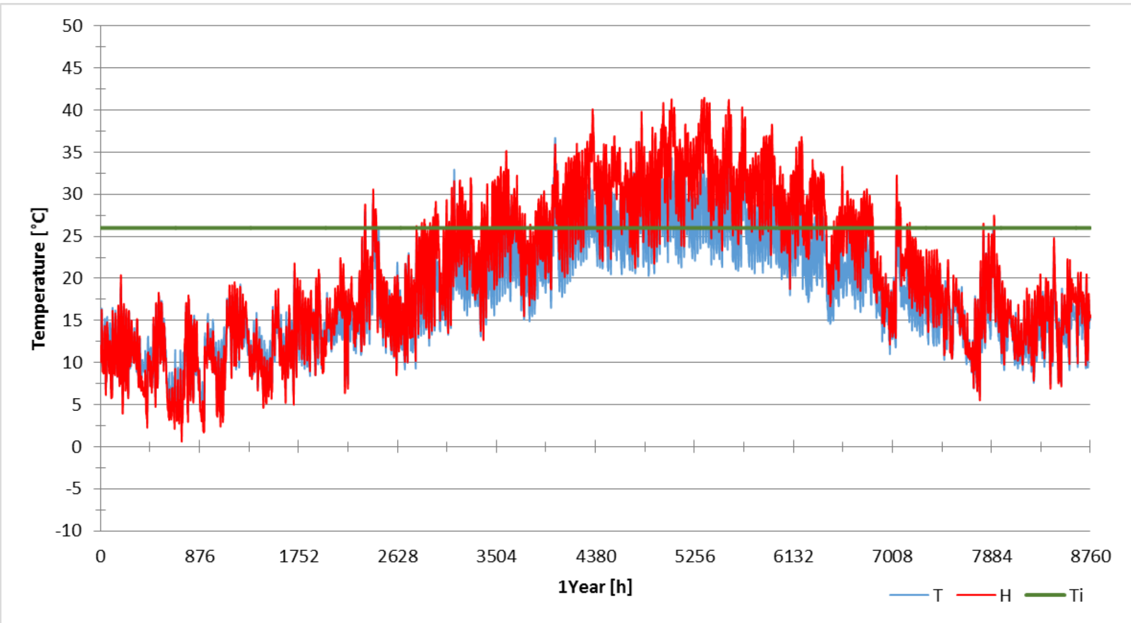


Figure 5.3: Palermo - Hourly outdoor temperature and hourly perceived temperature trends

According to the previous considerations, the total cost depend by the following parameters:

- climate conditions (HDD and CDD);
- building service systems (η_h and η_c);
- fuel price (C_{fh} and C_{fc});
- thermal properties of the other layers that compose the external wall (R_{wo});
- features and cost of the insulation material (λ_M, δ_M, C_M).

Since climate conditions, fuel price, building service systems, wall compositions and type of insulation material are known, the parameter that varies is the thickness of the insulation layer. Specifically, when total cost achieves the lowest value, the thickness of the insulation layer (δ_M) reaches the optimum (the minimum of the function f, Equation 5.3) [1].

In this research, the system type ("System 1" and "System 2") and the energy source (gas+electricity and electricity) are varied (as in Chapter 4) to investigate their influence on the results. Considering the values described in Table 5.2 as input, Table 5.3 presents the optimal insulation thickness for each location in order to minimize costs.

Seeing the results obtained for "System 1" (Table 5.3), it is possible to observe how the optimum thickness ($\delta_{1,opt}$) varies considerably from 7cm for Palermo to 12cm for Milano.

This implies the increasing of the thicknesses from the "Base Case" (δ_0) as also a reduction of the thermal transmittance ($U_{1,opt}$) of the 38% to 45%, comparing to the minimum imposed by regulations (U_{lim}).

Figures 5.4, 5.5 and 5.6 show the results in terms of useful/final/primary energy demands of the B case when firstly it is applied the thickness defined in Chapter 4 (δ_0) and secondly the optimized thickness ($\delta_{1,opt}$).

For instance (Figure 5.5), the differences in terms of final energy between the two cases are: Milano (MI) = 4.4kWh/m²a; Firenze (FI) = 2.1kWh/m²a; Roma (RM) = 1.2kWh/m²a; Napoli (NA) = 0.7kWh/m²a; Palermo almost the same.

INSULATION MATERIAL PROPERTIES			
λ_M	0.032 [3]	W/mK	
C_M	180 [4]	€/m³	
N	30	a	
R_{wo}	1.63	m²K/W	
SYSTEM 1			
η_h	0.9		
Energy source		gas	
C_{fh}		0.078[5]	€/kWh
SPF_c	2		
Energy source		electricity	
C_{fc}		0.2	€/kWh
SYSTEM 2			
COP_h	3		
COP_c	2		
Energy source		electricity	
C_f		0.2	€/kWh

Table 5.2: Input data: building systems features + thermal insulation material properties

CITY	D. Lgs. n. 311/2006	BASE CASE		SYSTEM 1			SYSTEM 2		
	U_{lim} [W/m²K]	U_0 [W/m²K]	δ_0 [cm]	$U_{1,opt}$ [W/m²K]	% of reduction respect U_{lim} [%]	$\delta_{1,opt}$ [cm]	$U_{2,opt}$ [W/m²K]	% of reduction respect U_{lim} [%]	$\delta_{2,opt}$ [cm]
MI	0.34	0.31	5	0.19	45	**12**	0.21	38	**10**
FI	0.36			0.21	42	**10**	0.24	33	**8**
RM	0.36			0.23	38	**9**	0.26	28	**7**
NA	0.40			0.24	40	**8**	0.26	35	**7**
PA	0.48			0.26	45	**7**	0.29	41	**6**

Table 5.3: Optimum thickness of the insulation layer and U values

[3] Xenergy [16]
[4] $C_M \approx 9$ €/m² [15]
[5] Gas and electricity costs for non-residential buildings in Italy [17]

It is possible to observe how the energy saved is quite contained and it is bigger for the cities where heating is predominant. Anyway, the values obtained by the optimization problem do not minimize the energy, but costs.

Despite that, the “iper-thermal insulation” is not the best solution to reduce heating demand. In fact, the growth of the thickness of the material has no a linear relation with the reduction of the heating demand. Figure 5.7 shows how adding 7cm (tot=12cm), involves an energy saving of 3.9kWh/m^{2}a, while adding other 12cm (tot=24cm) entails a further reduction of just 2.4kWh/m^{2}a. Hence, double the thickness of the insulation layer does not entail to halve the heating demand.

If the input data of “System 2” are used for the optimization (Equation 5.3), the result is that the thickness of the insulation layer loses its importance with very small values.

This occurs because, even if the main source is electricity (more expensive than gas), the energy paid to heat and cool the space is just a part.[6]

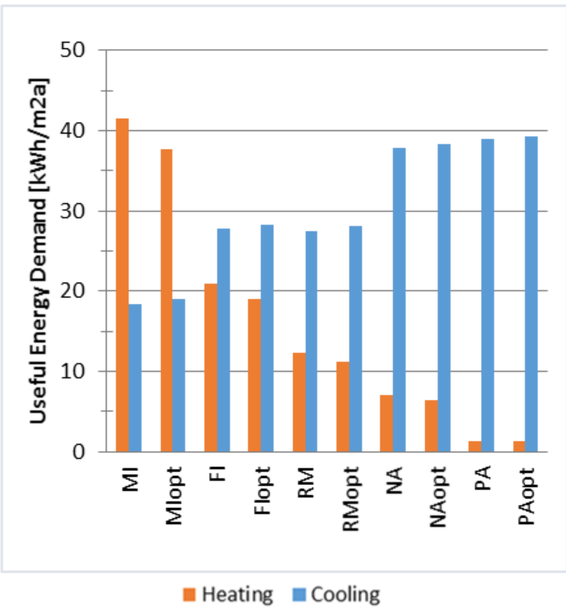


Figure 5.4: Useful energy demand - Comparison between Base Case (δ_0=5cm for all the cities) and Optimized Case ($\delta_{1,opt}$, Table 5.3) - Case B - All cities - “System 1”

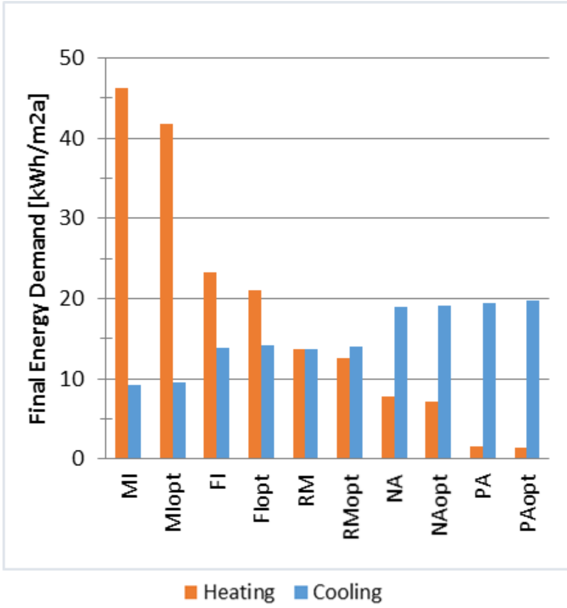


Figure 5.5: Final energy demand - Comparison between Base Case (δ_0=5cm for all the cities) and Optimized Case ($\delta_{1,opt}$, Table 5.3) - Case B - All cities - “System 1”

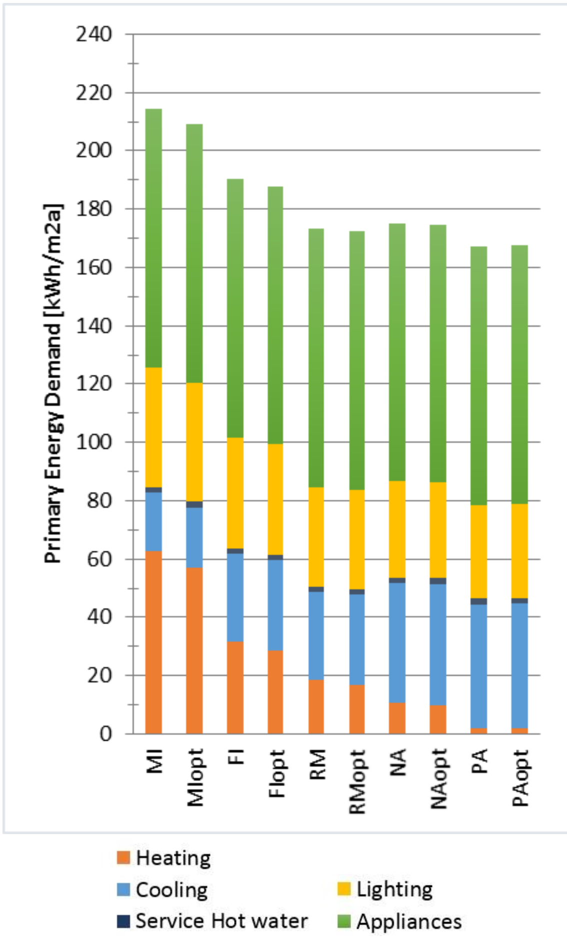


Figure 5.6: Primary energy demand - Comparison between Base Case (δ_0=5cm for all the cities) and Optimized Case ($\delta_{1,opt}$, Table 5.3) - Case B - All cities - “System 1”

[6] 1kWh of electricity consumed would provide 3kWh of output heat and 2kWh of output cooling. In terms of cost, it is paid just a portion. Therefore, for such optimization, the cost of the fuel is reduced of 1/2 (for the cooling part) and of 1/3 (for the heating part) and inserted in Equation 5.3.

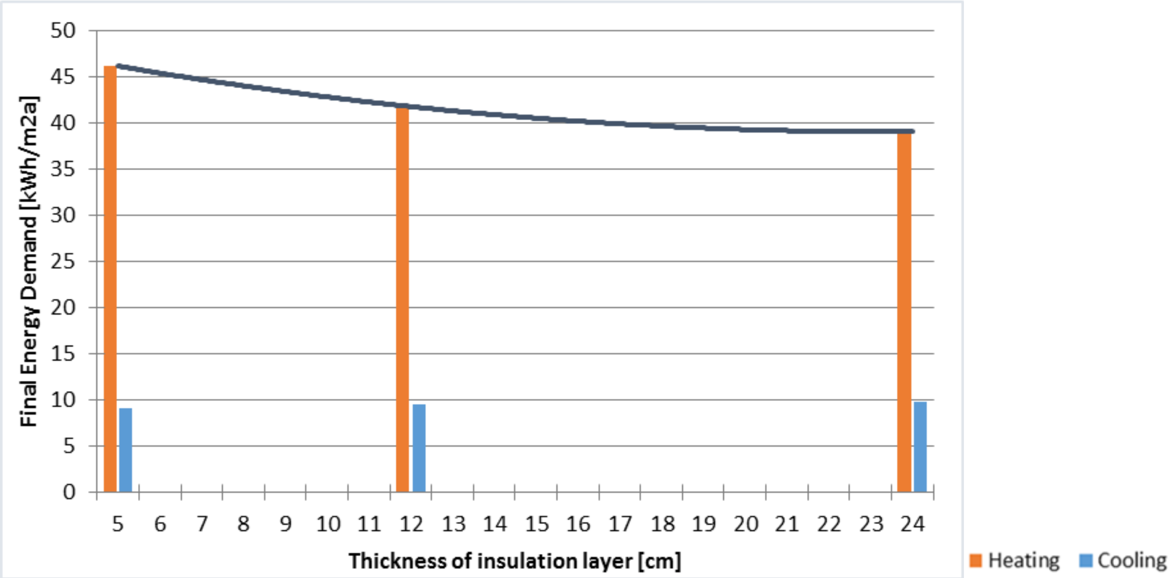


Figure 5.7: Useful energy demand - Comparison between cases with different thicknesses of the insulation layer (δ_M is 5cm, 12cm and 24cm) - Case B - Milano - "System 1"

In fact, the heat pump exploits renewable energy sources (ground, water, air) for the bigger part and it requires just a small part of electricity from the grid (that is the only portion that is paid).

Hence, if a heat pump is used ("System 2"), is less expensive and more convenient heating and cooling mechanically the space more than applying a high thickness insulation.

On contrary, if the cost of the energy is important ("System 1"), it is economically more convenient increasing the thickness of the material.

Nevertheless, a minimum insulation thickness is important to guarantee independently by the system or the energy source adopt. This, for example, in order to avoid thermal bridges (generally min 5cm) and guarantee airthigness. For these reasons, the following insulation thickness are recommended:

For "System 1" ($\delta_{1,opt}$, Table 5.3):

- Milano=12cm;
- Firenze=10cm;
- Roma=9cm;
- Napoli=8cm;
- Palermo=7cm.

For "System 2" ($\delta_{2,opt}$, Table 5.3):

- Milano=10cm;
- Firenze=8cm;
- Roma=Napoli=7cm;
- Palermo=6cm.

The equations adopted in the present paragraph considers the energy costs in relation to the energy balance of an external wall, without taking into account the initial investment cost of systems (ex. "System 2" is more expensive). Anyway, the investment cost of "System 2" can be paid back both if the energy saving through the years is important and if the heat pump is used for cooling and heating (reversible).

5.2 OPTIMUM WINDOW DESIGN

Heat transmission through windows is an important aspect to evaluate. For instance, the adoption of large transparencies implies heat gains during winter season and the growth of overheating in summer. This also has to merge with the optimum daylighting required by the interior spaces.

Considering the exterior wall with a window (with no shading devices), for example:

- heat transmissions depends by Window-to-Wall Ratio (WWR); thermal transmittances of both the transparent and the opaque parts (U_{opaque}, U_{glass} and ΔU) and the Solar Heat Gain Coefficient (SHGC).
  Specifically, increasing the window area does not entail the decrease completely of the heating demand because heat gains are not synchronous with the heating demand (Figure 5.9);[7]
- daylighting depends by the Window-to-Wall Ratio (WWR), the Visible Transmittance (VT), the shading devices and the interior layout characteristics.

According to these considerations, what is the best window design for Italian cities?

What is the compromise between reducing heating demand, containing cooling demand and controlling lighting?

Some investigations are conducted considering a group of offices[8] (Figure 5.8) and varying (Table 5.4):

- **location** (Milano, Firenze, Roma, Napoli, Palermo);
- **orientation** (North, South, West, East);
- **WWR** (from 20% to 100%);
- **type of glazing**;
- **shading devices** (different types and orientation).

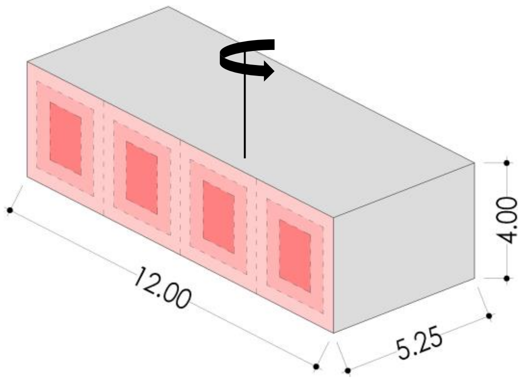


Figure 5.8: Model of the group of offices

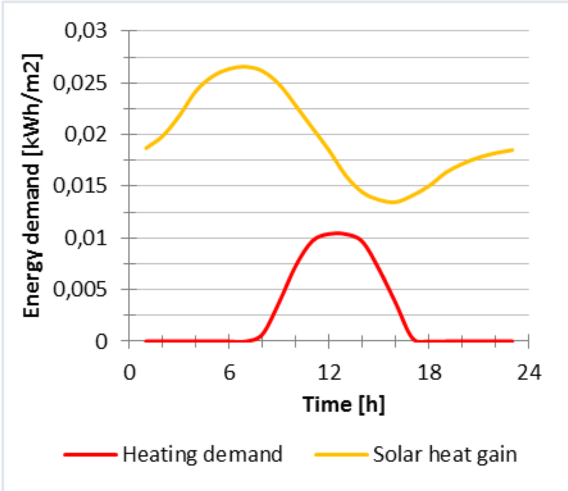


Figure 5.9: Energy demand: 21st December in Firenze

Location	Milano (MI); Firenze (FI); Roma (RM); Napoli (NA); Palermo (PA)
Orientation	North (N); West (W), South (S); East (E)
Glass type	Glass Type 1 (GT1); Glass Type 2 (GT2); Glass Type 3 (GT3)
Overhang	Length: O1=0.5m; O2=1.0m; O3=1.5m
Louvers	Angle: L1=15°; L2=30°; L3=45°;
Blinds	Medium=0.5 (MVB) and High = 0.8 (HVB) reflectance level for vertical blinds
	Medium=0.5 (MHB) and High=0.8 (HHB) reflectance for horizontal blinds

Table 5.4: List of parameters and their abbreviations

[7] For this reason, it is defined a solar gain effectiveness-factor (η).

[8] The geometry of the floor plan of the model is a rectangle 12m·5.25m (Figure 5.8). At the beginning, the features of the model (ex. opaque component, glass component, WWR, indoor conditions, etc.) are the same used for the Base Cases (Chapter 4).

5.2.1 WWR AND GLAZING TYPE

The Window-to-Wall Ratio (WWR)[9] influences considerably the energy behavior of the building and, in this Paragraph, it varies according to the location, the orientation and three different types of glazing. Specifically, the range varies from a minimum value of 20% (it is a value acceptable for offices, meeting rooms, etc.) until a completely glass wall (WWR=100%). Three types of glazing are investigated differing for thermal and light properties:

1. **GLASS TYPE 1 (GT1)**[10]**:**
   Composition: 6mm Pyrolitic Clear Glass + 16mm Argon + 4.4·2mm Laminated glass with PVB interlayer;
   Properties: LSG=1.12; SHGC=0.63; VT=0.71; U=1.7W/m^{2}K;
2. **GLASS TYPE 2 (GT2):**
   Composition: 6mm Spectral Selective Glass + 16mm Argon + 4.4·2mm Laminated glass with PVB interlayer;
   Properties: LSG=1.63; SHGC=0.41; VT=0.67; U=1.37W/m^{2}K;
3. **GLASS TYPE 3 (GT3):**
   Composition: 6mm Low-e Spectral Selective Glass + 16mm Argon + 4.4·2mm Laminated glass with PVB interlayer;
   Properties: LSG=2.04; SHGC=0.24; VT=0.49; U=1.01W/m^{2}K.

5.2.2 WWR AND SHADING DEVICES

Protecting from overheating and from glare, without renouncing to a see-contact with the exterior space, is a fundamental aspect of the envelope design. Many solutions should be adopted for this purpose and, in this research, some aspects of the design of exterior shading devices are investigated. The shading devices are combined with the base glass[11] (GT1) also adopted in Chapter 4.
More in detail, the shading systems considered are the following (Figure 5.10):

- **OVERHANG:** it corresponds with the size of the window[12] and the length is the parameter that varies from the minimum of 0.5m to 1.5m, according to the variation of the WWR (**O1=0.5m, O2=1.0m, O3=1.5m**);
- **HORIZONTAL LOUVERS:** they correspond with the size of the window. They are fixed aluminum elements during the year with the angle that changes (**L1**=15°, **L2**=30°; **L3**=45°) according also to the variation of the WWR;
- **VERTICAL AND HORIZONTAL BLINDS** (**VB** and **HB**): they correspond with the size of the window. Their slats[13]can move from 0° to 180° according to a control system based on solar radiation. The parameter is the reflectance that shares in medium (**MVB** and **MHB** → reflectance equal to 0.5) and high reflectance levels (**HVB** and **HHB** → reflectance equal to 0.8).

Specifically, the parameters are:
- WWR versus dimensions of the overhang;
- WWR versus angle of the horizontal louvers;
- WWR versus reflectance index of horizontal/vertical blinds.

According to different orientations of the offices, it has been tested for:

- **NORTH:** Glazing type (No shading device);
- **SOUTH:** Glazing type (No shading devices), overhang, horizontal louvers and horizontal blinds;
- **WEST AND EAST:** Glazing type (No shading devices) and vertical blinds.

[9] It represents the relation between the glazing area and the area of the wall.
[10] It is the same glass adopted in Chapter 4 for the Base Cases.
[11] At the end of the paragraph, there are some examples (only for the city of Milano and Palermo and for the South orientation) with the combination of the shading elements (the blind type) with more performing glazing (GT2 and GT3).
[12] Vertical offset from the top of the window equal to 0m and horizontal window overlap equal to 0m.
[13] The geometry of slats is the same for louvers and blinds. Some characteristics are: distance between slats equal to 15cm, slats width equal to 30cm, distance from the glass equal to 30cm. For louvers, the angle is univocally defined, for blinds, it changes depending by the solar radiation.

The results of the optimum window design, for each city and each orientation, are presented as:

- graphics in terms of useful energy demand (cooling and heating) and final energy demand (heating, cooling and total energy)[14]. Specifically, for the last one, the results are presented applying firstly "System 1" and then "System 2".
  The inclination of the lines is an indicator on how the parameters affect the energy performance giving quantitative advices;
- summary tables easy to consult where the symbols ("+","-" and "0") and the colors (green, yellow and red) identify if the design choices are "Strongly", "Less" and "Not recommended" (Table 5.5).
  To make possible a hierarchy of solutions and to give recommendations, **±5kWh/m²a** is the range considered. Specifically, if:

$Q_{u,Case} - Q_{u,Best}$[15]

< 5kWh/m²a → STRONGLY ("+")
from 5 to 10kWh/m²a → LESS ("-")
> 10 kWh/m²a → NOT ("0")

WWR	GT1	GT2	GT3
20%	+	+	0
30%	+	+	-
40%	+	+	+
50%	-	+	+
60%	0	+	+
70%	0	-	+
80%	0	-	-
90%	0	0	-
100%	0	0	-

0	Not Recommended
-	Less Recommended
+	Strongly Recommended

Table 5.5: Example of table, Firenze, North orientation

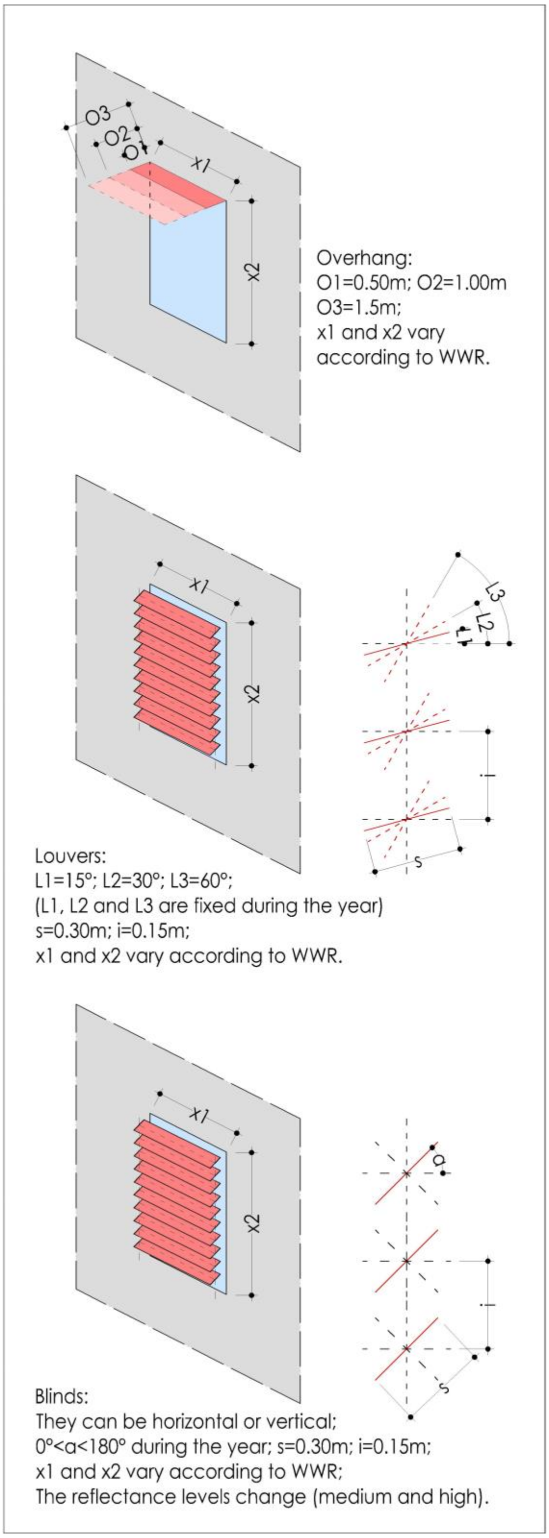


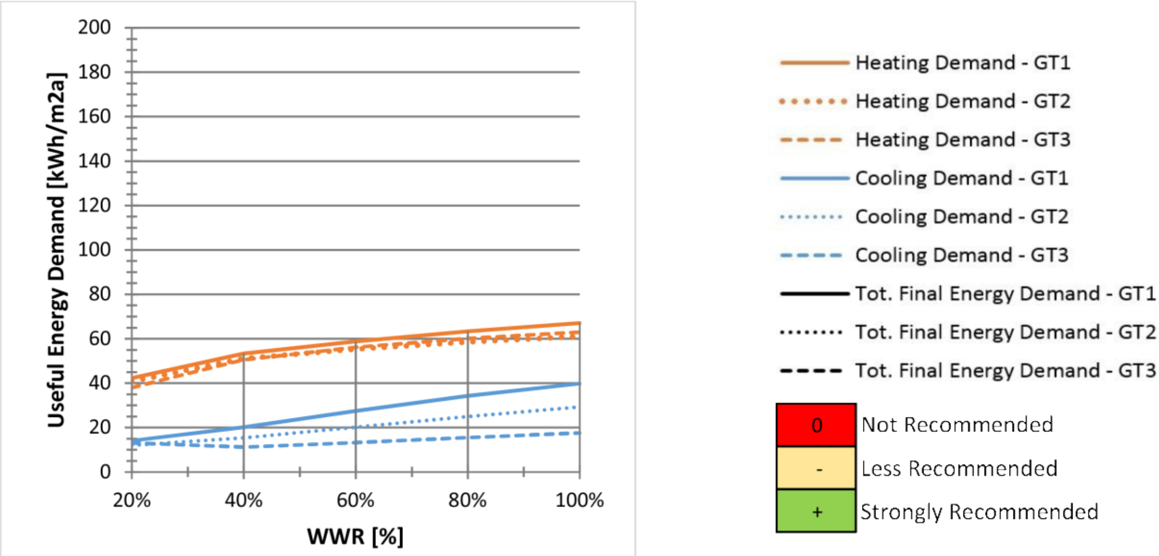
Figure 5.10: Sketch with shading devices

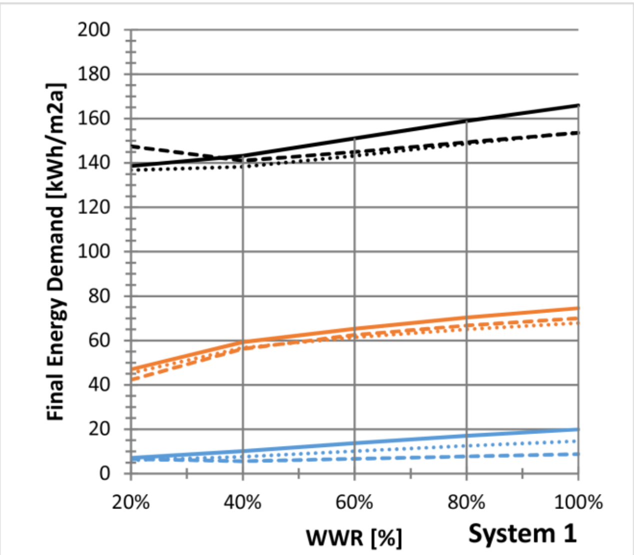
[14] Total final energy demand is the sum of the energy demand for heating, cooling, lighting, service hot water and appliances.

[15] It is the difference between the final energy demand of the solution and the final energy demand of the best solution. The best solution has the lowest final energy demand.

MILANO

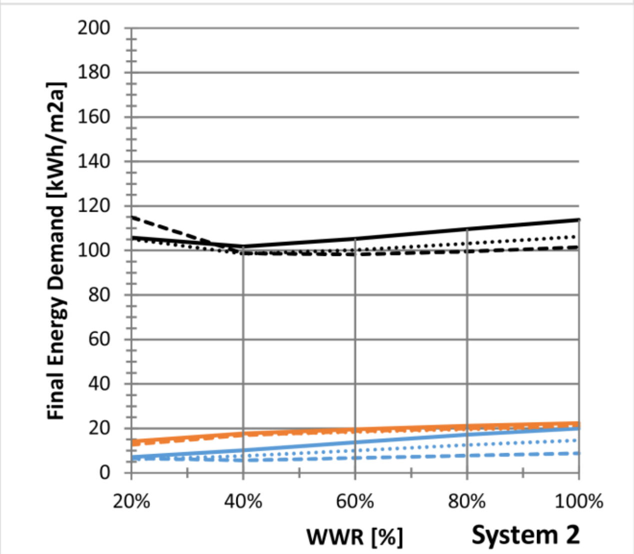
NORTH - Glass type/No shading devices





Recommendations when System 1

WWR	GT1	GT2	GT3
20%	+	+	0
30%	+	+	-
40%	-	+	+
50%	0	+	-
60%	0	-	-
70%	0	-	0
80%	0	0	0
90%	0	0	0
100%	0	0	0



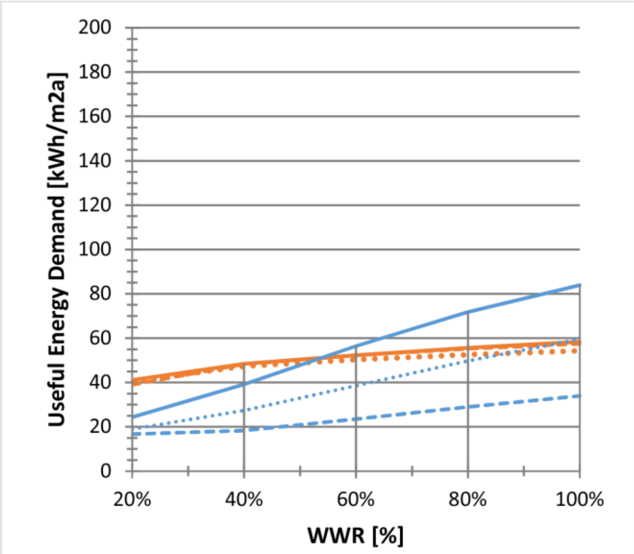
Recommendations when System 2

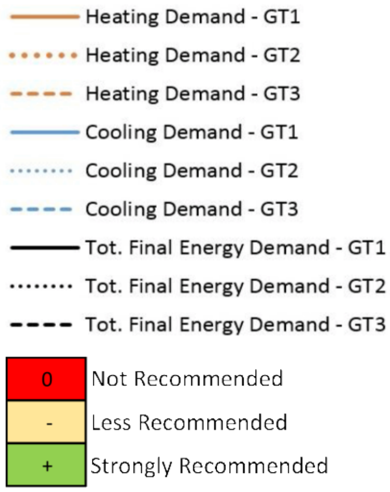
WWR	GT1	GT2	GT3
20%	-	-	0
30%	-	+	-
40%	+	+	+
50%	-	+	+
60%	-	+	+
70%	-	+	+
80%	0	+	+
90%	0	-	+
100%	0	-	+

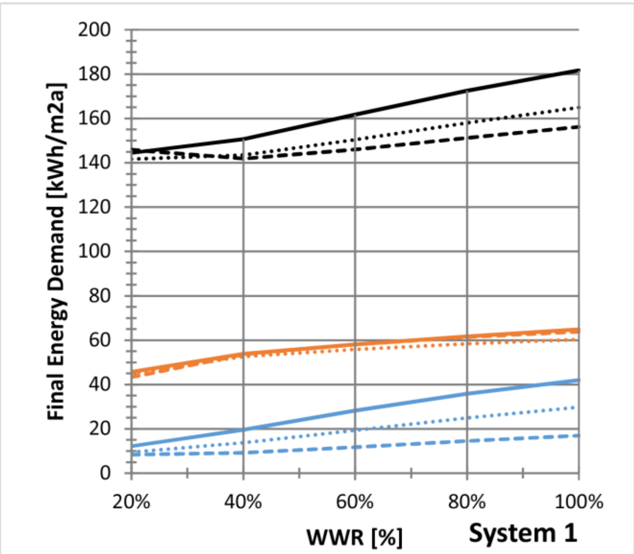
Figure 5.11: Graphics and tables with recommendations for Milano, North, Glass type

MILANO

WEST - Glass type/No shading devices

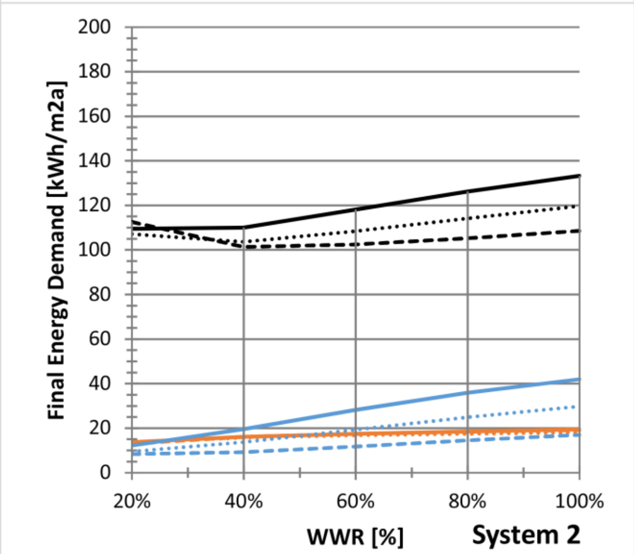






Recommendations when System 1

WWR	GT1	GT2	GT3
20%	+	+	+
30%	-	+	+
40%	-	+	+
50%	0	-	+
60%	0	-	+
70%	0	0	-
80%	0	0	-
90%	0	0	0
100%	0	0	0



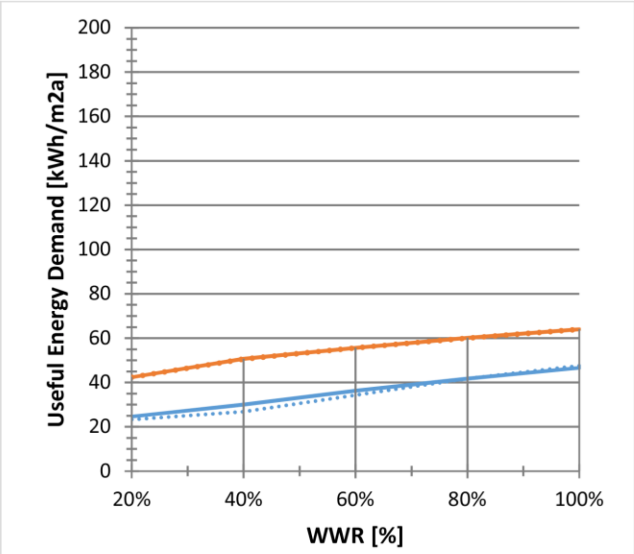
Recommendations when System 2

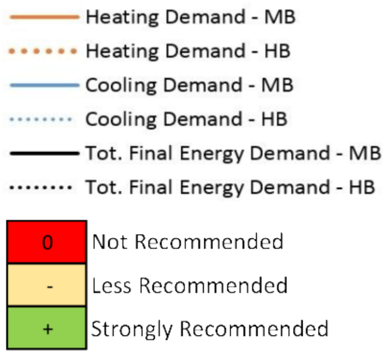
WWR	GT1	GT2	GT3
20%	-	-	0
30%	-	+	-
40%	-	+	+
50%	0	+	+
60%	0	-	+
70%	0	-	+
80%	0	0	+
90%	0	0	-
100%	0	0	-

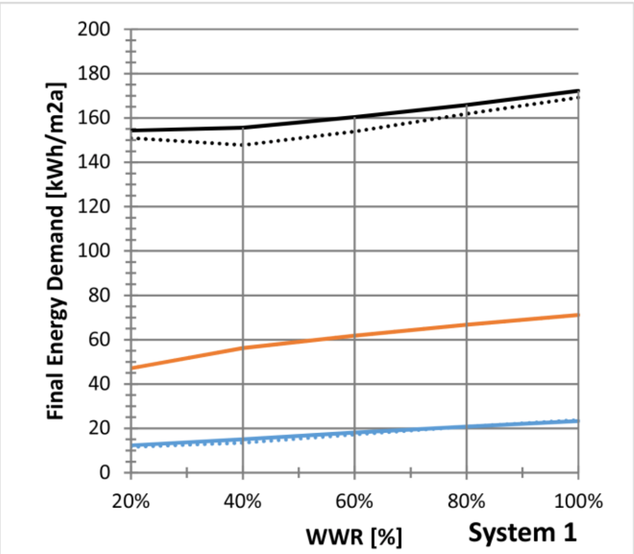
Figure 5.12: Graphics and tables with recommendations for Milano, West, Glass type

MILANO

WEST - Vertical Blinds

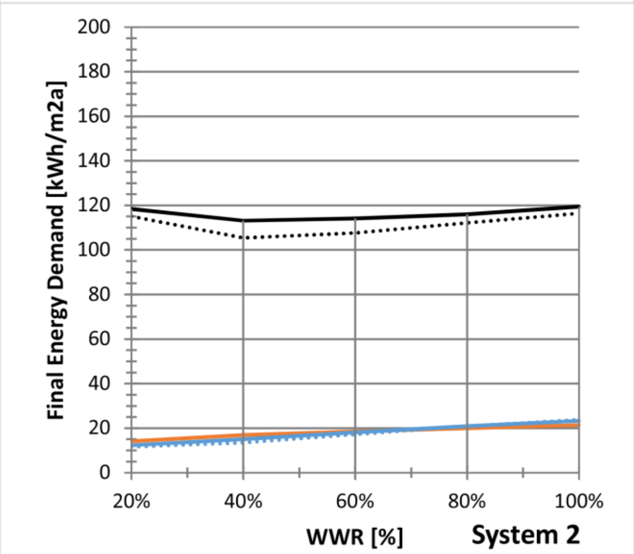






Recommendations when System 1

WWR	MVB	HVB
20%	-	+
30%	-	+
40%	-	+
50%	0	+
60%	0	-
70%	0	0
80%	0	0
90%	0	0
100%	0	0

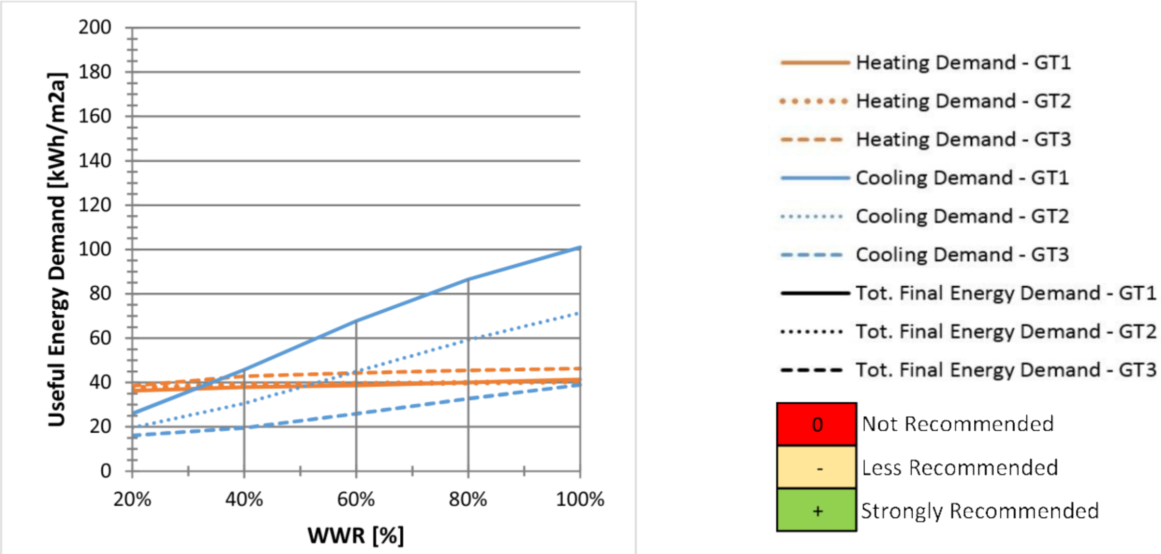


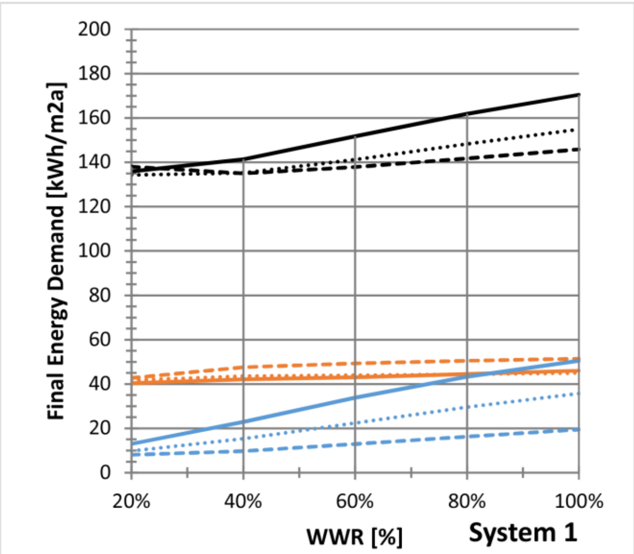
Recommendations when System 2

WWR	MVB	HVB
20%	0	-
30%	0	+
40%	-	+
50%	-	+
60%	-	+
70%	-	+
80%	0	-
90%	0	-
100%	0	0

Figure 5.13: Graphics and tables with recommendations for Milano, West, Vertical blinds

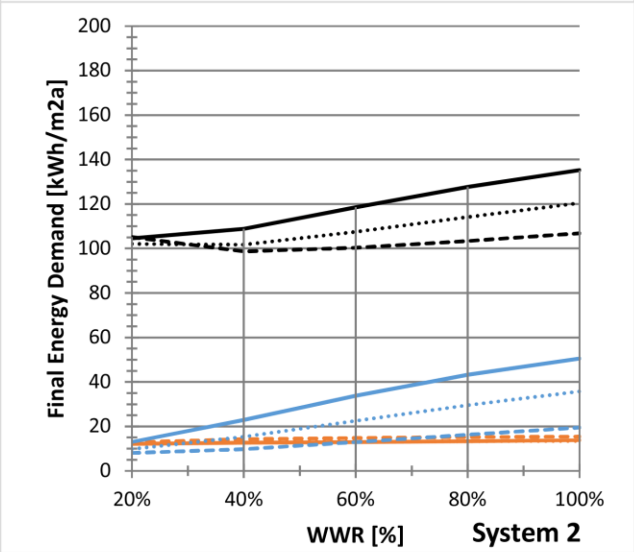
MILANO
SOUTH - Glass type/No shading devices





Recommendations when System 1

WWR	GT1	GT2	GT3
20%	+	+	+
30%	+	+	+
40%	-	+	+
50%	0	+	+
60%	0	-	+
70%	0	0	-
80%	0	0	-
90%	0	0	-
100%	0	0	0



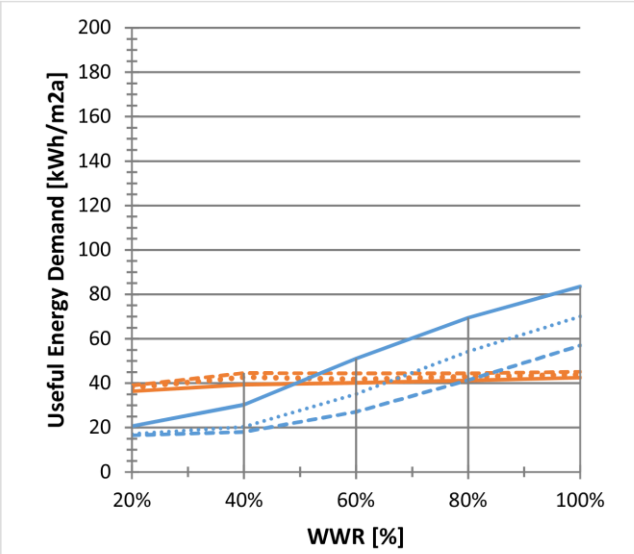
Recommendations when System 2

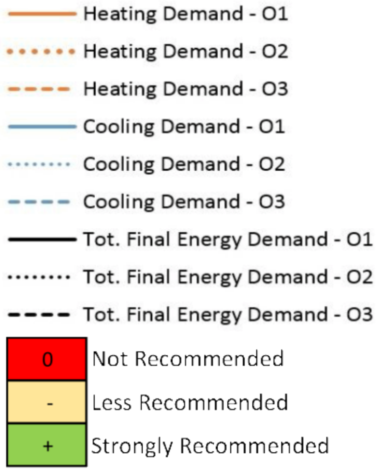
WWR	GT1	GT2	GT3
20%	-	+	-
30%	-	+	+
40%	0	+	+
50%	0	-	+
60%	0	-	+
70%	0	0	+
80%	0	0	+
90%	0	0	-
100%	0	0	-

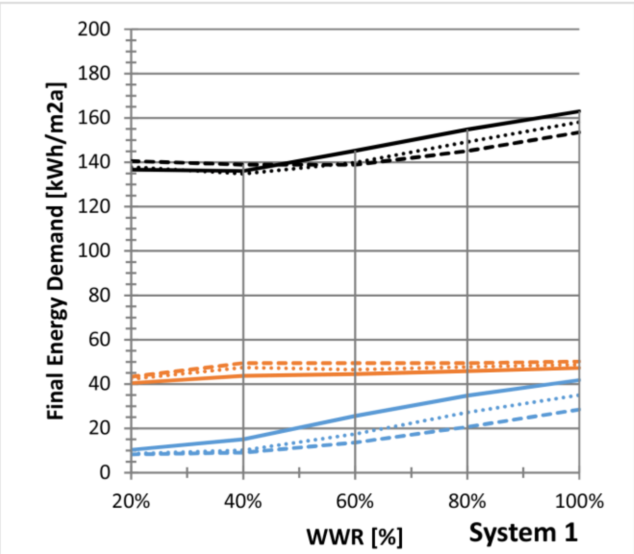
Figure 5.14: Graphics and tables with recommendations for Milano, South, Glass type

MILANO

SOUTH - Overhangs

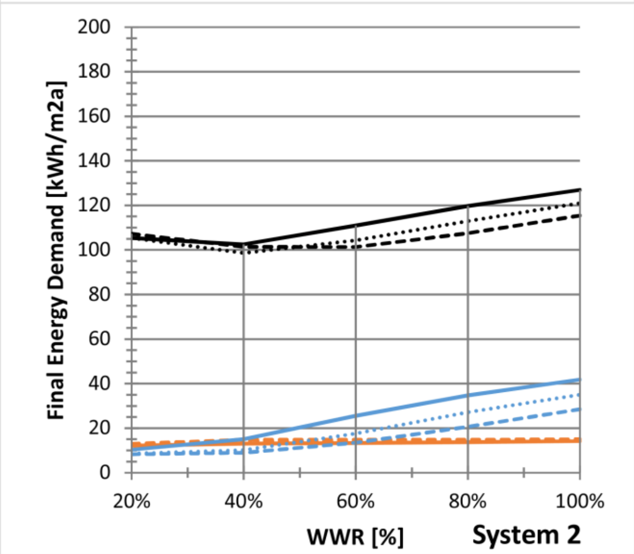






Recommendations when System 1

WWR	O1	O2	O3
20%	+	+	-
30%	+	+	+
40%	+	+	+
50%	-	+	+
60%	0	-	+
70%	0	-	-
80%	0	0	0
90%	0	0	0
100%	0	0	0



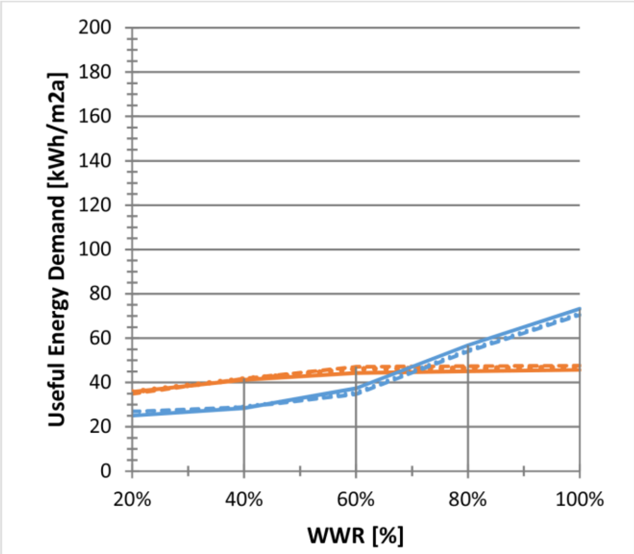
Recommendations when System 2

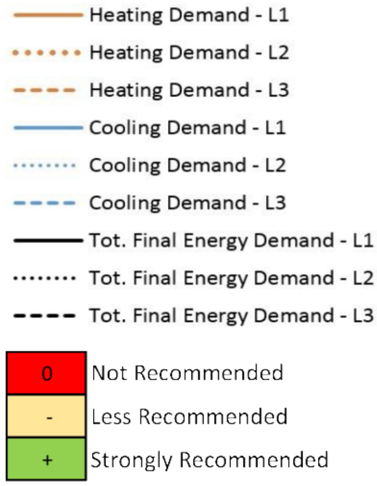
WWR	O1	O2	O3
20%	-	-	-
30%	-	+	-
40%	+	+	+
50%	-	+	+
60%	0	-	+
70%	0	0	-
80%	0	0	-
90%	0	0	0
100%	0	0	0

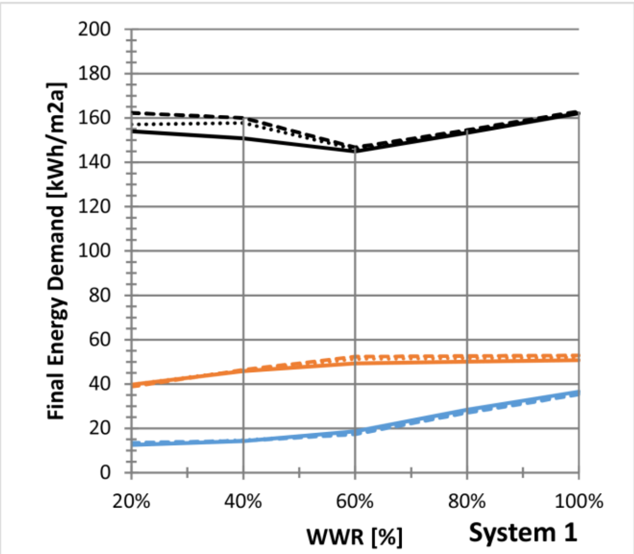
Figure 5.15: Graphics and tables with recommendations for Milano, South, Overhangs

MILANO

SOUTH - Horizontal Louvers

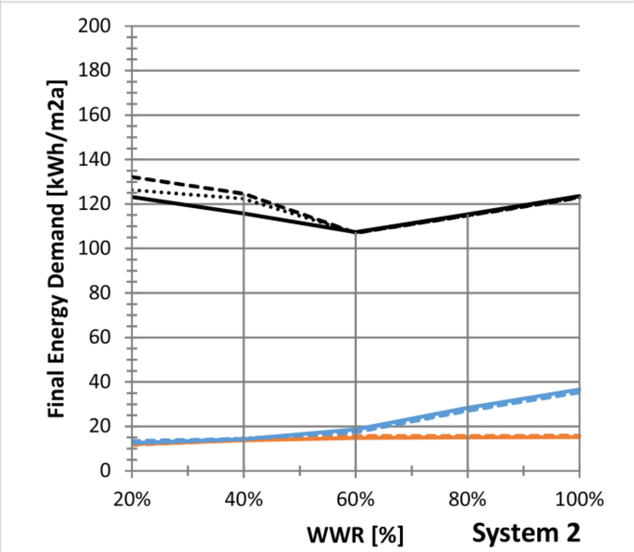






Recommendations when System 1

WWR	L1	L2	L3
20%	-	0	0
30%	-	0	0
40%	-	0	0
50%	+	-	-
60%	+	+	+
70%	+	-	-
80%	-	-	-
90%	0	0	0
100%	0	0	0



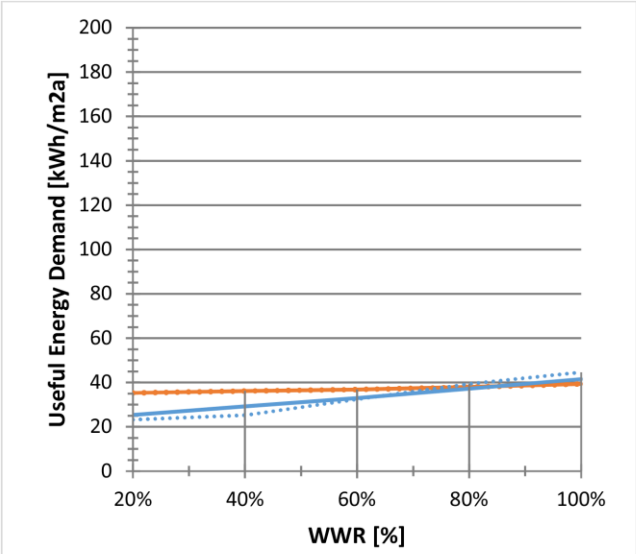
Recommendations when System 2

WWR	L1	L2	L3
20%	0	0	0
30%	0	0	0
40%	-	0	0
50%	+	-	-
60%	+	+	+
70%	+	+	+
80%	-	-	-
90%	0	0	0
100%	0	0	0

Figure 5.16: Graphics and tables with recommendations for Milano, South, Louvers

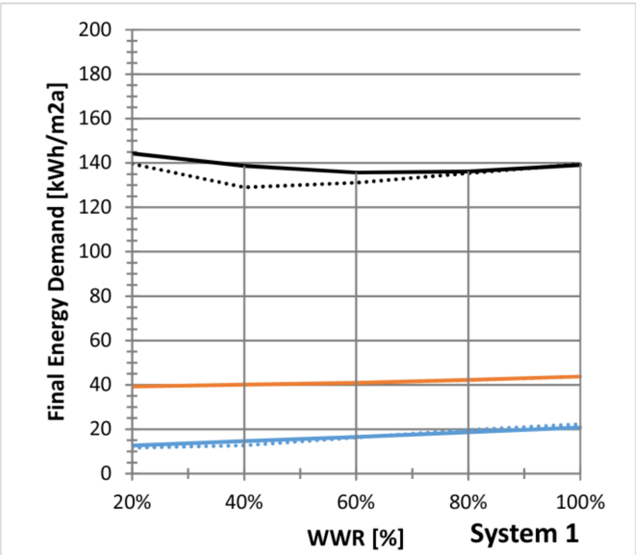
MILANO

SOUTH - Horizontal Blinds



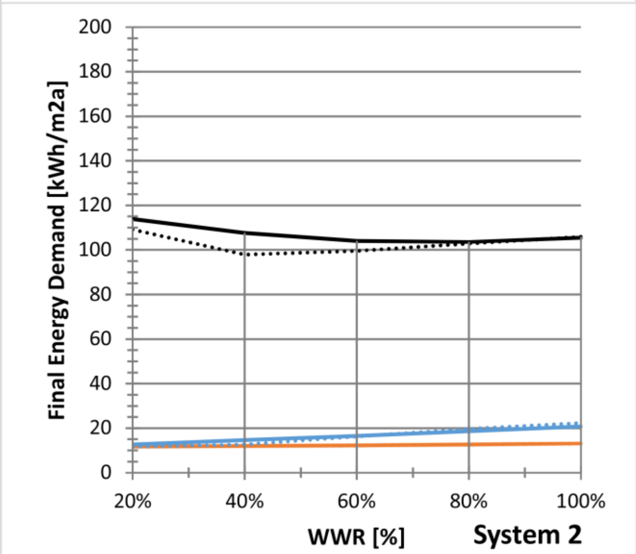
Heating Demand - MB
Heating Demand - HB
Cooling Demand - MB
Cooling Demand - HB
Tot. Final Energy Demand - MB
Tot. Final Energy Demand - HB

0	Not Recommended
-	Less Recommended
+	Strongly Recommended



Recommendations when System 1

WWR	MHB	HHB
20%	0	0
30%	0	-
40%	-	+
50%	-	+
60%	-	+
70%	-	+
80%	-	-
90%	-	-
100%	0	0



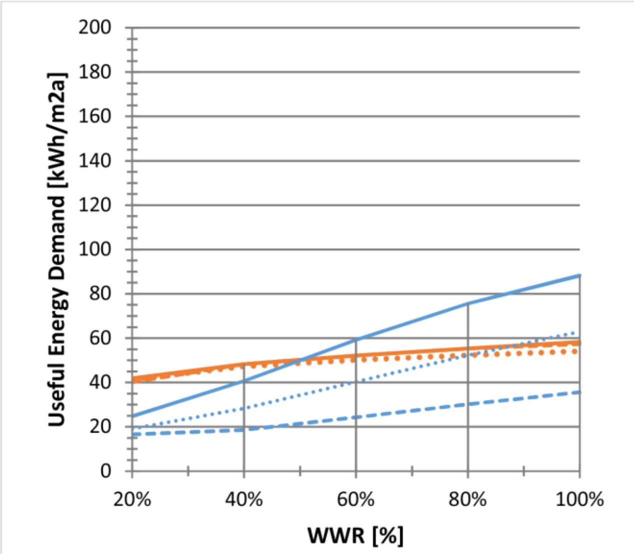
Recommendations when System 2

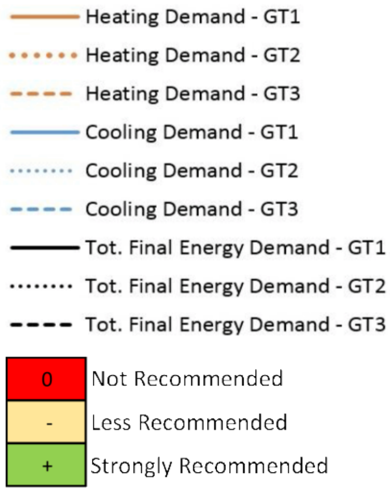
WWR	MHB	HHB
20%	0	0
30%	0	-
40%	-	+
50%	-	+
60%	-	+
70%	-	+
80%	-	+
90%	-	-
100%	-	-

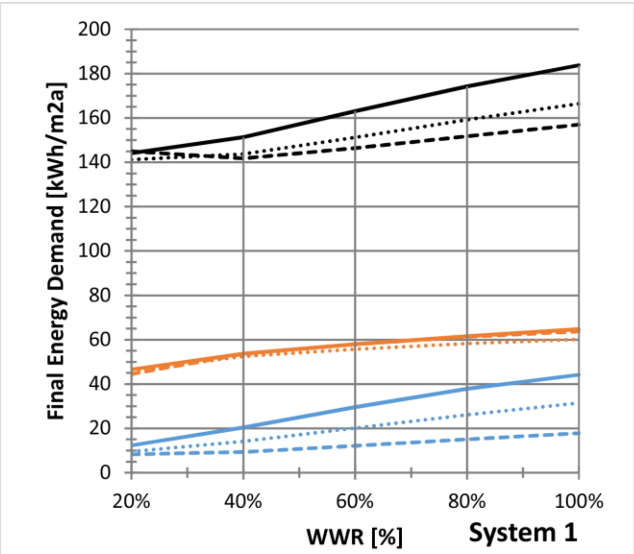
Figure 5.17: Graphics and tables with recommendations for Milano, South, Horizontal blinds

MILANO

EAST - Glass type/No shading devices

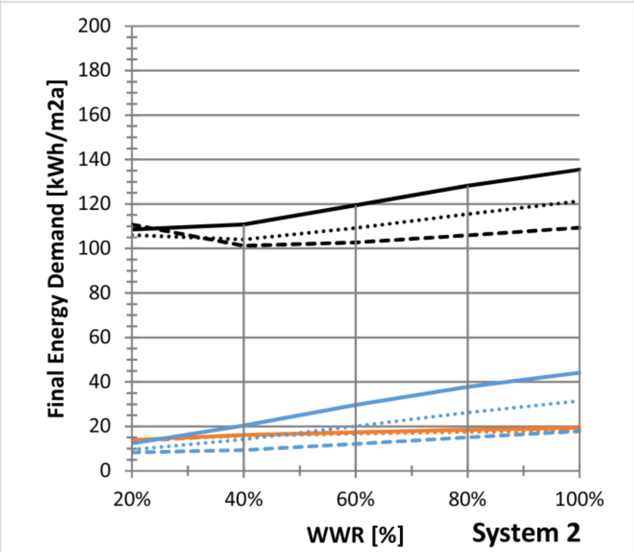






Recommendations when System 1

WWR	GT1	GT2	GT3
20%	+	+	+
30%	-	+	+
40%	0	+	+
50%	0	-	+
60%	0	-	-
70%	0	0	-
80%	0	0	0
90%	0	0	0
100%	0	0	0



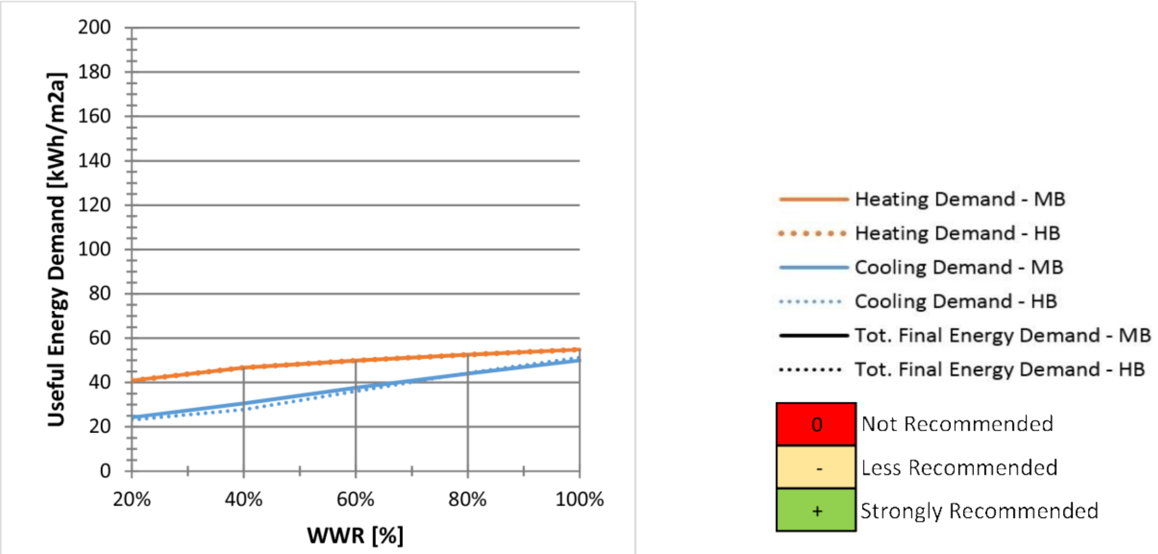
Recommendations when System 2

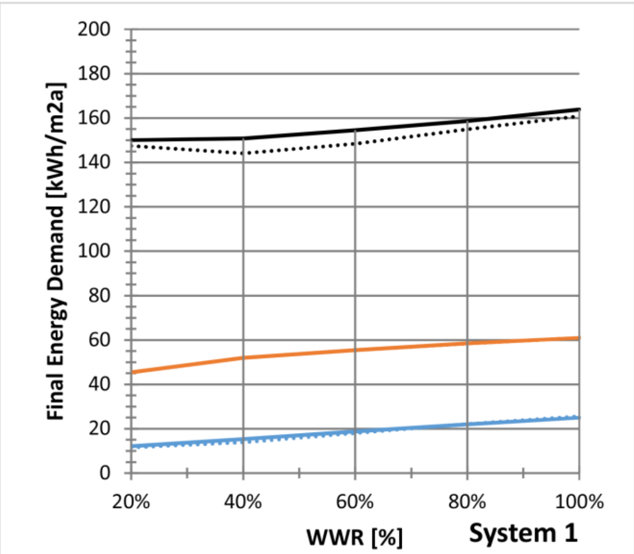
WWR	GT1	GT2	GT3
20%	-	+	-
30%	-	+	+
40%	-	+	+
50%	0	-	+
60%	0	-	+
70%	0	0	+
80%	0	0	+
90%	0	0	-
100%	0	0	-

Figure 5.18: Graphics and tables with recommendations for Milano, East, Glass type

MILANO

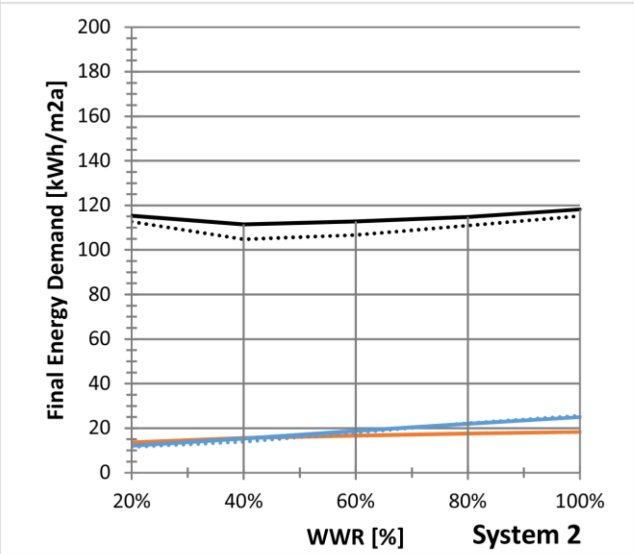
EAST - Vertical Blinds





Recommendations when System 1

WWR	MVB	HVB
20%	-	+
30%	-	+
40%	-	+
50%	-	+
60%	0	+
70%	0	-
80%	0	0
90%	0	0
100%	0	0



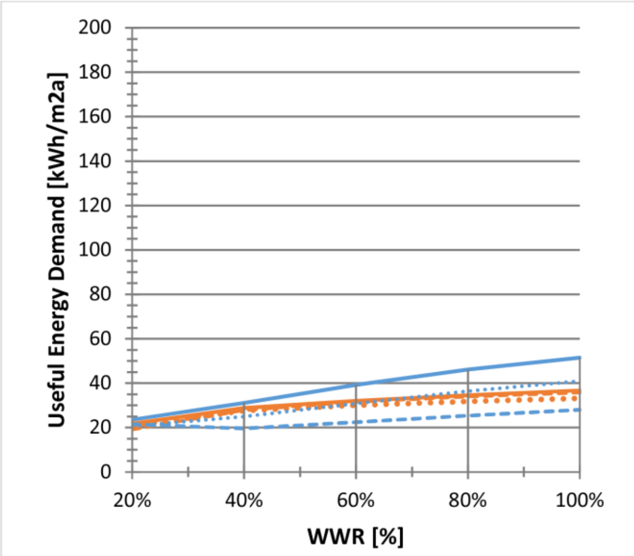
Recommendations when System 2

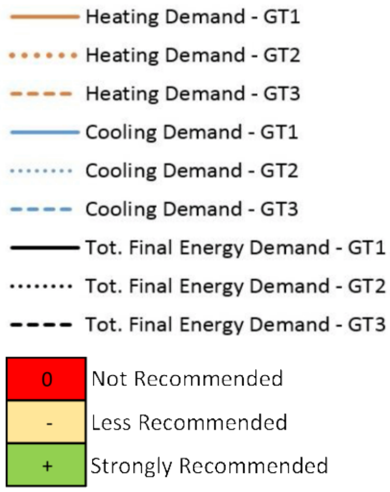
WWR	MVB	HVB
20%	0	-
30%	-	+
40%	-	+
50%	-	+
60%	-	+
70%	-	+
80%	0	-
90%	0	-
100%	0	0

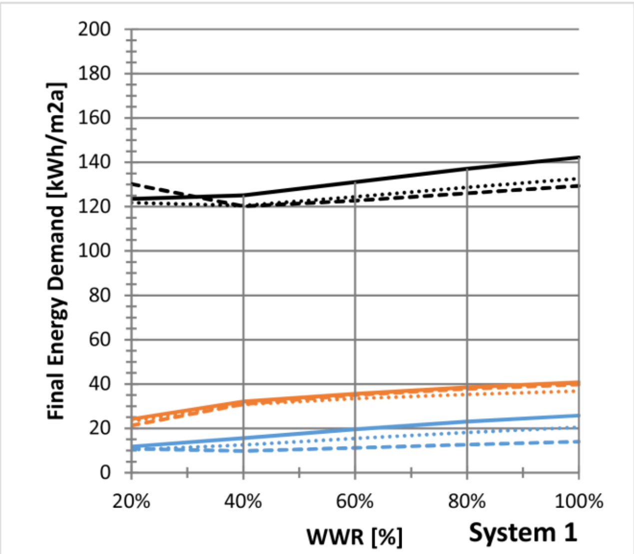
Figure 5.19: Graphics and tables with recommendations for Milano, East, Vertical Blinds

FIRENZE

NORTH - Glass type/No shading devices

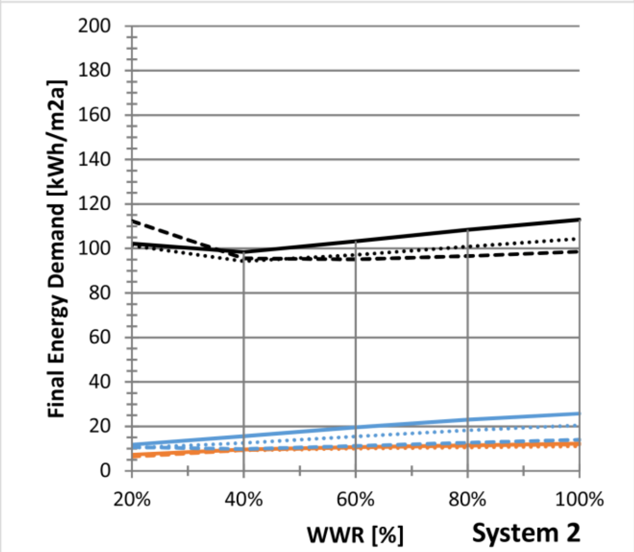






Recommendations when System 1

WWR	GT1	GT2	GT3
20%	+	+	0
30%	+	+	-
40%	+	+	+
50%	-	+	+
60%	0	+	+
70%	0	-	+
80%	0	-	-
90%	0	0	-
100%	0	0	-

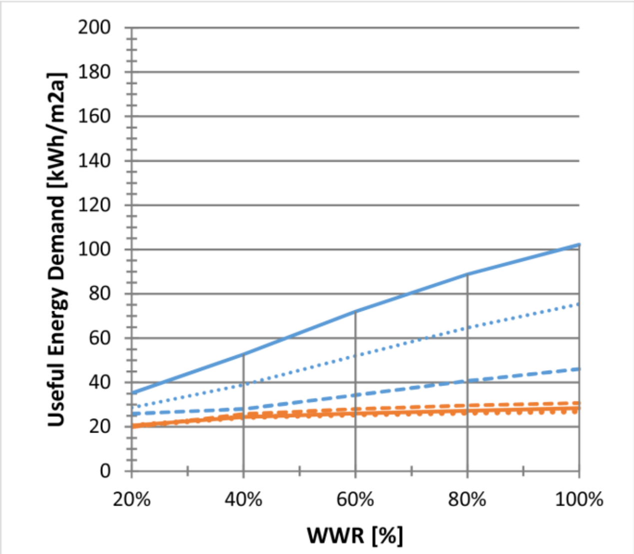


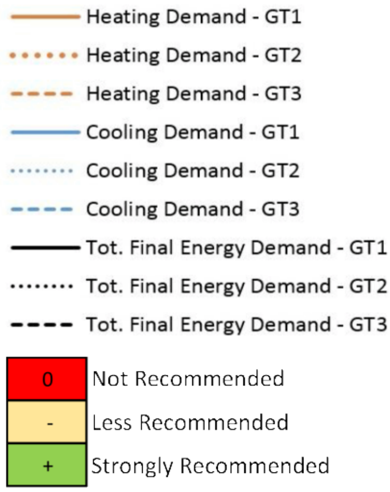
Recommendations when System 2

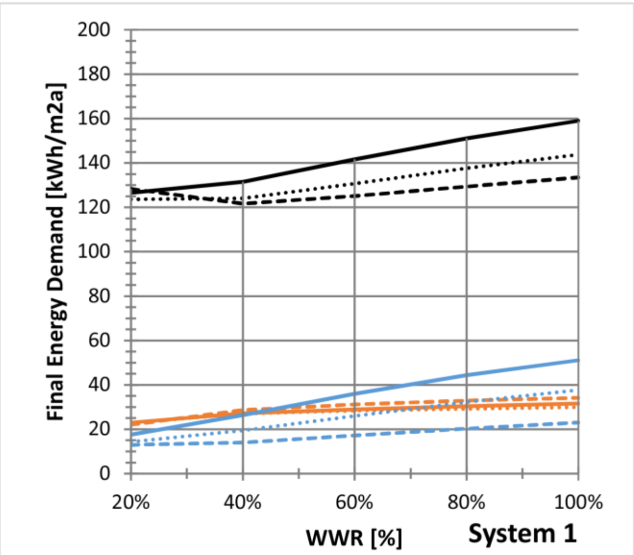
WWR	GT1	GT2	GT3
20%	-	-	0
30%	-	+	-
40%	+	+	+
50%	-	+	+
60%	-	+	+
70%	0	+	+
80%	0	-	+
90%	0	-	+
100%	0	0	+

Figure 5.20: Graphics and tables with recommendations for Firenze, North, Glass type

FIRENZE
WEST - Glass type/No shading devices

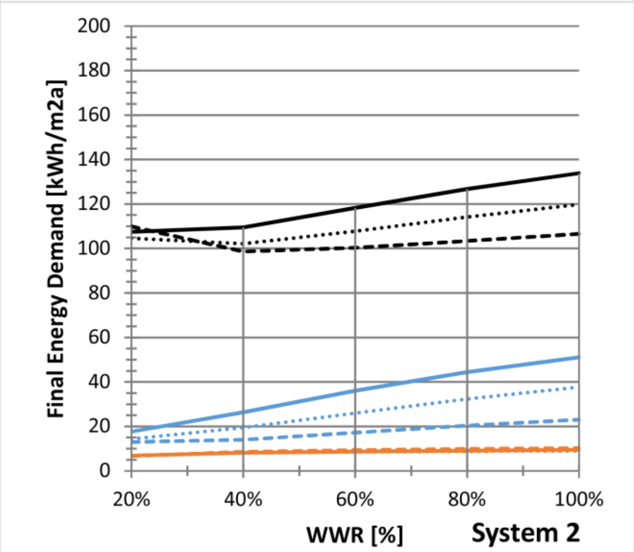






Recommendations when System 1

WWR	GT1	GT2	GT3
20%	+	+	-
30%	-	+	+
40%	-	+	+
50%	0	-	+
60%	0	-	+
70%	0	0	-
80%	0	0	-
90%	0	0	-
100%	0	0	0



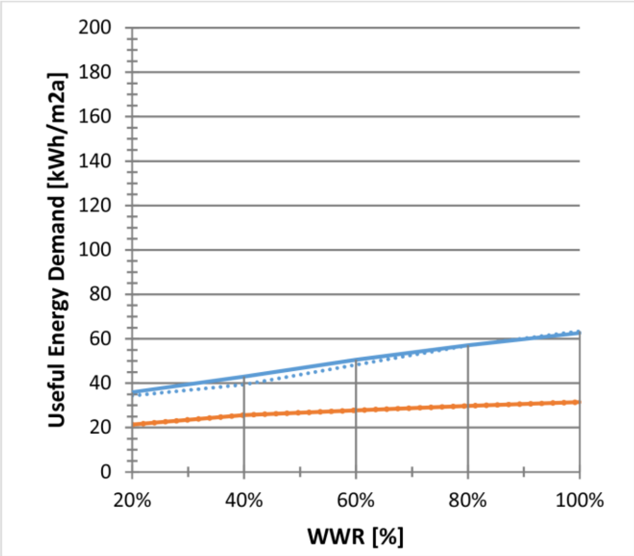
Recommendations when System 2

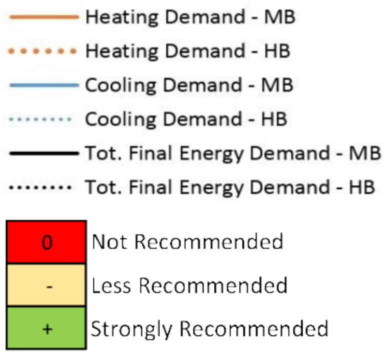
WWR	GT1	GT2	GT3
20%	-	-	0
30%	-	+	-
40%	0	+	+
50%	0	-	+
60%	0	-	+
70%	0	0	+
80%	0	0	+
90%	0	0	-
100%	0	0	-

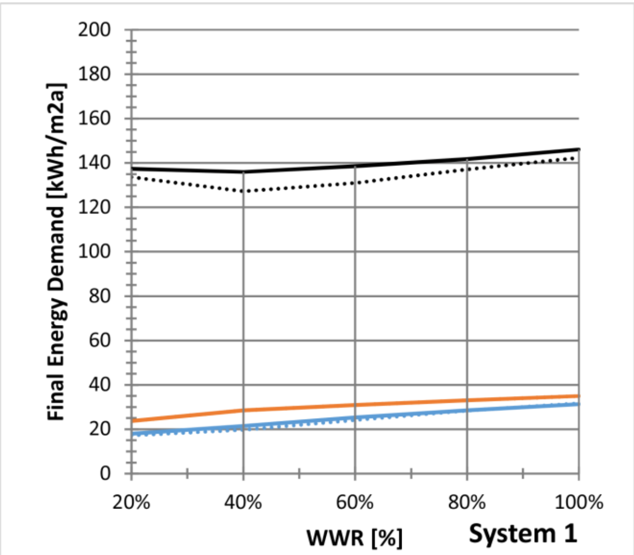
Figure 5.21: Graphics and tables with recommendations for Firenze, West, Glass type

FIRENZE

WEST - Vertical Blinds

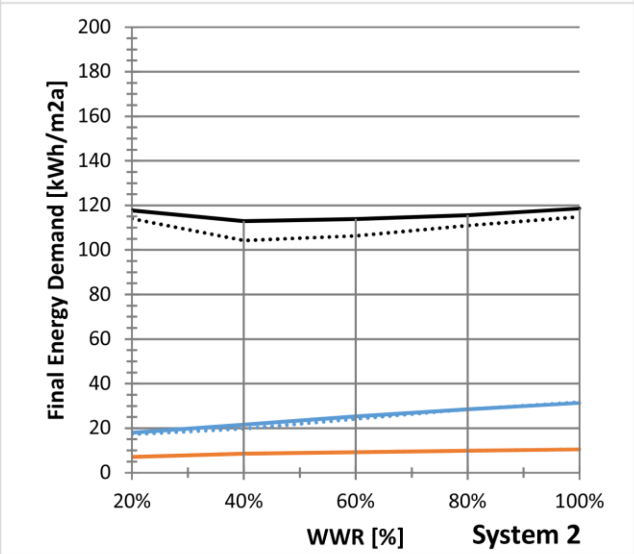






Recommendations when System 1

WWR	MVB	HVB
20%	0	-
30%	-	+
40%	-	+
50%	0	+
60%	0	+
70%	0	-
80%	0	-
90%	0	0
100%	0	0

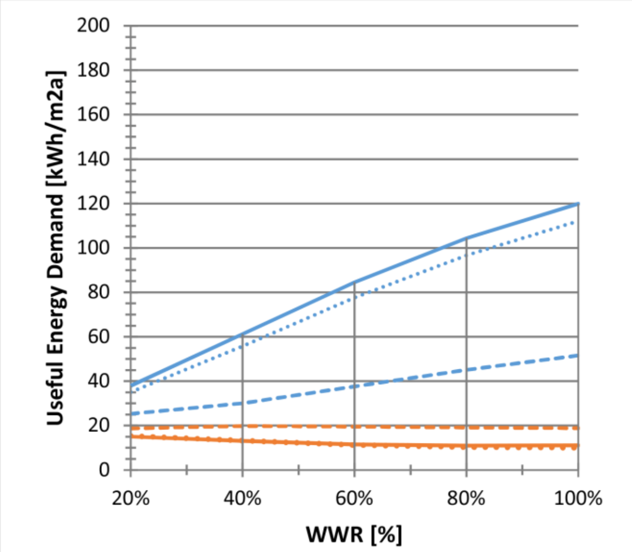


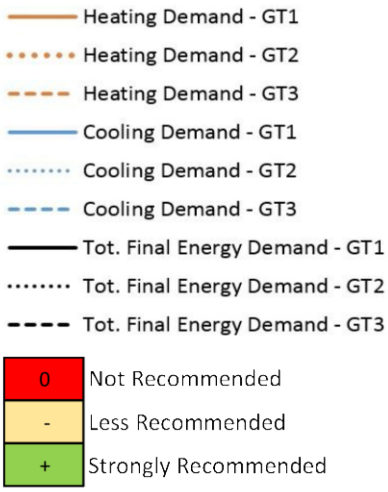
Recommendations when System 2

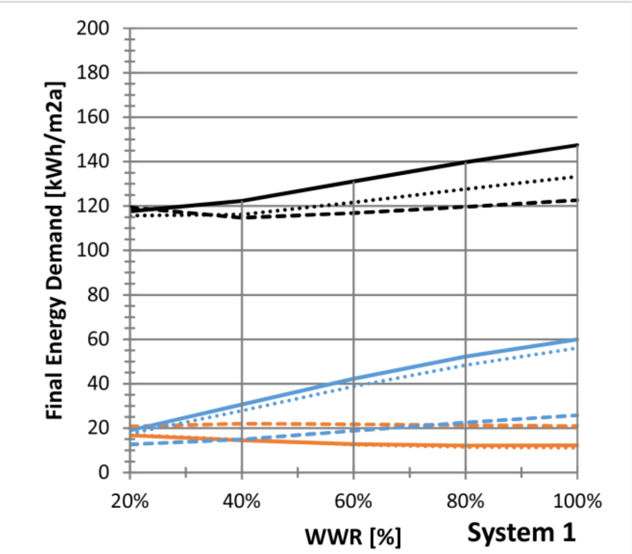
WWR	MVB	HVB
20%	0	-
30%	0	+
40%	-	+
50%	-	+
60%	-	+
70%	0	+
80%	0	-
90%	0	-
100%	0	0

Figure 5.22: Graphics and tables with recommendations for Firenze, West, Vertical Blinds

FIRENZE
SOUTH - Glass type/No shading devices

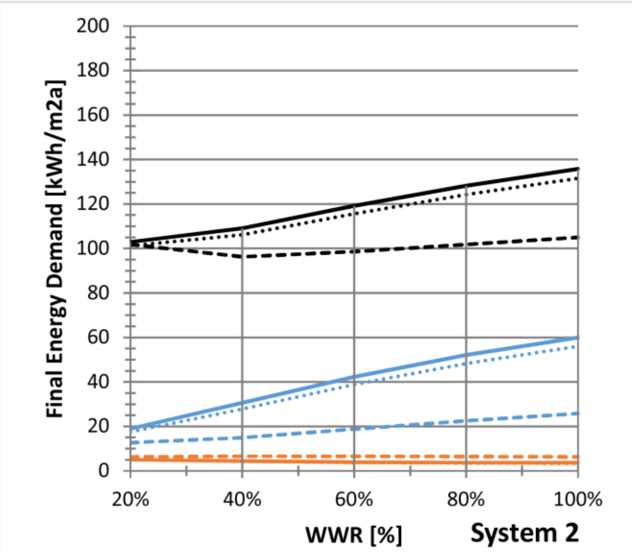






Recommendations when System 1

WWR	GT1	GT2	GT3
20%	+	+	+
30%	-	+	+
40%	-	+	+
50%	0	+	+
60%	0	-	+
70%	0	-	+
80%	0	0	-
90%	0	0	-
100%	0	0	-



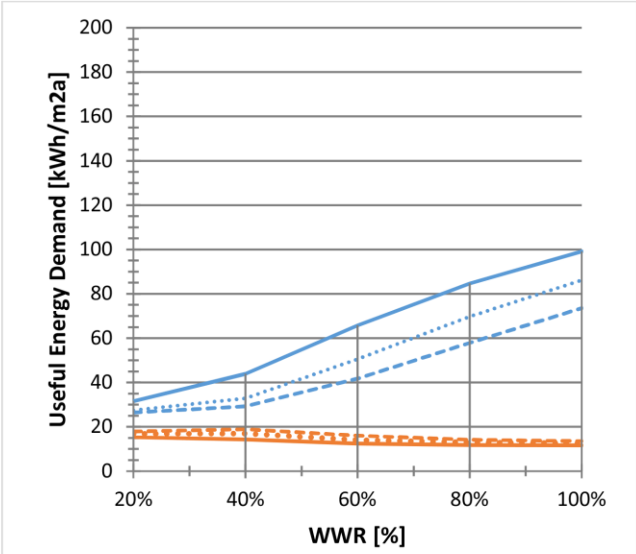
Recommendations when System 2

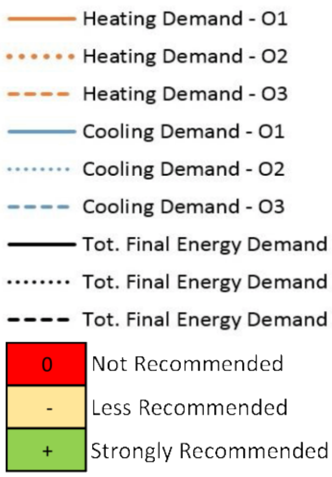
WWR	GT1	GT2	GT3
20%	-	+	-
30%	-	-	+
40%	0	-	+
50%	0	0	+
60%	0	0	+
70%	0	0	+
80%	0	0	-
90%	0	0	-
100%	0	0	-

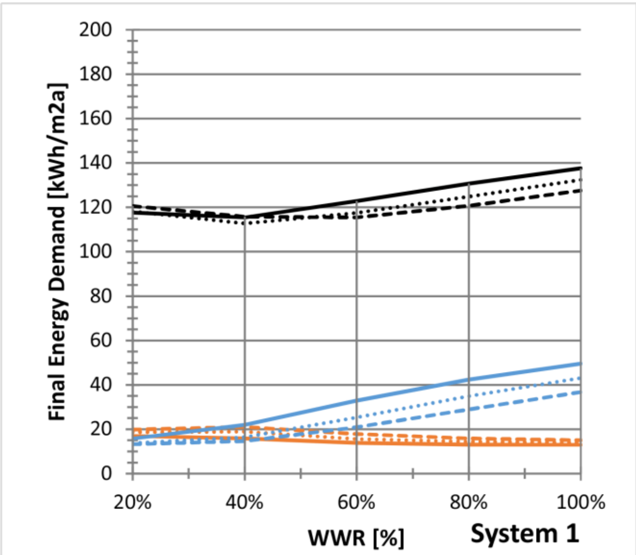
Figure 5.23: Graphics and tables with recommendations for Firenze, South, Glass type

FIRENZE

SOUTH - Overhangs

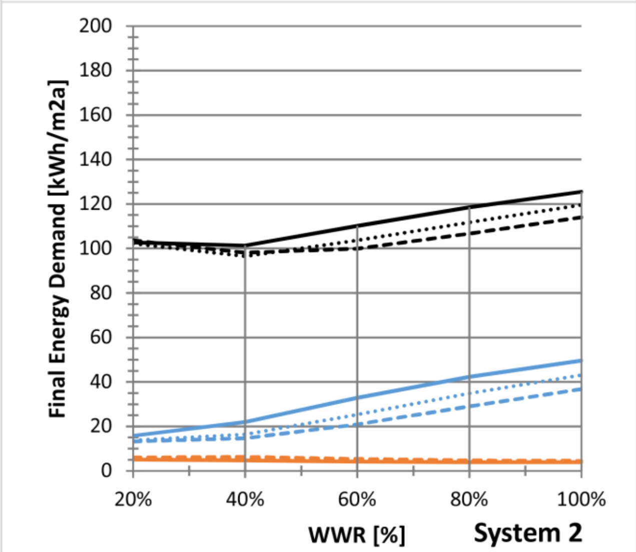






Recommendations when System 1

WWR	O1	O2	O3
20%	+	-	-
30%	+	+	-
40%	+	+	+
50%	-	+	+
60%	0	+	+
70%	0	-	-
80%	0	0	-
90%	0	0	0
100%	0	0	0

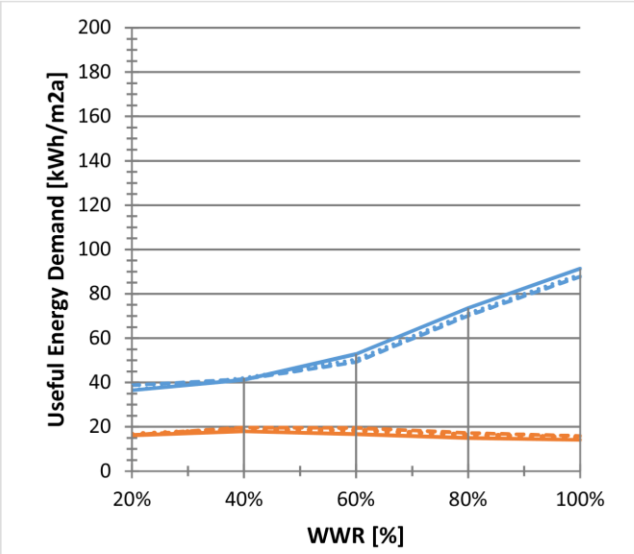


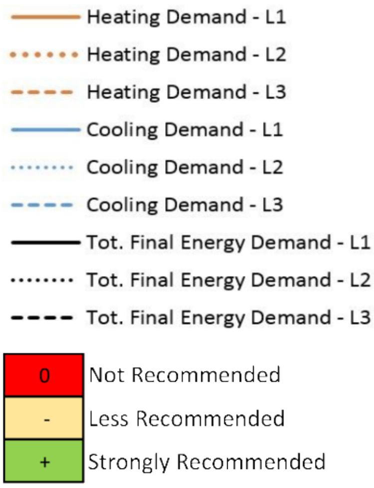
Recommendations when System 2

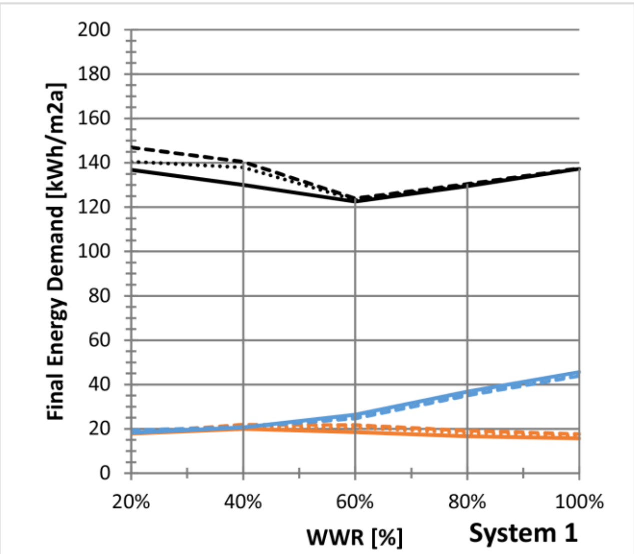
WWR	O1	O2	O3
20%	-	-	-
30%	-	+	+
40%	+	+	+
50%	-	+	+
60%	0	-	+
70%	0	0	-
80%	0	0	0
90%	0	0	0
100%	0	0	0

Figure 5.24: Graphics and tables with recommendations for Firenze, South, Overhangs

FIRENZE
SOUTH - Horizontal Louvers

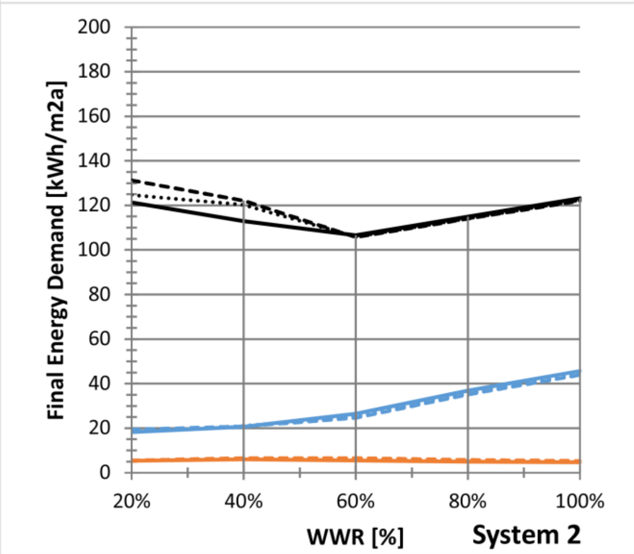






Recommendations when System 1

WWR	L1	L2	L3
20%	0	0	0
30%	0	0	0
40%	-	0	0
50%	+	-	-
60%	+	+	+
70%	+	+	+
80%	-	-	-
90%	0	0	0
100%	0	0	0



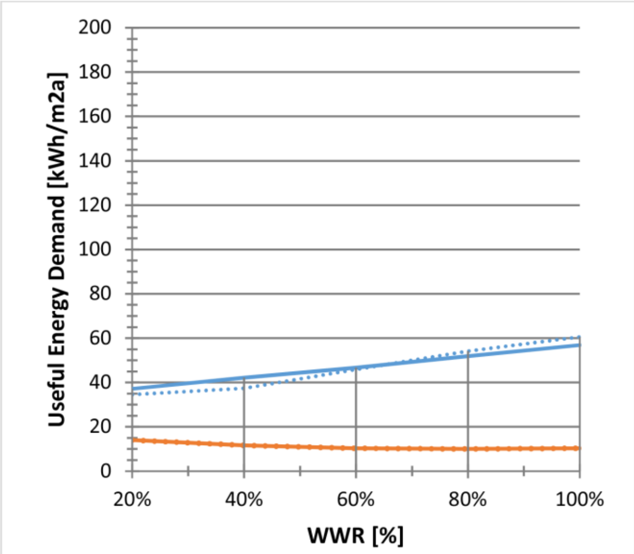
Recommendations when System 2

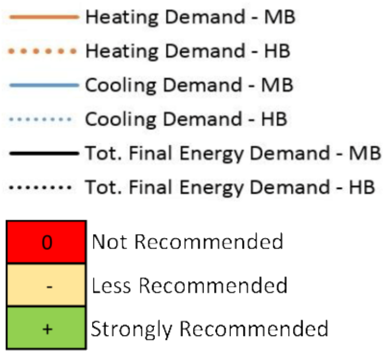
WWR	L1	L2	L3
20%	0	0	0
30%	0	0	0
40%	-	0	0
50%	+	-	-
60%	+	+	+
70%	+	+	+
80%	-	-	-
90%	0	0	0
100%	0	0	0

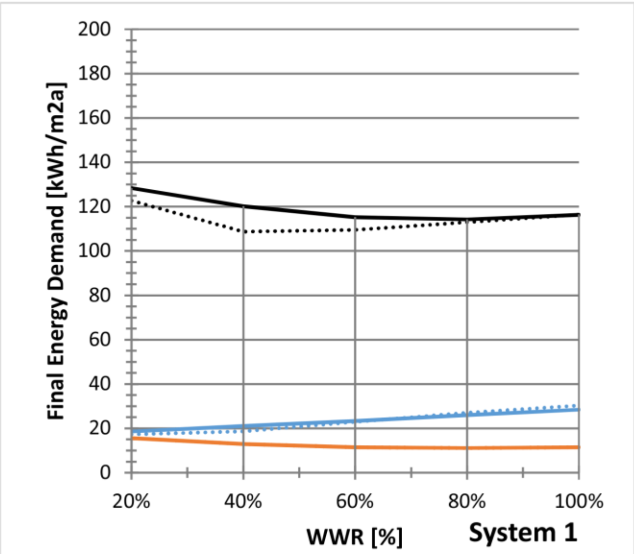
Figure 5.25: Graphics and tables with recommendations for Firenze, South, Louvers

FIRENZE

SOUTH - Horizontal Blinds

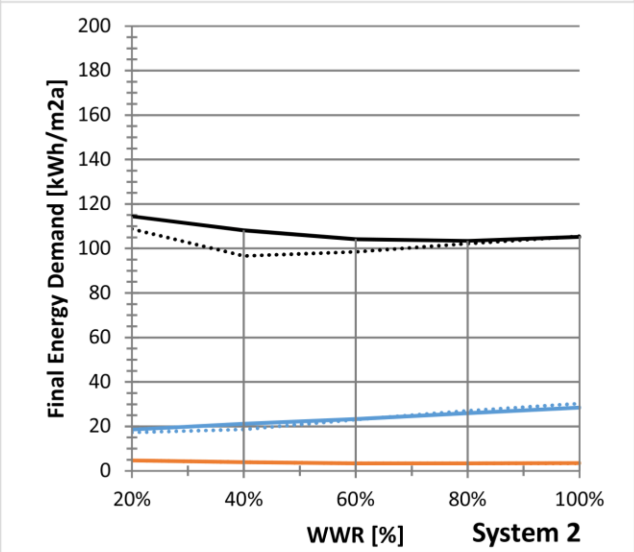






Recommendations when System 1

WWR	MHB	HHB
20%	0	0
30%	0	-
40%	0	+
50%	-	+
60%	-	+
70%	-	+
80%	-	+
90%	-	-
100%	-	-

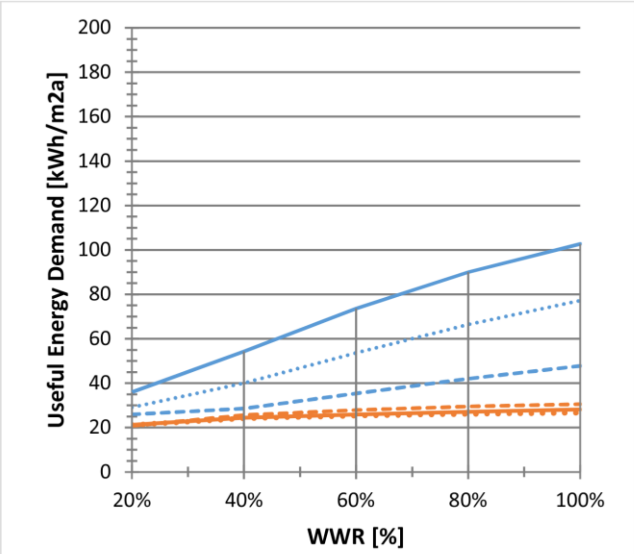


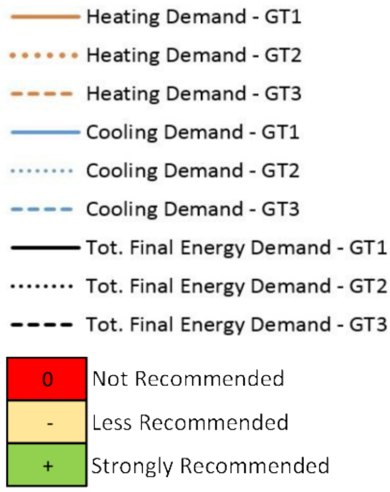
Recommendations when System 2

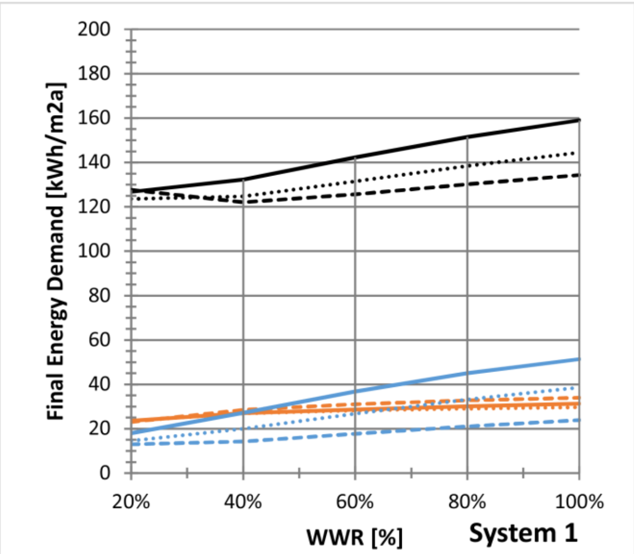
WWR	MHB	HHB
20%	0	0
30%	0	-
40%	0	+
50%	-	+
60%	-	+
70%	-	+
80%	-	-
90%	-	-
100%	-	-

Figure 5.26: Graphics and tables with recommendations for Firenze, South, Horizontal Blinds

FIRENZE
EAST - Glass type/No shading devices

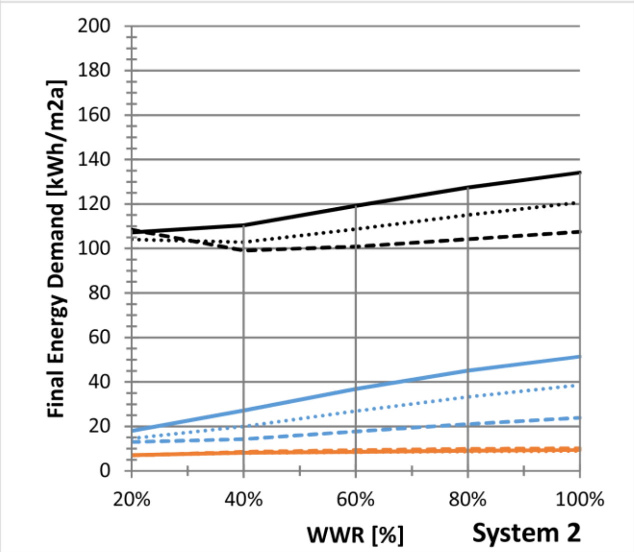






Recommendations when System 1

WWR	GT1	GT2	GT3
20%	+	+	-
30%	-	+	+
40%	0	+	+
50%	0	-	+
60%	0	-	+
70%	0	0	-
80%	0	0	-
90%	0	0	0
100%	0	0	0

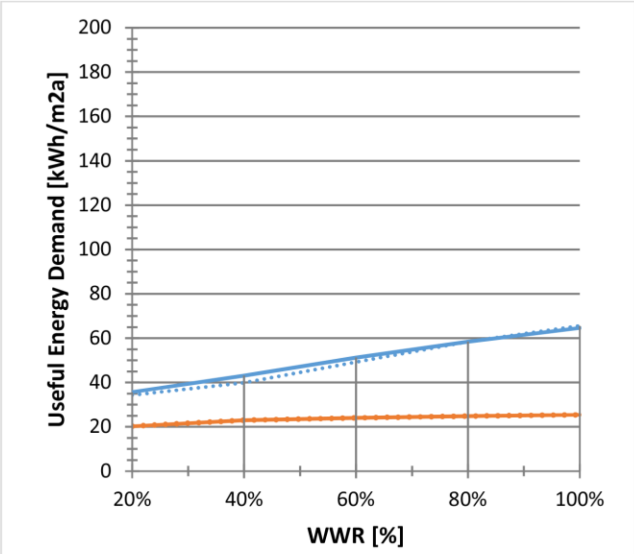


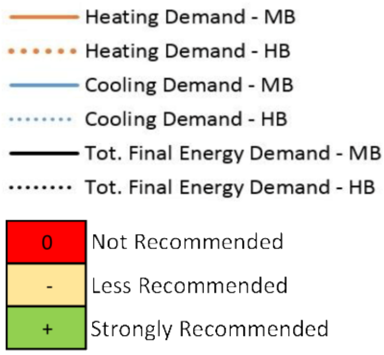
Recommendations when System 2

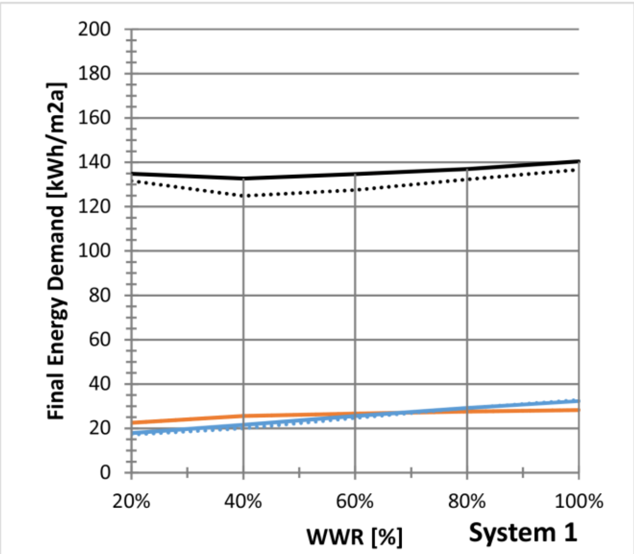
WWR	GT1	GT2	GT3
20%	-	-	-
30%	-	+	+
40%	0	+	+
50%	0	-	+
60%	0	-	+
70%	0	0	+
80%	0	0	-
90%	0	0	-
100%	0	0	-

Figure 5.27: Graphics and tables with recommendations for Firenze, East, Glass type

FIRENZE
EAST - Vertical Blinds

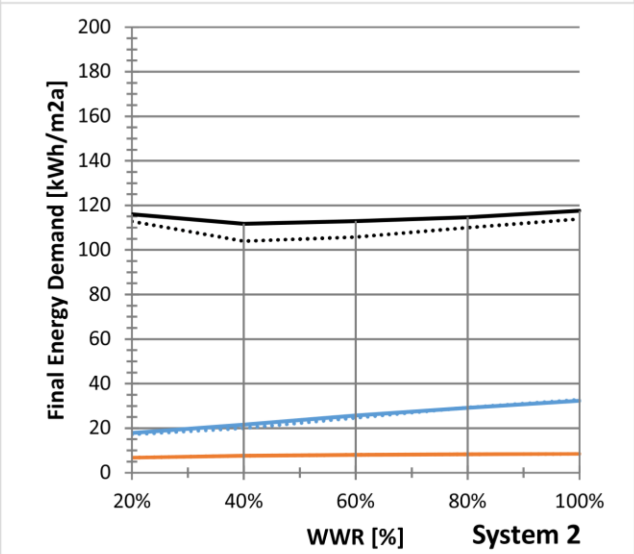






Recommendations when System 1

WWR	MVB	HVB
20%	-	-
30%	-	+
40%	-	+
50%	-	+
60%	-	+
70%	0	-
80%	0	-
90%	0	-
100%	0	0



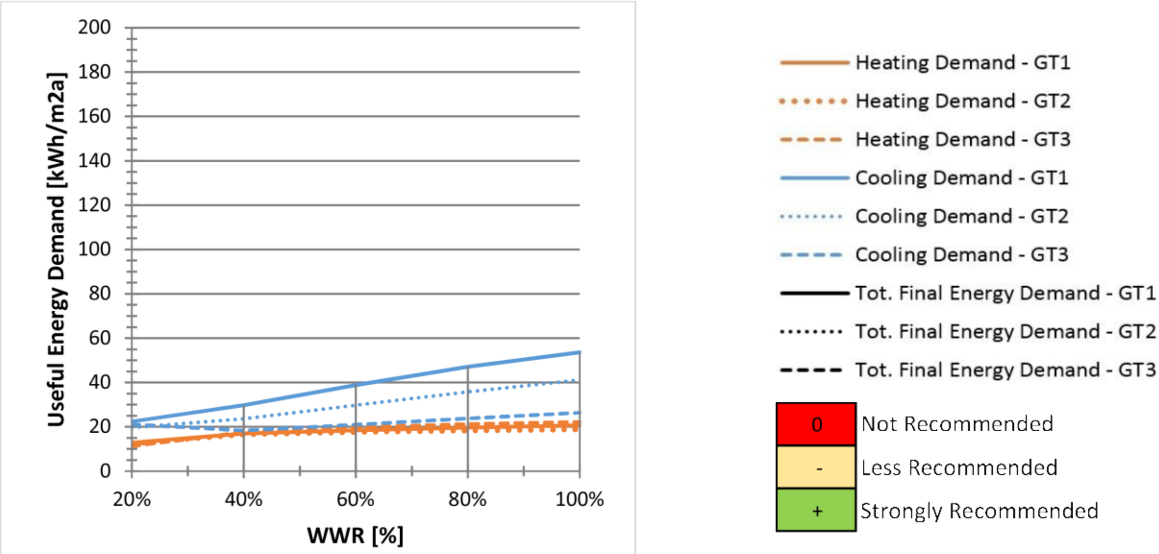
Recommendations when System 2

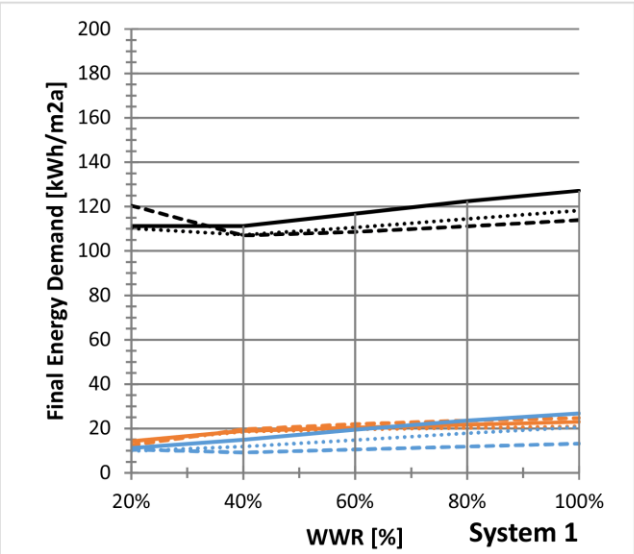
WWR	MVB	HVB
20%	0	-
30%	-	+
40%	-	+
50%	-	+
60%	-	+
70%	-	+
80%	0	-
90%	0	-
100%	0	-

Figure 5.28: Graphics and tables with recommendations for Firenze, East, Vertical Blinds

ROMA

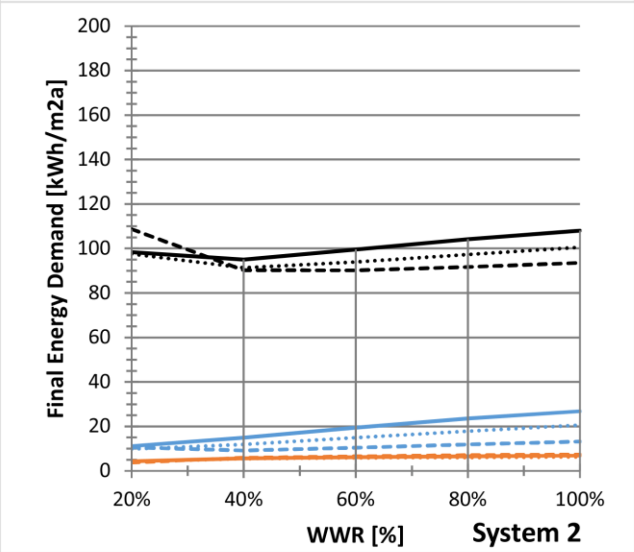
NORTH - Glass type/No shading devices





Recommendations when System 1

WWR	GT1	GT2	GT3
20%	+	+	0
30%	+	+	-
40%	+	+	+
50%	-	+	+
60%	-	+	+
70%	0	-	+
80%	0	-	+
90%	0	-	-
100%	0	0	-



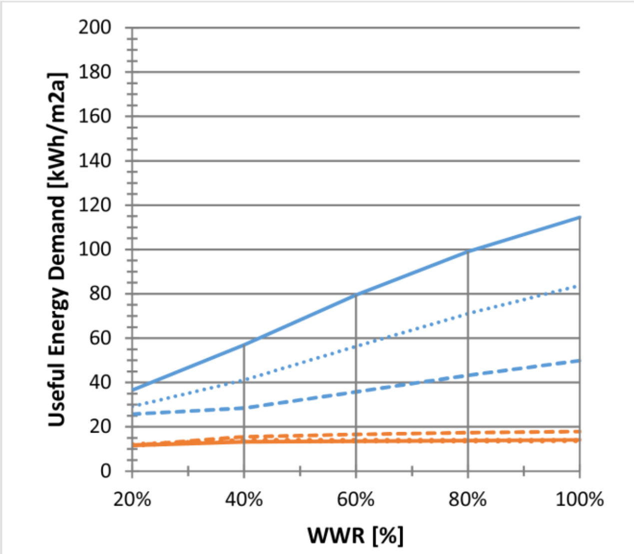
Recommendations when System 2

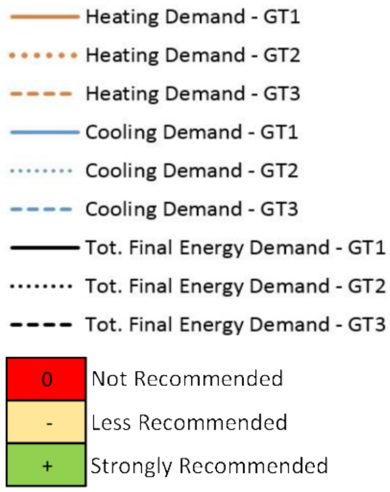
WWR	GT1	GT2	GT3
20%	-	-	0
30%	-	+	-
40%	+	+	+
50%	-	+	+
60%	-	+	+
70%	0	-	+
80%	0	-	+
90%	0	-	+
100%	0	0	+

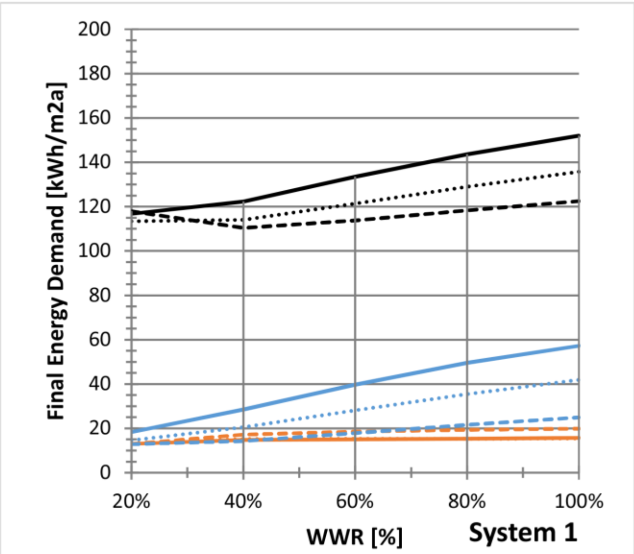
Figure 5.29: Graphics and tables with recommendations for Roma, North, Glass type

ROMA

WEST - Glass type/No shading devices

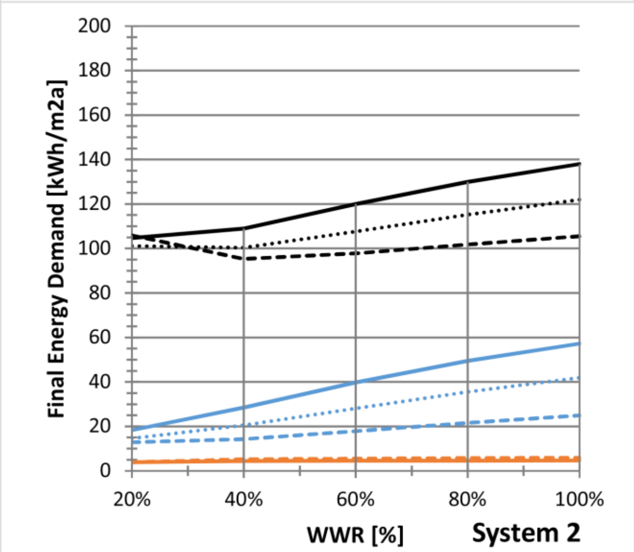






Recommendations when System 1

WWR	GT1	GT2	GT3
20%	-	+	-
30%	-	+	+
40%	0	+	+
50%	0	-	+
60%	0	0	+
70%	0	0	-
80%	0	0	-
90%	0	0	-
100%	0	0	0



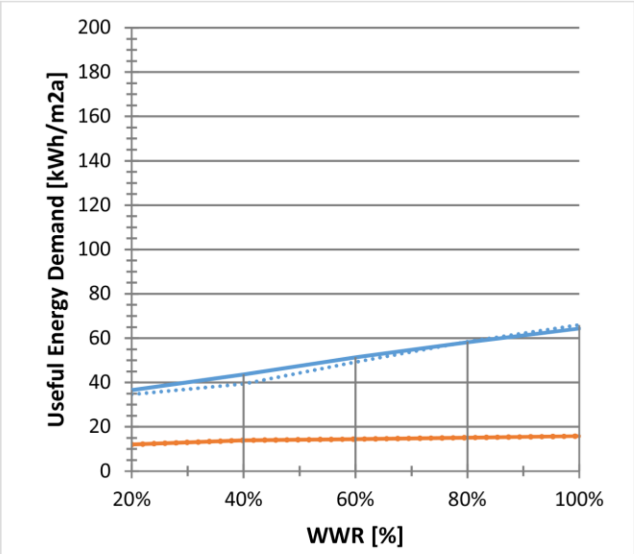
Recommendations when System 2

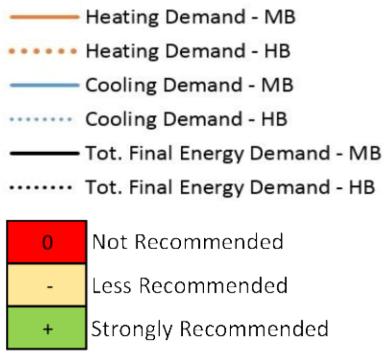
WWR	GT1	GT2	GT3
20%	-	-	0
30%	0	-	-
40%	0	-	+
50%	0	-	+
60%	0	0	+
70%	0	0	+
80%	0	0	-
90%	0	0	-
100%	0	0	0

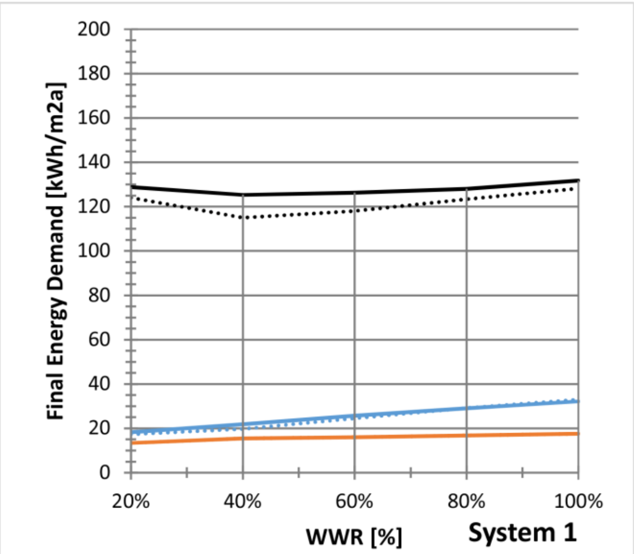
Figure 5.30: Graphics and tables with recommendations for Roma, West, Glass type

ROMA

WEST - Vertical Blinds

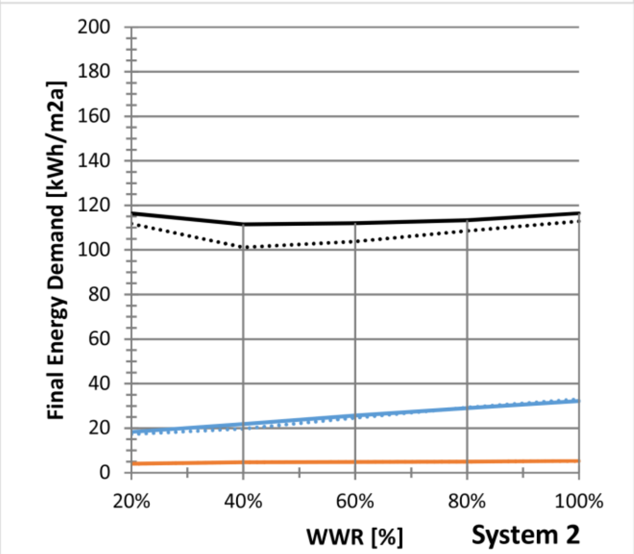






Recommendations when System 1

WWR	MVB	HVB
20%	0	-
30%	0	+
40%	0	+
50%	0	+
60%	0	+
70%	0	-
80%	0	-
90%	0	0
100%	0	0



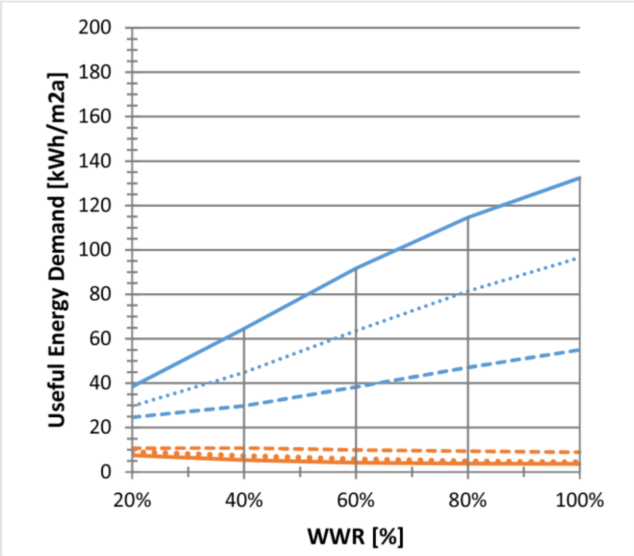
Recommendations when System 2

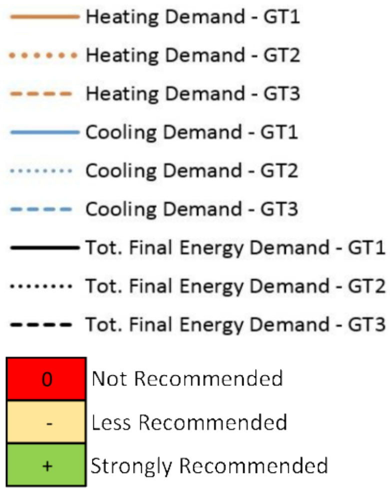
WWR	MVB	HVB
20%	0	0
30%	0	-
40%	0	+
50%	0	+
60%	0	+
70%	0	+
80%	0	-
90%	0	-
100%	0	0

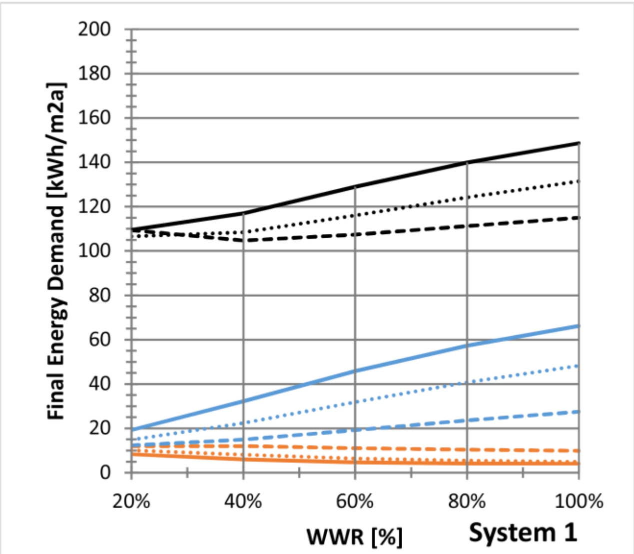
Figure 5.31: Graphics and tables with recommendations for Roma, West, Vertical Blinds

ROMA

SOUTH - Glass type/No shading devices

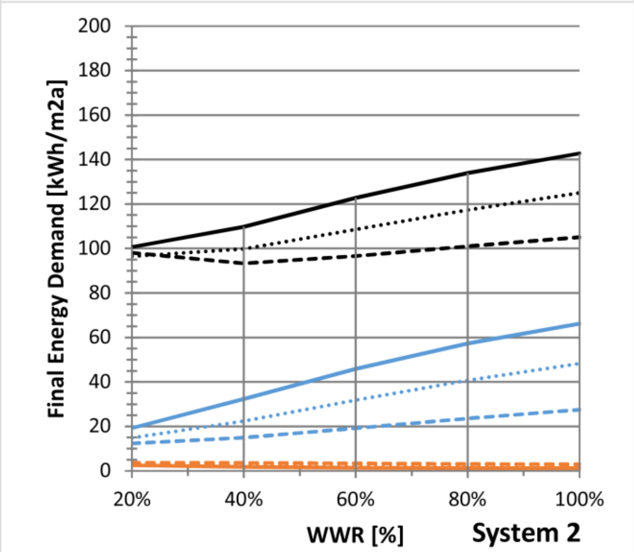






Recommendations when System 1

WWR	GT1	GT2	GT3
20%	+	+	+
30%	-	+	+
40%	0	+	+
50%	0	-	+
60%	0	0	+
70%	0	0	+
80%	0	0	-
90%	0	0	-
100%	0	0	0

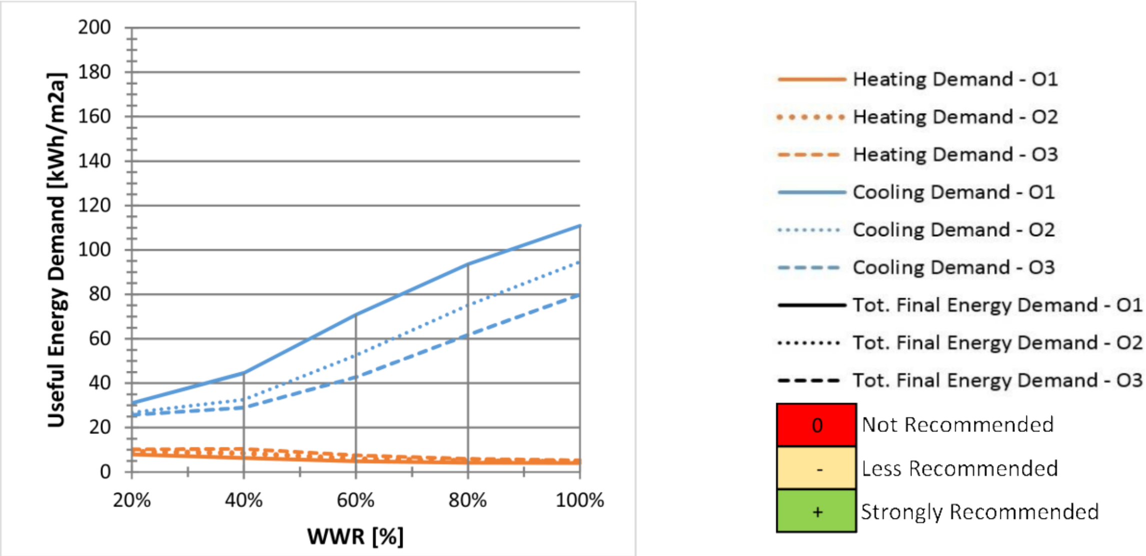


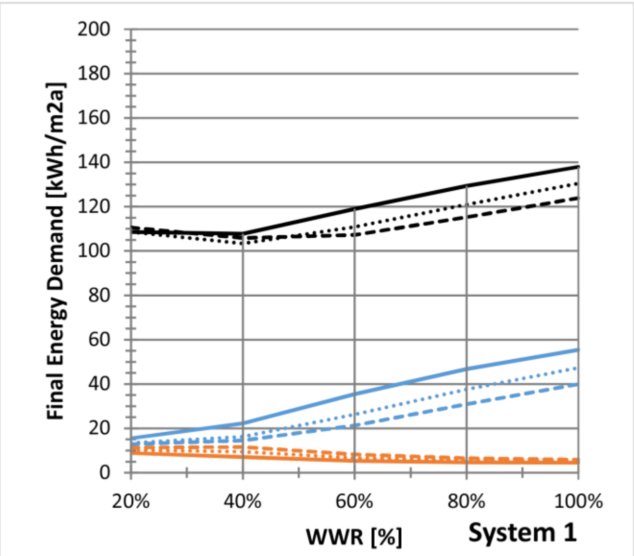
Recommendations when System 2

WWR	GT1	GT2	GT3
20%	-	+	+
30%	0	+	+
40%	0	-	+
50%	0	0	+
60%	0	0	+
70%	0	0	-
80%	0	0	-
90%	0	0	-
100%	0	0	0

Figure 5.32: Graphics and tables with recommendations for Roma, South, Glass type

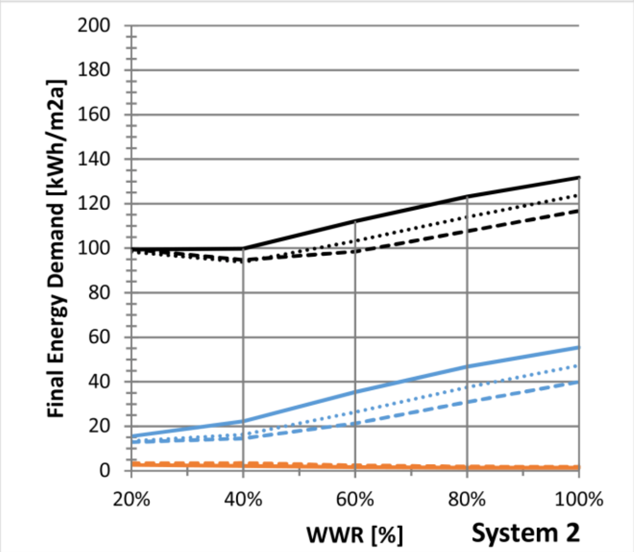
ROMA
SOUTH - Overhangs





Recommendations when System 1

WWR	O1	O2	O3
20%	-	-	-
30%	+	+	+
40%	+	+	+
50%	-	+	+
60%	0	-	+
70%	0	0	-
80%	0	0	0
90%	0	0	0
100%	0	0	0



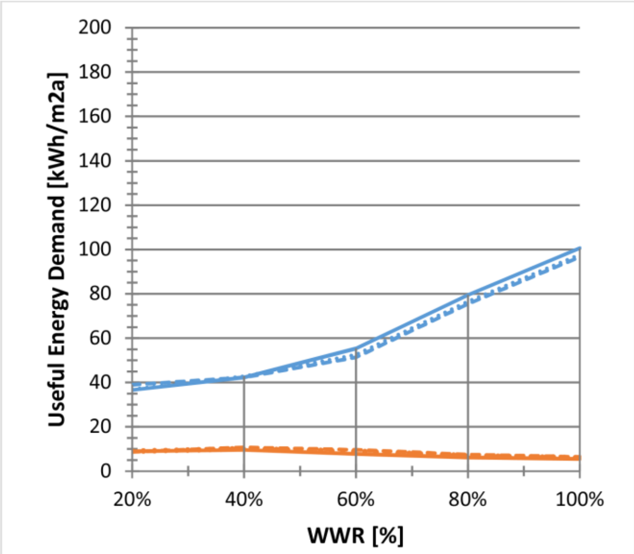
Recommendations when System 2

WWR	O1	O2	O3
20%	-	+	-
30%	-	+	+
40%	-	+	+
50%	0	+	+
60%	0	-	+
70%	0	0	-
80%	0	0	0
90%	0	0	0
100%	0	0	0

Figure 5.33: Graphics and tables with recommendations for Roma, South orientation, Overhangs

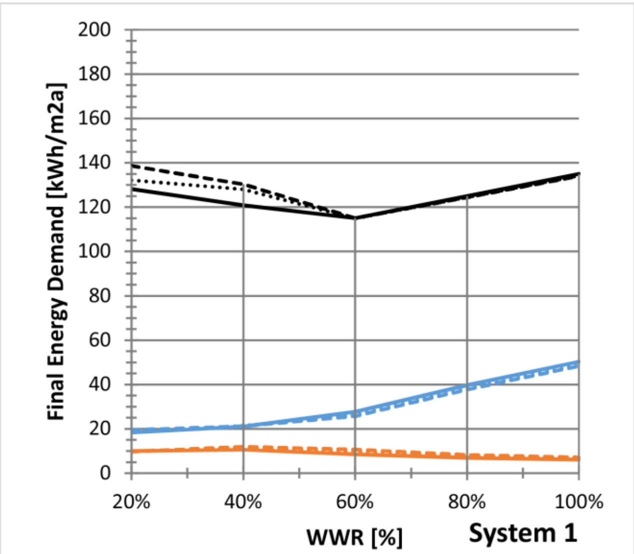
ROMA

SOUTH - Horizontal Louvers



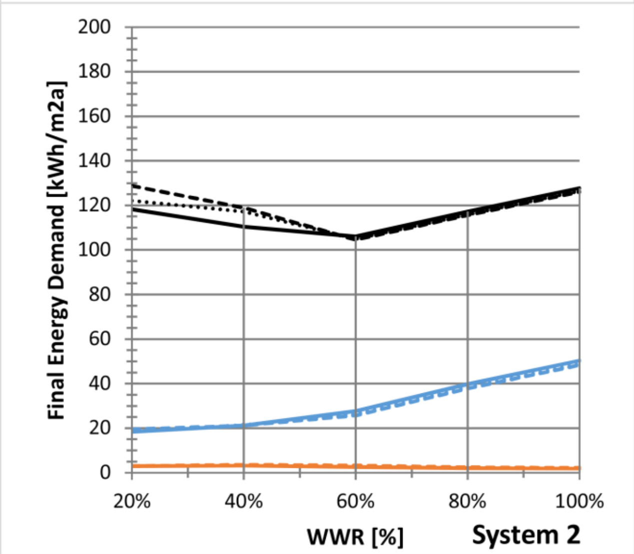
Heating Demand - L1
Heating Demand - L2
Heating Demand - L3
Cooling Demand - L1
Cooling Demand - L2
Cooling Demand - L3
Tot. Final Energy Demand - L1
Tot. Final Energy Demand - L2
Tot. Final Energy Demand - L3

0	Not Recommended
-	Less Recommended
+	Strongly Recommended



Recommendations when System 1

WWR	L1	L2	L3
20%	0	0	0
30%	-	0	0
40%	-	0	0
50%	+	-	-
60%	+	+	+
70%	-	+	+
80%	0	-	-
90%	0	0	0
100%	0	0	0

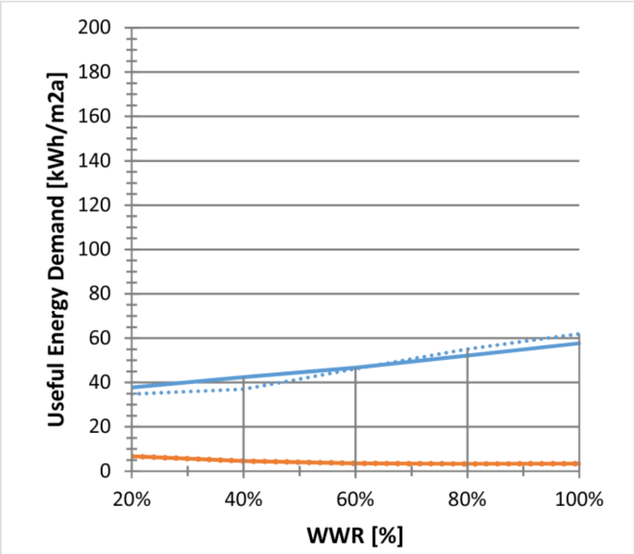


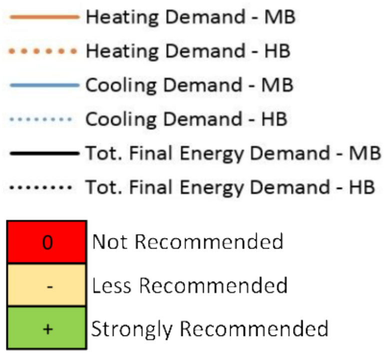
Recommendations when System 2

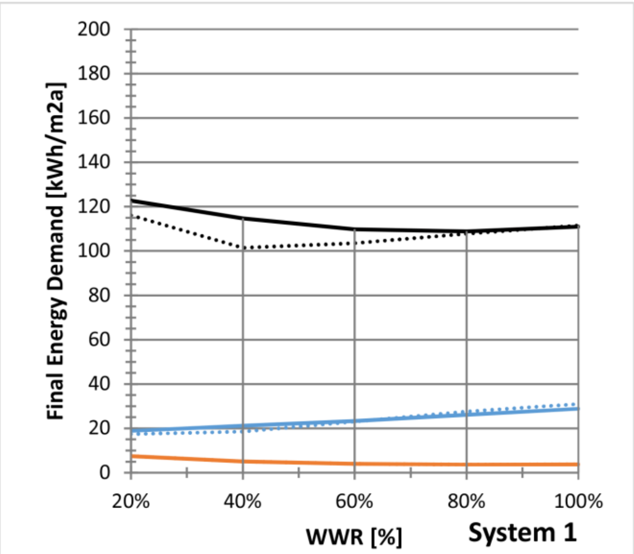
WWR	L1	L2	L3
20%	0	0	0
30%	-	0	0
40%	-	0	0
50%	+	-	-
60%	+	+	+
70%	-	-	-
80%	0	0	0
90%	0	0	0
100%	0	0	0

Figure 5.34: Graphics and tables with recommendations for Roma, South orientation, Louvers

ROMA
SOUTH - Horizontal Blinds

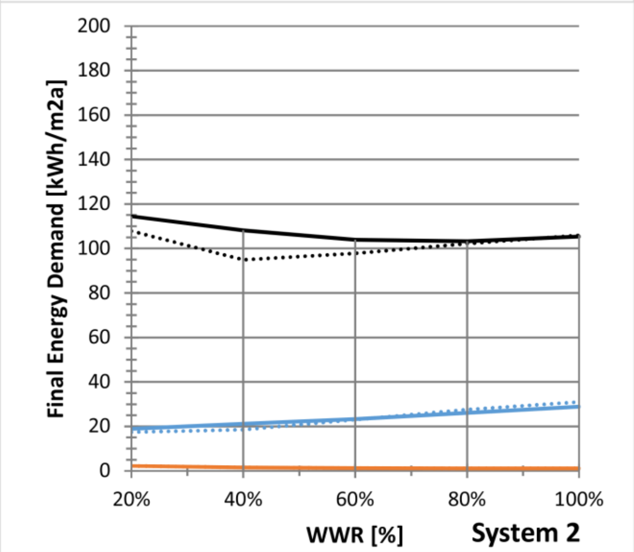






Recommendations when System 1

WWR	MHB	HHB
20%	0	0
30%	0	-
40%	0	+
50%	0	+
60%	-	+
70%	-	+
80%	-	-
90%	-	-
100%	-	0



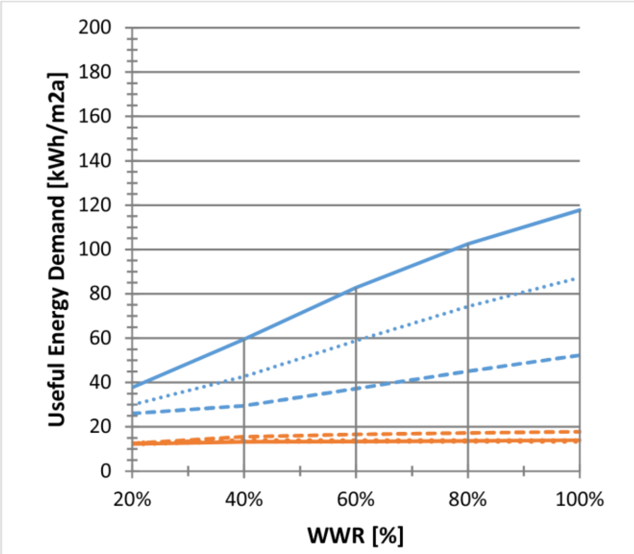
Recommendations when System 2

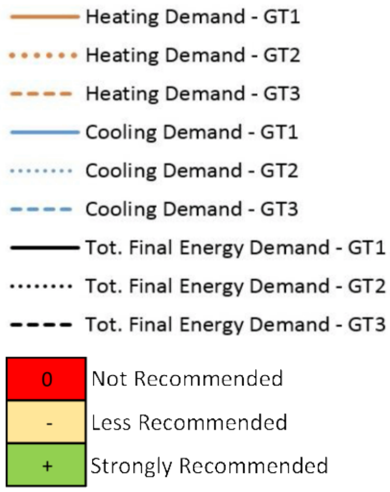
WWR	MHB	HHB
20%	0	0
30%	0	-
40%	0	+
50%	0	+
60%	-	+
70%	-	-
80%	-	-
90%	-	-
100%	0	0

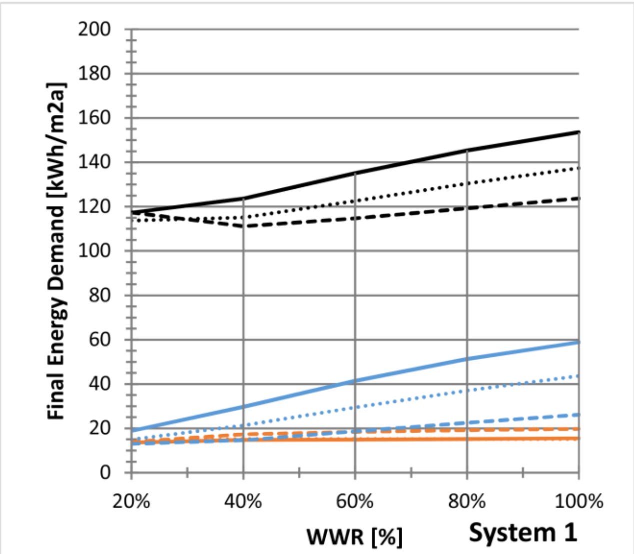
Figure 5.35: Graphics and tables with recommendations for Roma, South, Horizontal Blinds

ROMA

EAST - Glass type/No shading devices

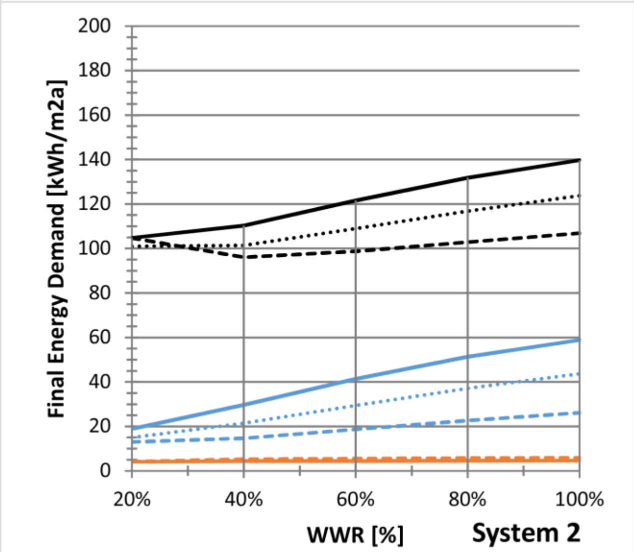






Recommendations when System 1

WWR	GT1	GT2	GT3
20%	-	+	-
30%	-	+	+
40%	0	+	+
50%	0	-	+
60%	0	0	+
70%	0	0	-
80%	0	0	-
90%	0	0	0
100%	0	0	0



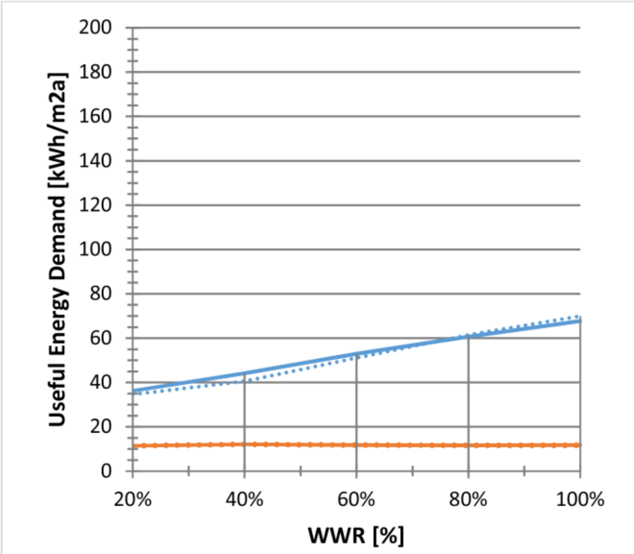
Recommendations when System 2

WWR	GT1	GT2	GT3
20%	-	+	-
30%	0	-	+
40%	0	-	+
50%	0	-	+
60%	0	0	+
70%	0	0	+
80%	0	0	-
90%	0	0	-
100%	0	0	0

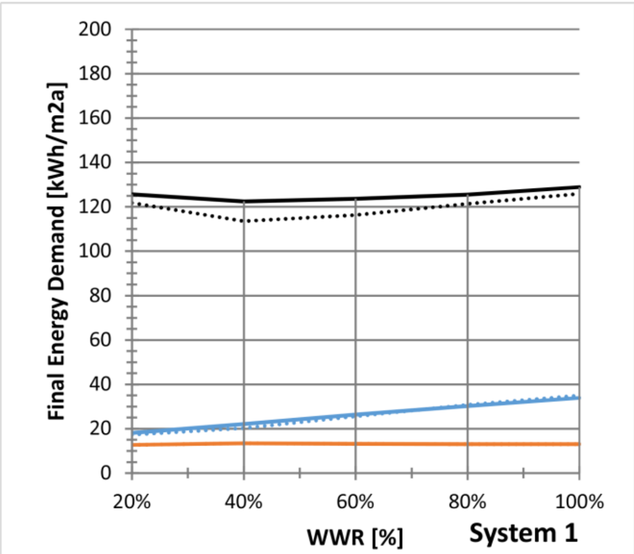
Figure 5.36: Graphics and tables with recommendations for Roma, East, Glass type

ROMA

EAST - Vertical Blinds

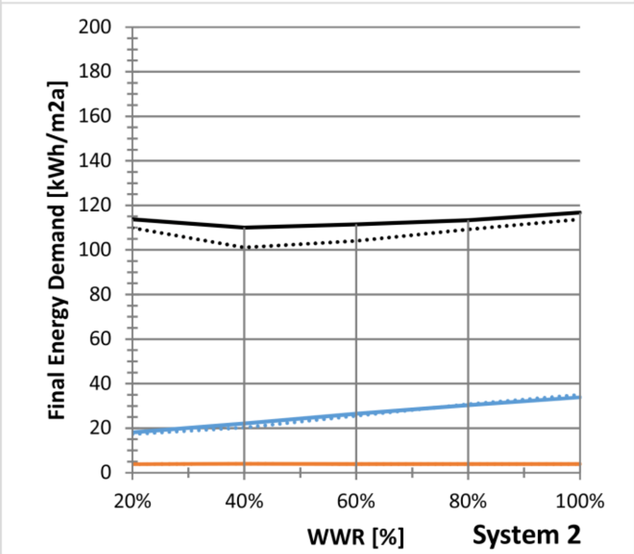


0	Not Recommended
-	Less Recommended
+	Strongly Recommended



Recommendations when System 1

WWR	MVB	HVB
20%	0	-
30%	0	+
40%	-	+
50%	-	+
60%	0	+
70%	0	-
80%	0	-
90%	0	0
100%	0	0



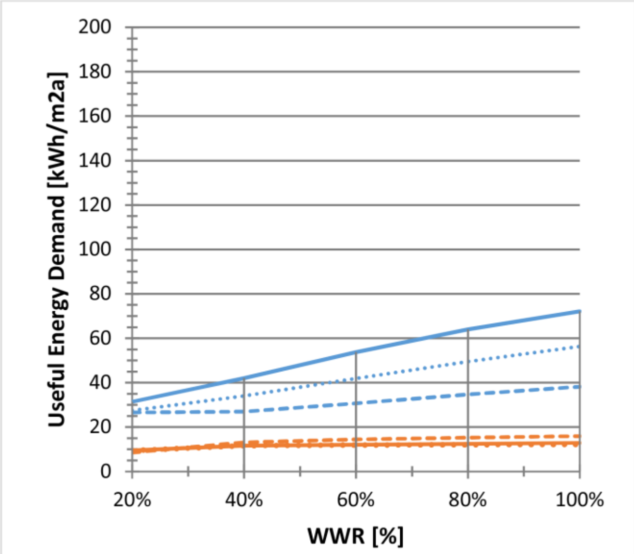
Recommendations when System 2

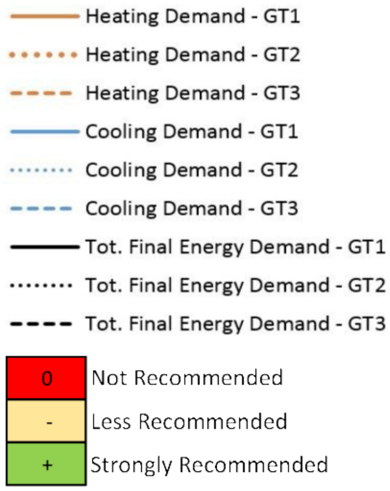
WWR	MVB	HVB
20%	0	-
30%	0	+
40%	-	+
50%	-	+
60%	0	+
70%	0	-
80%	0	-
90%	0	0
100%	0	0

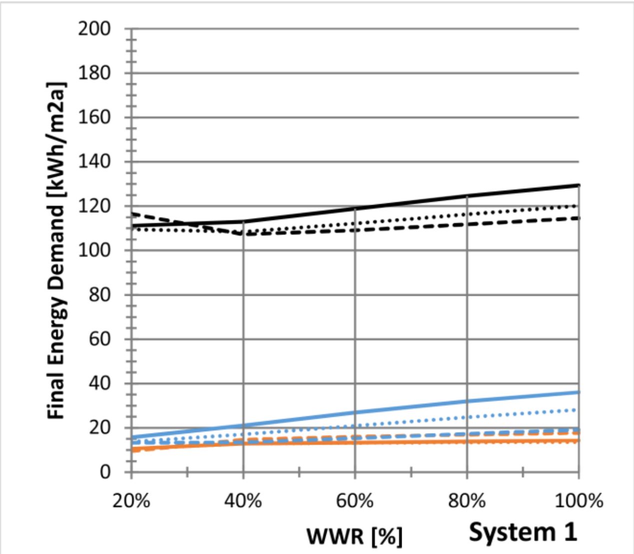
Figure 5.37: Graphics and tables with recommendations for Roma, East, Vertical Blinds

NAPOLI

NORTH - Glass type/No shading devices

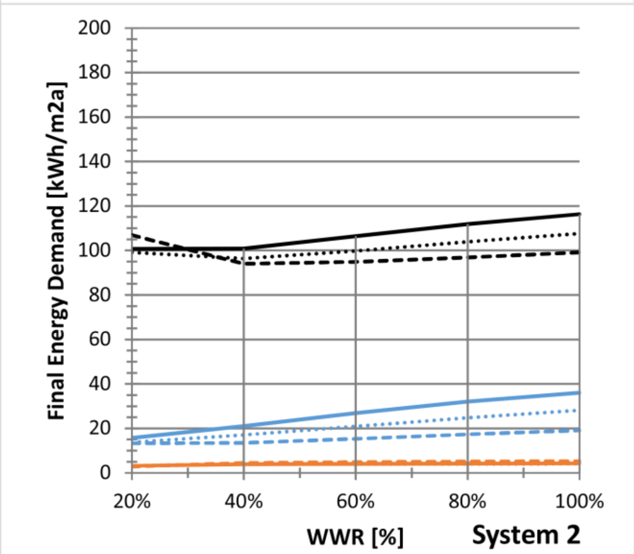






Recommendations when System 1

WWR	GT1	GT2	GT3
20%	+	+	-
30%	+	+	+
40%	-	+	+
50%	-	+	+
60%	0	+	+
70%	0	-	+
80%	0	-	+
90%	0	0	-
100%	0	0	-



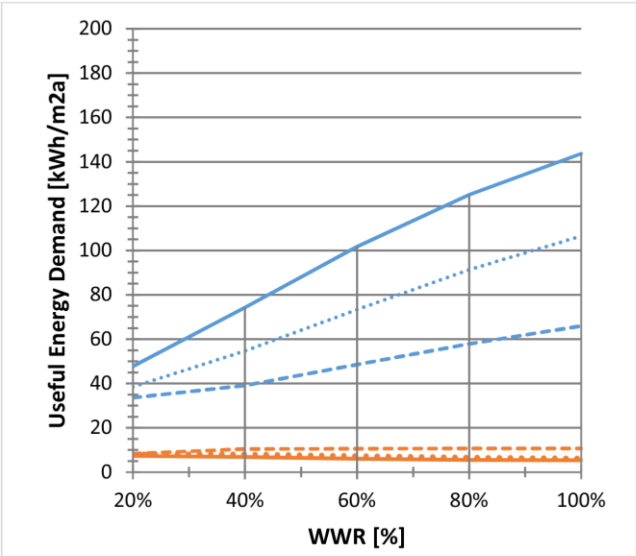
Recommendations when System 2

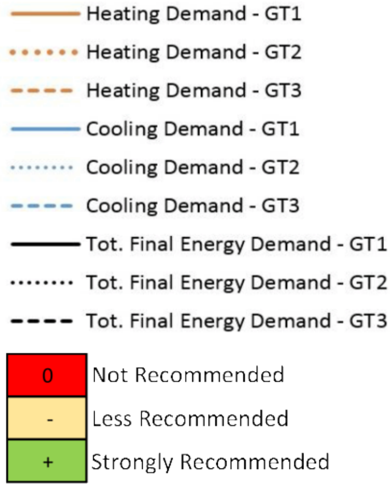
WWR	GT1	GT2	GT3
20%	-	-	0
30%	-	+	-
40%	-	+	+
50%	-	+	+
60%	0	-	+
70%	0	-	+
80%	0	-	+
90%	0	0	+
100%	0	0	-

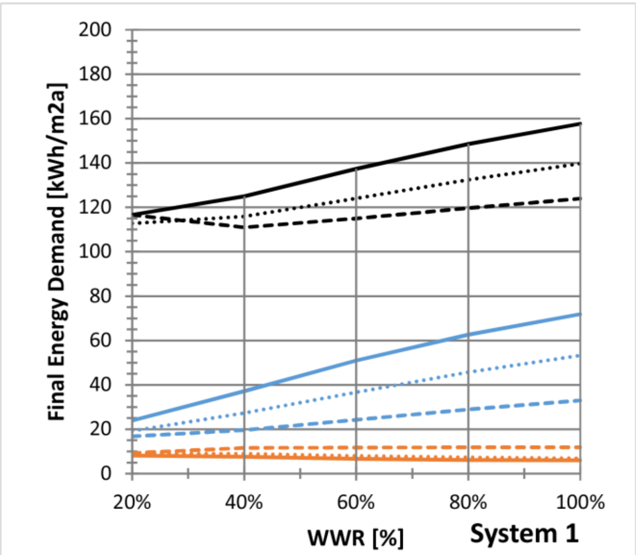
Figure 5.38: Graphics and tables with recommendations for Napoli, North, Glass type

NAPOLI

WEST - Glass type/No shading devices

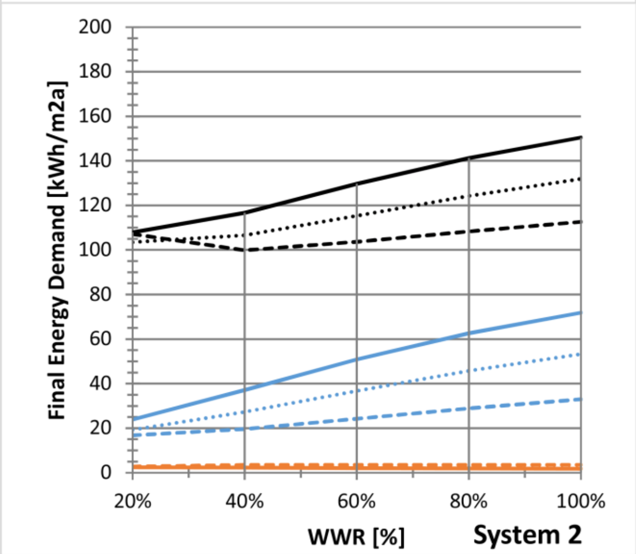






Recommendations when System 1

WWR	GT1	GT2	GT3
20%	-	+	-
30%	-	+	+
40%	0	+	+
50%	0	-	+
60%	0	0	+
70%	0	0	-
80%	0	0	-
90%	0	0	0
100%	0	0	0



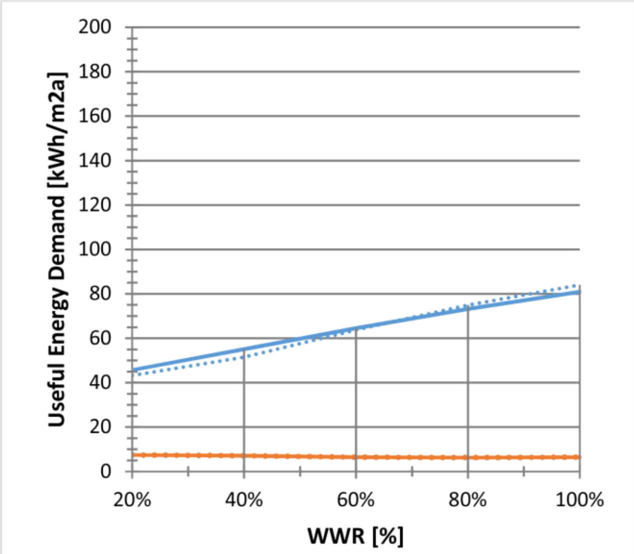
Recommendations when System 2

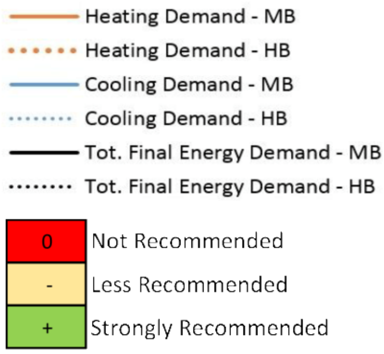
WWR	GT1	GT2	GT3
20%	-	+	-
30%	0	-	+
40%	0	-	+
50%	0	0	+
60%	0	0	+
70%	0	0	-
80%	0	0	-
90%	0	0	0
100%	0	0	0

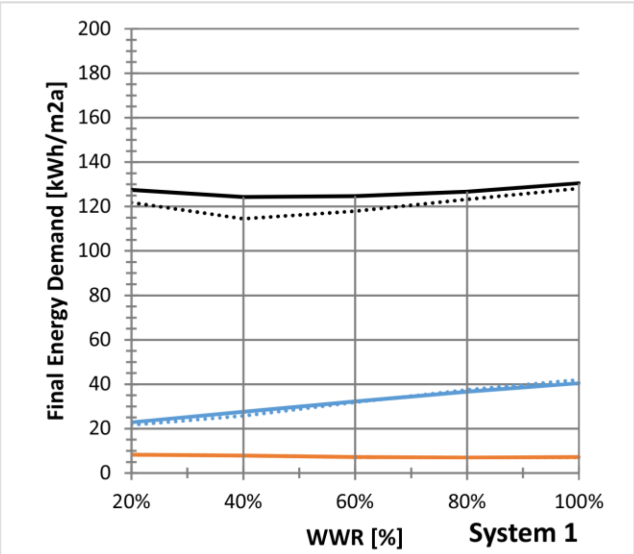
Figure 5.39: Graphics and tables with recommendations for Napoli, West, Glass type

NAPOLI

WEST - Vertical Blinds

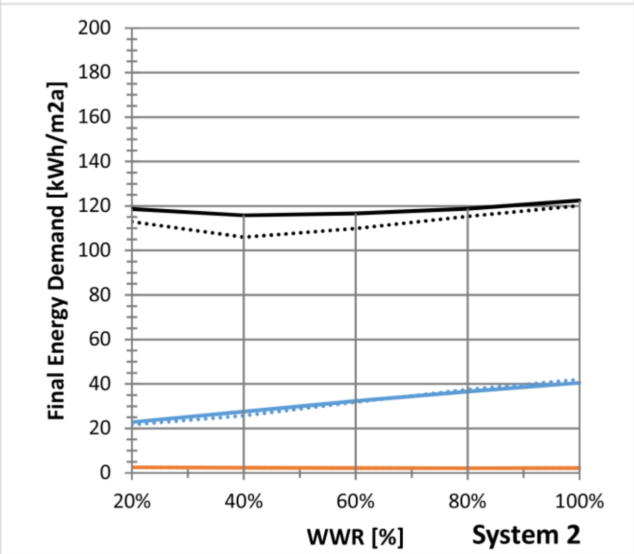






Recommendations when System 1

WWR	MVB	HVB
20%	0	-
30%	0	+
40%	-	+
50%	-	+
60%	0	+
70%	0	-
80%	0	-
90%	0	0
100%	0	0



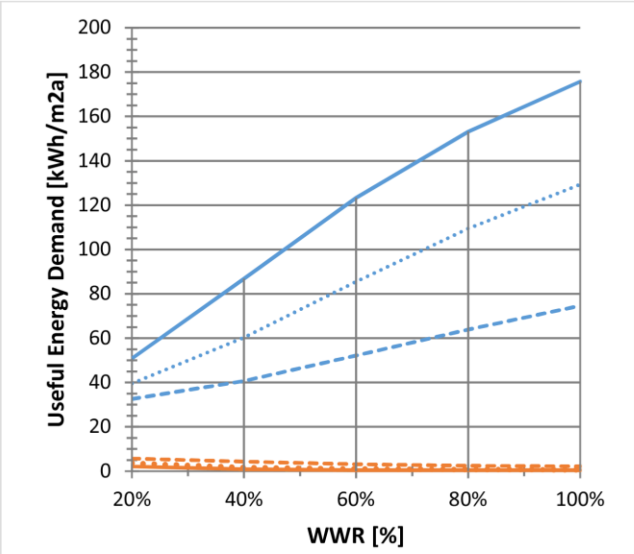
Recommendations when System 2

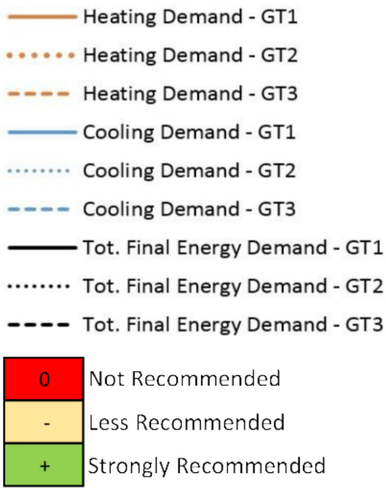
WWR	MVB	HVB
20%	0	-
30%	0	+
40%	-	+
50%	0	+
60%	0	+
70%	0	-
80%	0	-
90%	0	0
100%	0	0

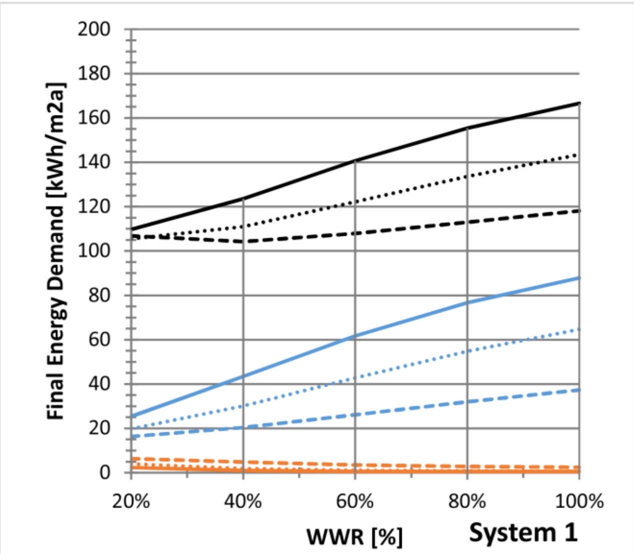
Figure 5.40: Graphics and tables with recommendations for Napoli, West, Vertical Blinds

NAPOLI

SOUTH - Glass type/No shading devices

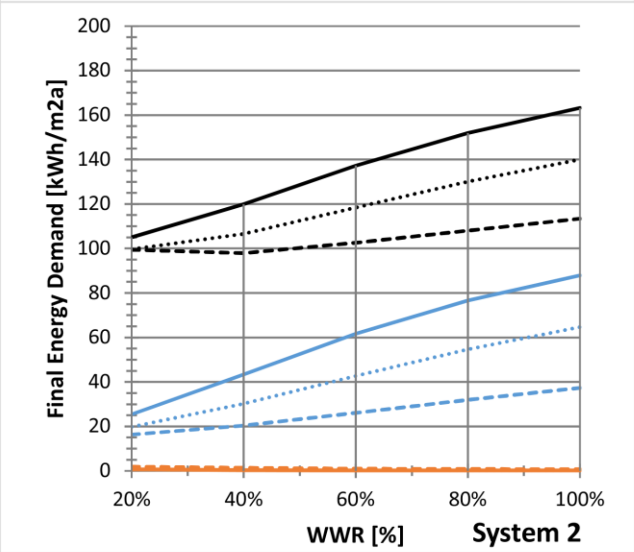






Recommendations when System 1

WWR	GT1	GT2	GT3
20%	-	+	+
30%	0	+	+
40%	0	-	+
50%	0	0	+
60%	0	0	+
70%	0	0	-
80%	0	0	-
90%	0	0	0
100%	0	0	0

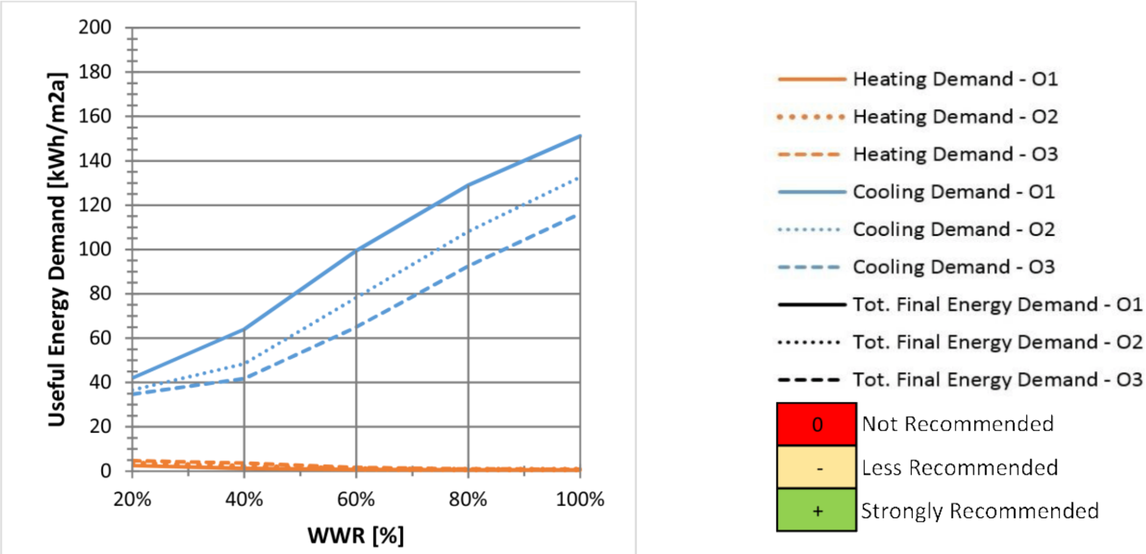


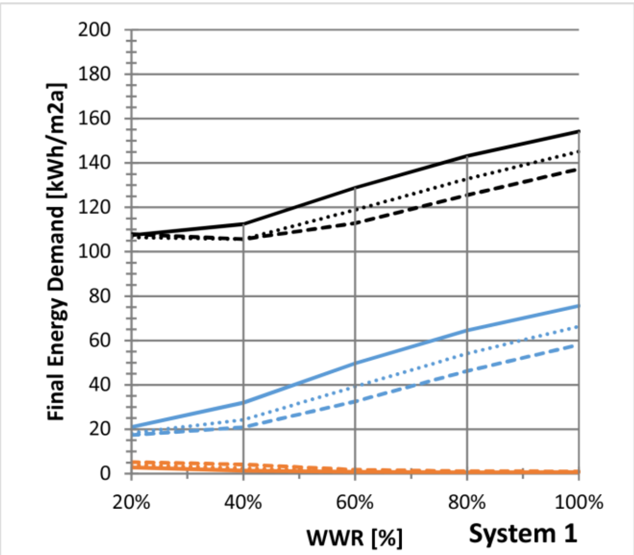
Recommendations when System 2

WWR	GT1	GT2	GT3
20%	-	+	+
30%	0	-	+
40%	0	-	+
50%	0	0	+
60%	0	0	+
70%	0	0	-
80%	0	0	0
90%	0	0	0
100%	0	0	0

Figure 5.41: Graphics and tables with recommendations for Napoli, South, Glass type

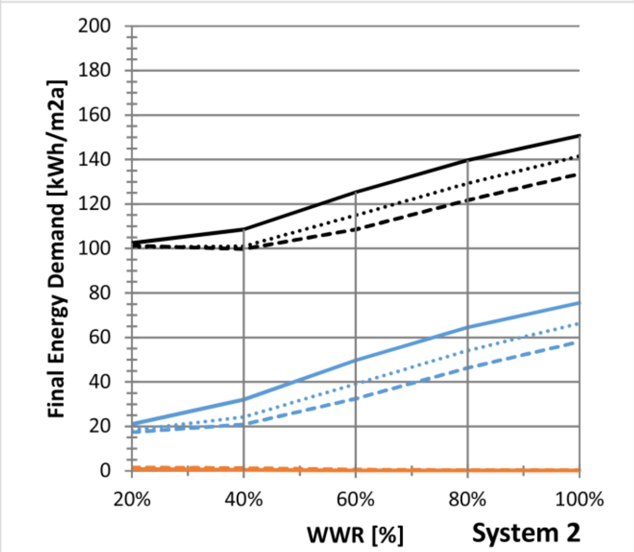
NAPOLI
SOUTH - Overhangs





Recommendations when System 1

WWR	O1	O2	O3
20%	+	+	+
30%	+	+	+
40%	-	+	+
50%	0	-	+
60%	0	0	-
70%	0	0	0
80%	0	0	0
90%	0	0	0
100%	0	0	0

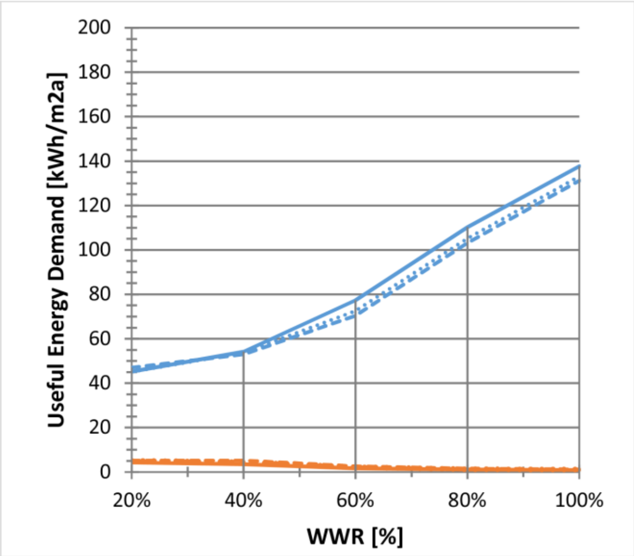


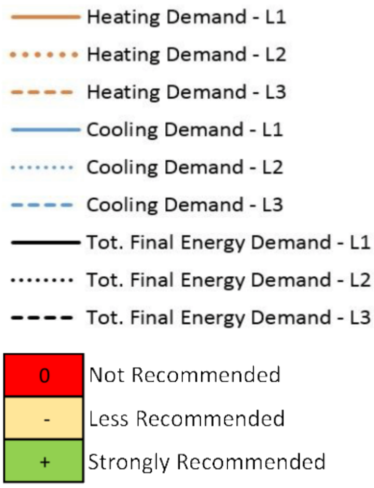
Recommendations when System 2

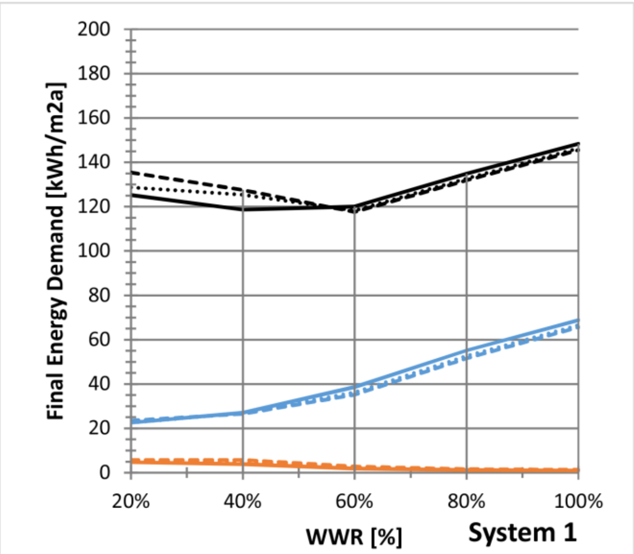
WWR	O1	O2	O3
20%	+	+	+
30%	-	+	+
40%	-	+	+
50%	0	-	+
60%	0	0	-
70%	0	0	0
80%	0	0	0
90%	0	0	0
100%	0	0	0

Figure 5.42: Graphics and tables with recommendations for Napoli, South, Overhangs

NAPOLI
SOUTH - Horizontal Louvers

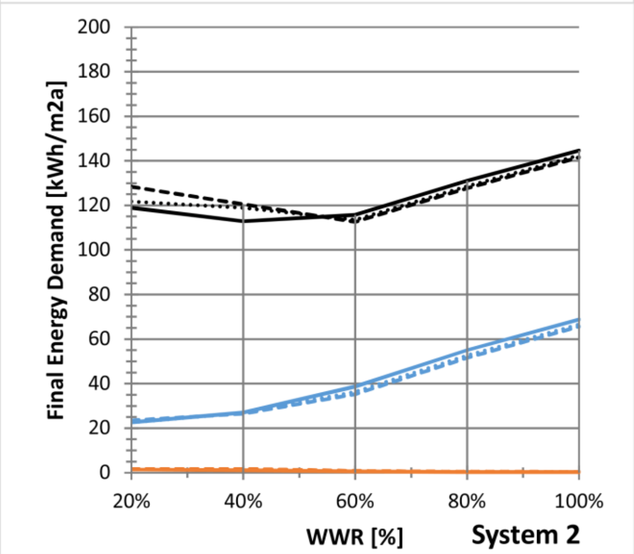






Recommendations when System 1

WWR	L1	L2	L3
20%	-	0	0
30%	+	-	0
40%	+	-	-
50%	+	+	+
60%	+	+	+
70%	-	-	-
80%	0	0	0
90%	0	0	0
100%	0	0	0



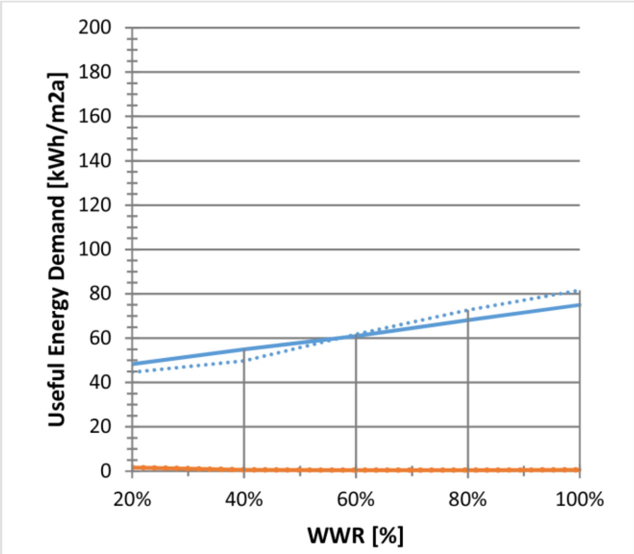
Recommendations when System 2

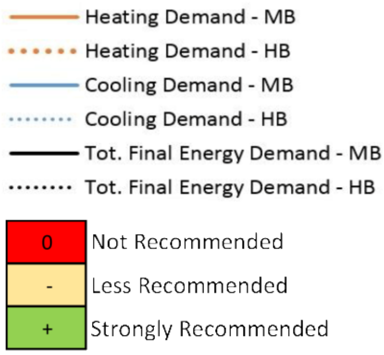
WWR	L1	L2	L3
20%	-	-	0
30%	+	-	0
40%	+	-	-
50%	+	+	+
60%	+	+	+
70%	0	-	-
80%	0	0	0
90%	0	0	0
100%	0	0	0

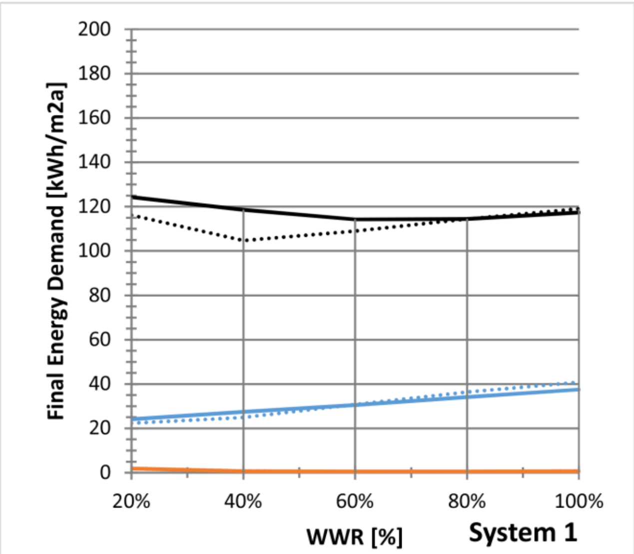
Figure 5.43: Graphics and tables with recommendations for Napoli, South, Louvers

NAPOLI

SOUTH - Horizontal Blinds

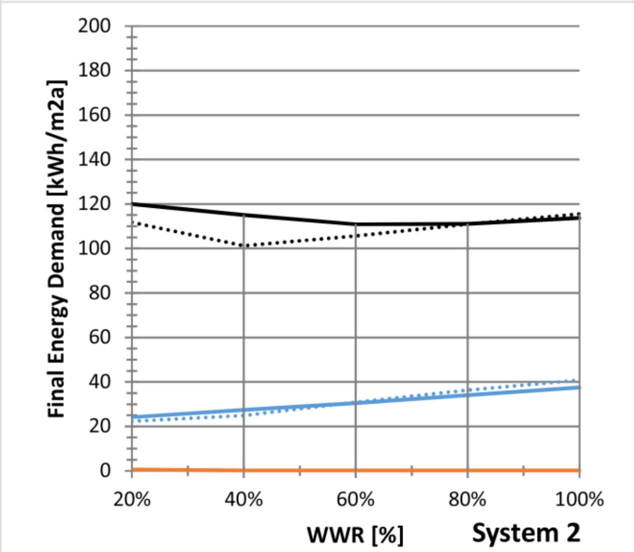






Recommendations when System 1

WWR	MHB	HHB
20%	0	0
30%	0	-
40%	0	+
50%	0	+
60%	-	+
70%	-	-
80%	-	-
90%	0	0
100%	0	0



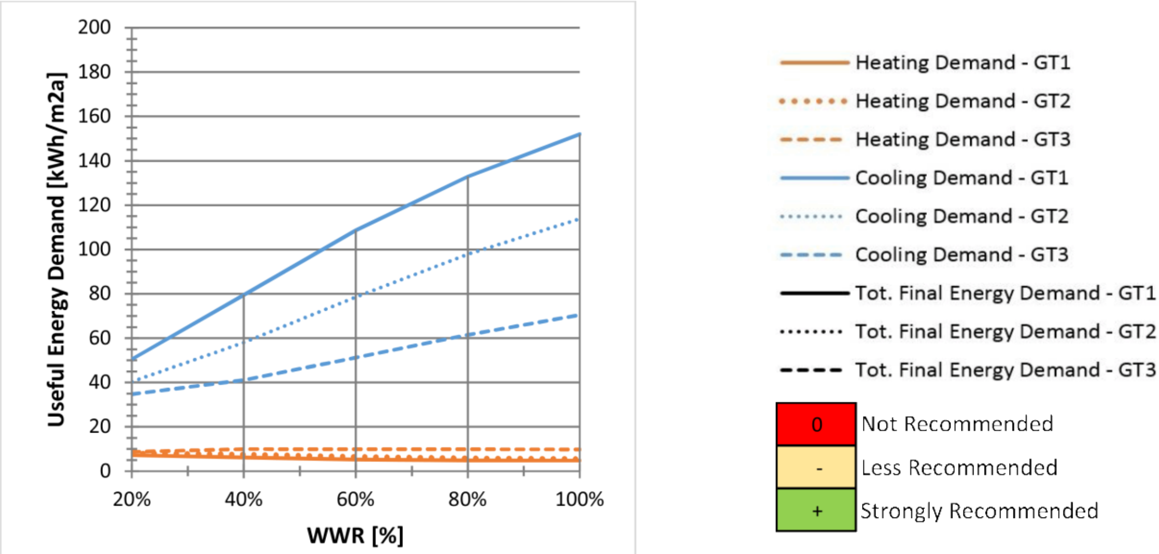
Recommendations when System 2

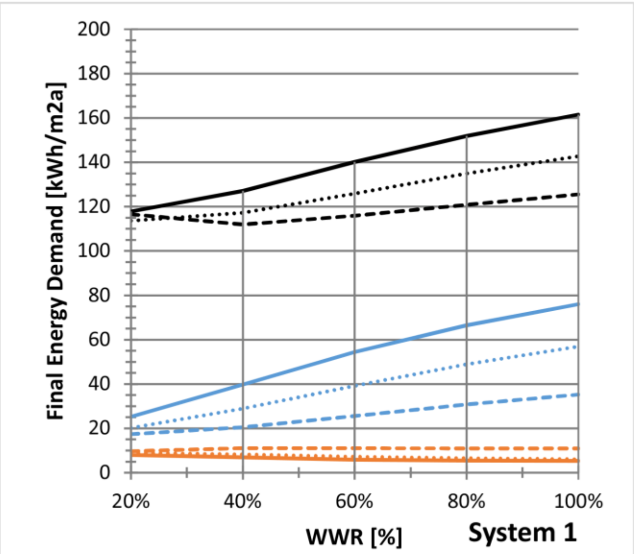
WWR	MHB	HHB
20%	0	0
30%	0	-
40%	0	+
50%	0	+
60%	-	+
70%	-	-
80%	-	-
90%	0	0
100%	0	0

Figure 5.44: Graphics and tables with recommendations for Napoli, South, Horizontal Blinds

NAPOLI

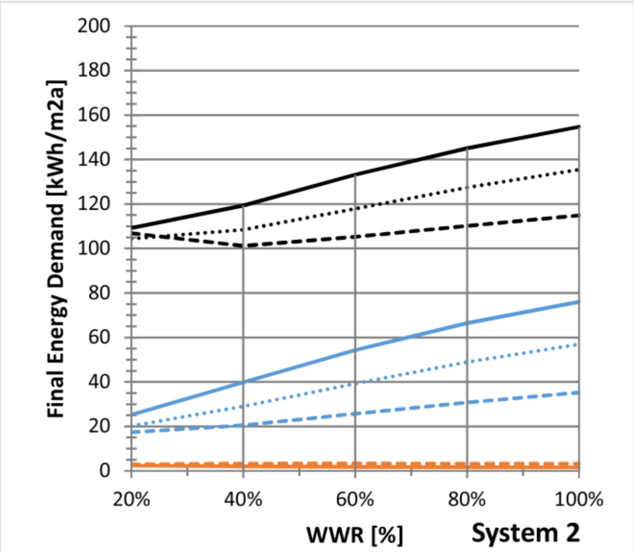
EAST - Glass type/No shading devices





Recommendations when System 1

WWR	GT1	GT2	GT3
20%	-	+	+
30%	0	+	+
40%	0	-	+
50%	0	-	+
60%	0	0	+
70%	0	0	-
80%	0	0	-
90%	0	0	0
100%	0	0	0

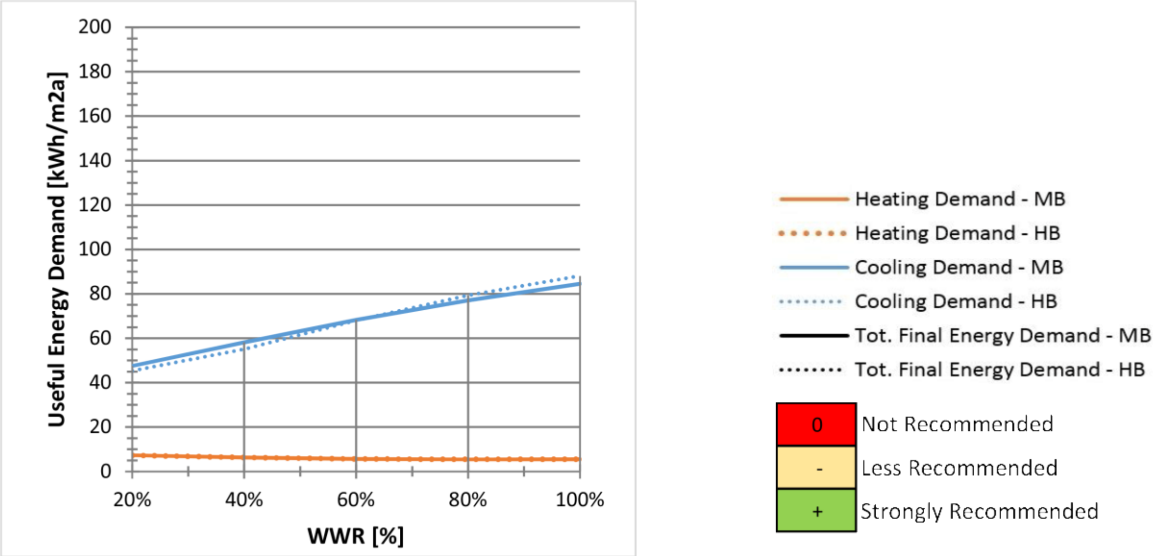


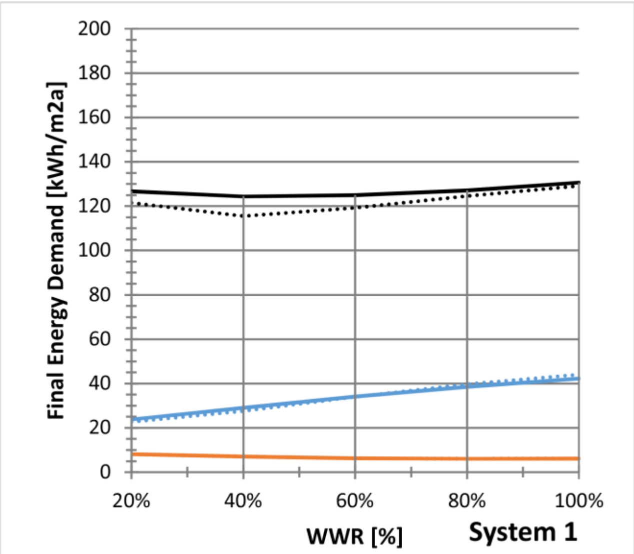
Recommendations when System 2

WWR	GT1	GT2	GT3
20%	-	+	-
30%	0	-	+
40%	0	-	+
50%	0	0	+
60%	0	0	+
70%	0	0	-
80%	0	0	-
90%	0	0	0
100%	0	0	0

Figure 5.45: Graphics and tables with recommendations for Napoli, East, Glass type

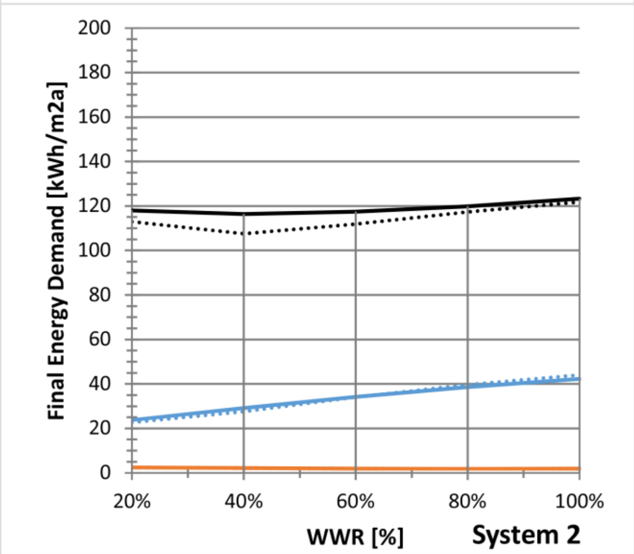
NAPOLI
EAST - Vertical Blinds





Recommendations when System 1

WWR	MVB	HVB
20%	0	-
30%	0	+
40%	-	+
50%	-	+
60%	-	+
70%	0	-
80%	0	-
90%	0	0
100%	0	0



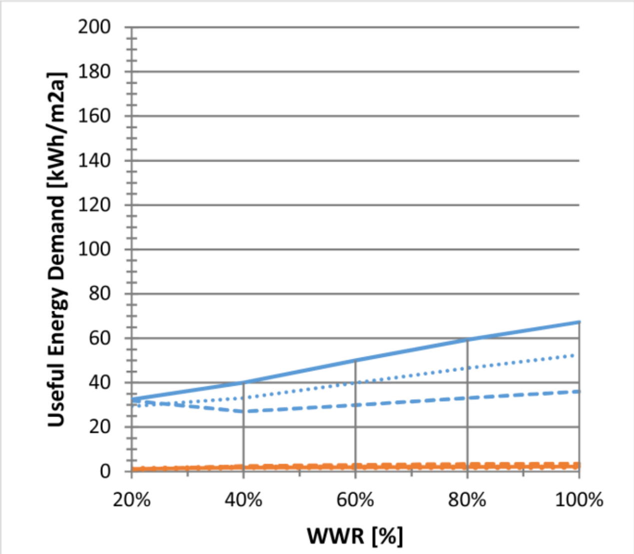
Recommendations when System 2

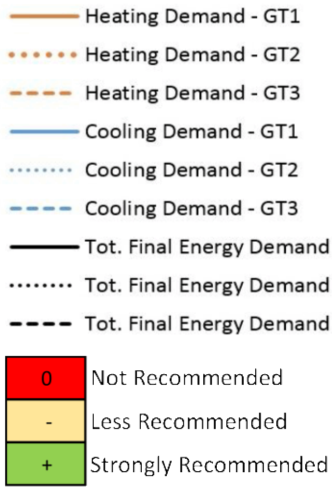
WWR	MVB	HVB
20%	0	-
30%	-	+
40%	-	+
50%	-	+
60%	-	+
70%	0	-
80%	0	-
90%	0	0
100%	0	0

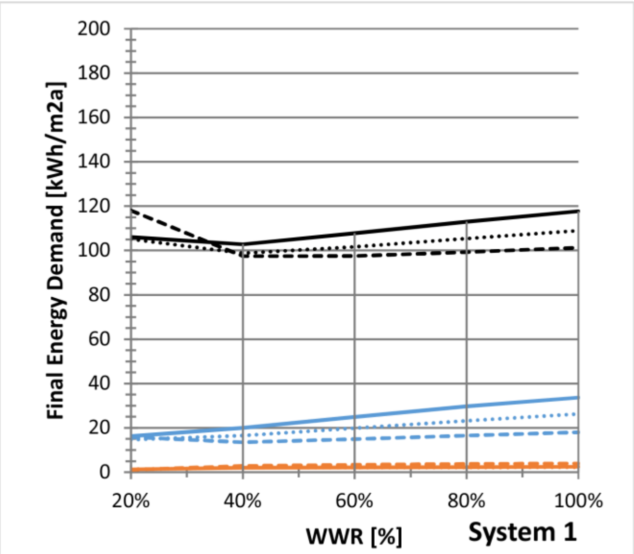
Figure 5.46: Graphics and tables with recommendations for Napoli, East, Vertical Blinds

PALERMO

NORTH - Glass type/No shading devices

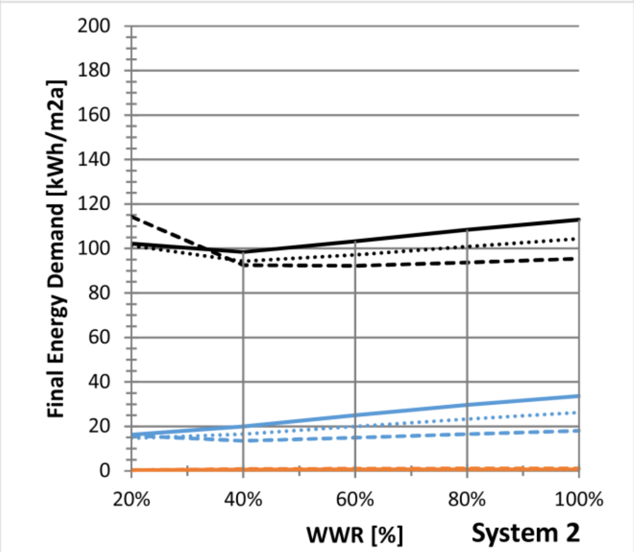






Recommendations when System 1

WWR	GT1	GT2	GT3
20%	-	-	0
30%	-	+	0
40%	-	+	+
50%	-	+	+
60%	0	+	+
70%	0	-	+
80%	0	-	+
90%	0	-	+
100%	0	0	+

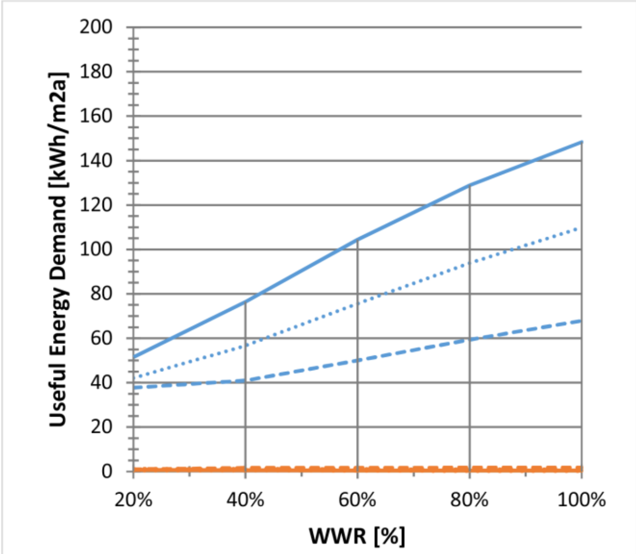


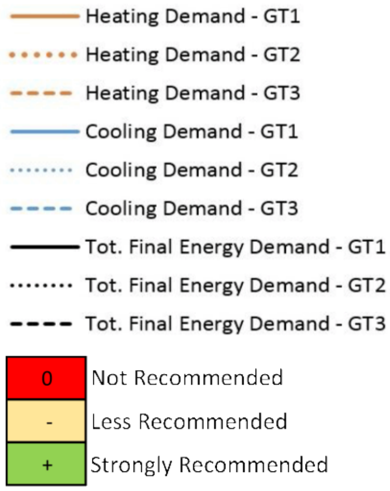
Recommendations when System 2

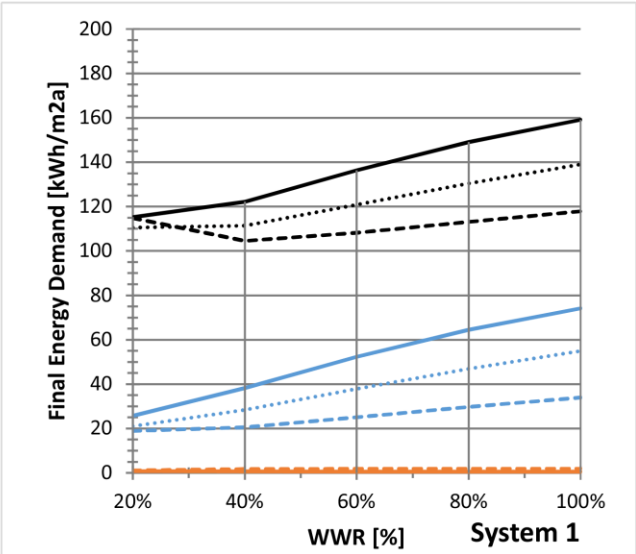
WWR	GT1	GT2	GT3
20%	-	-	0
30%	-	-	0
40%	-	+	+
50%	-	+	+
60%	0	+	+
70%	0	-	+
80%	0	-	+
90%	0	0	+
100%	0	0	+

Figure 5.47: Graphics and tables with recommendations for Palermo, North, Glass type

WEST - Glass type/No shading devices

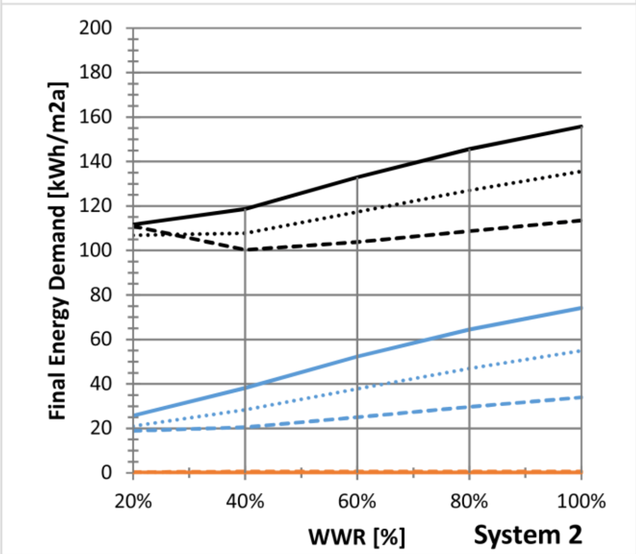






Recommendations when System 1

WWR	GT1	GT2	GT3
20%	0	-	0
30%	0	-	-
40%	0	-	+
50%	0	0	+
60%	0	0	+
70%	0	0	-
80%	0	0	-
90%	0	0	0
100%	0	0	0

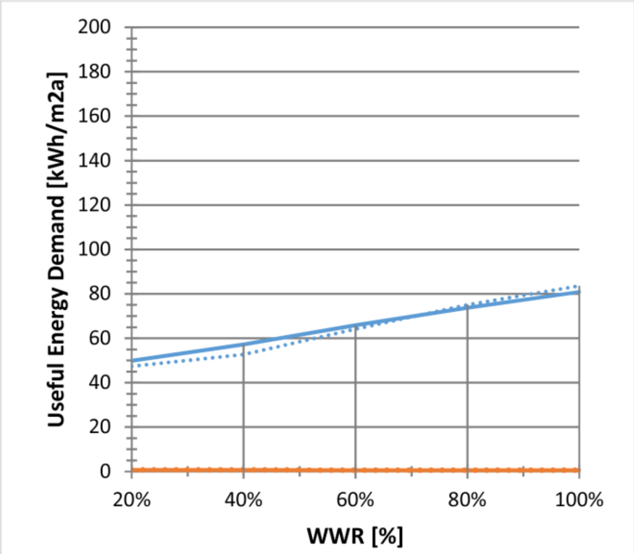


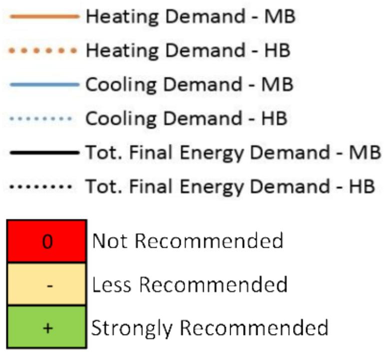
Recommendations when System 2

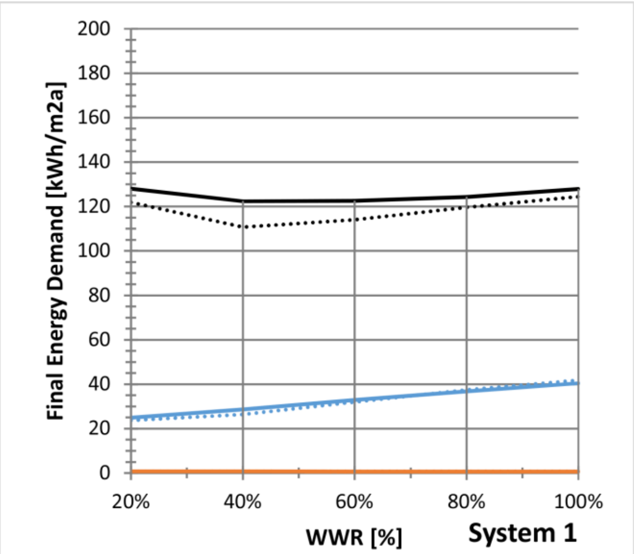
WWR	GT1	GT2	GT3
20%	0	-	0
30%	0	-	-
40%	0	-	+
50%	0	0	+
60%	0	0	+
70%	0	0	-
80%	0	0	-
90%	0	0	0
100%	0	0	0

Figure 5.48: Graphics and tables with recommendations for Palermo, West, Glass type

PALERMO
WEST - Vertical Blinds

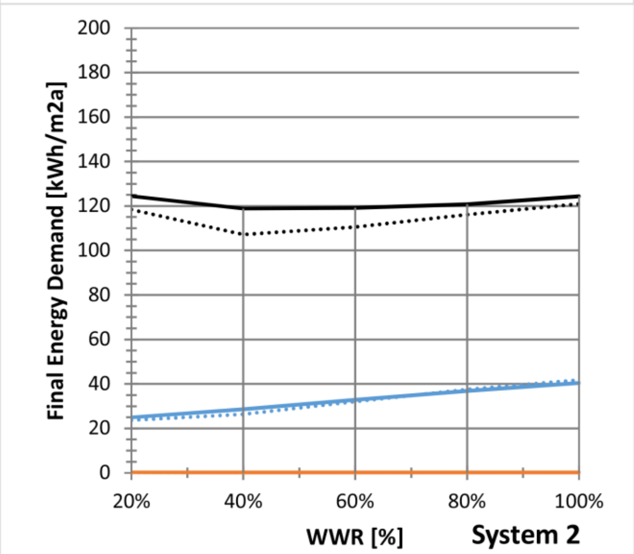






Recommendations when System 1

WWR	MVB	HVB
20%	0	0
30%	0	-
40%	0	+
50%	0	+
60%	0	+
70%	0	-
80%	0	-
90%	0	0
100%	0	0



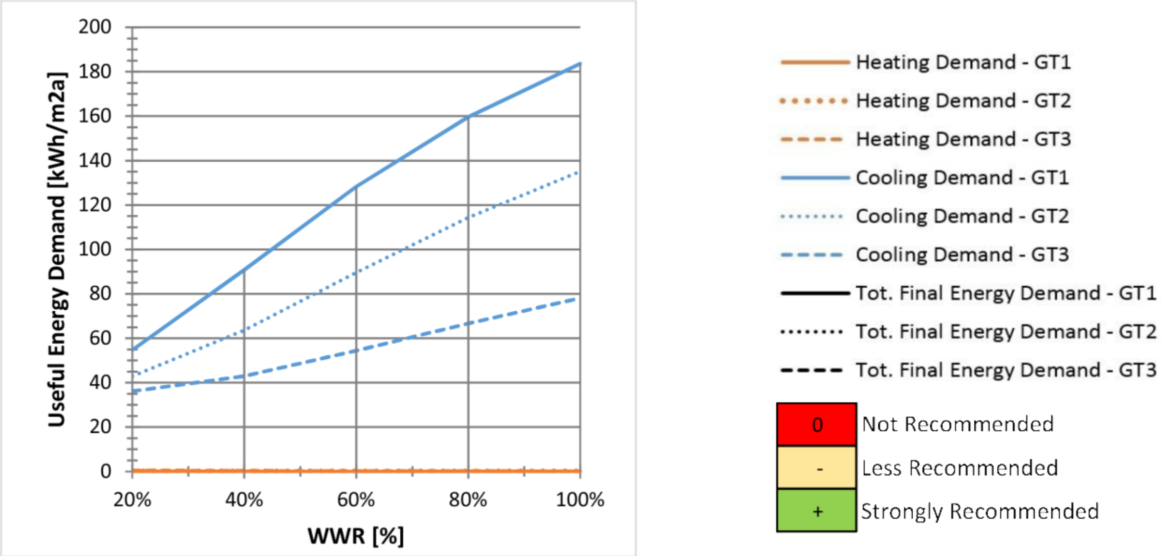
Recommendations when System 2

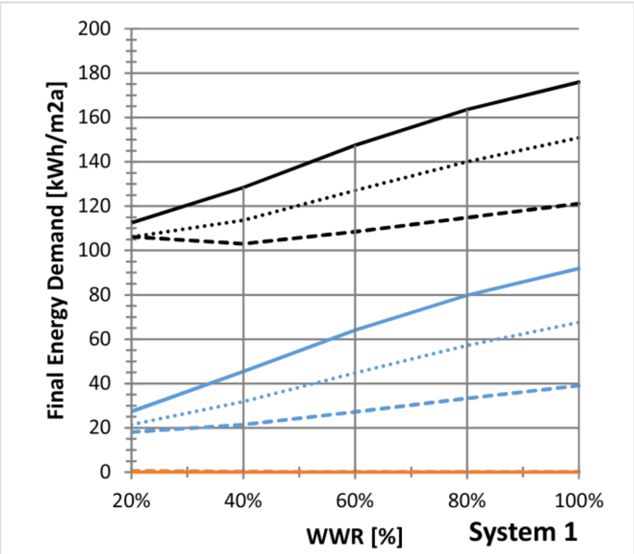
WWR	MVB	HVB
20%	0	0
30%	0	-
40%	0	+
50%	0	+
60%	0	+
70%	0	-
80%	0	-
90%	0	0
100%	0	0

Figure 5.49: Graphics and tables with recommendations for Palermo, West, Vertical Blinds

PALERMO

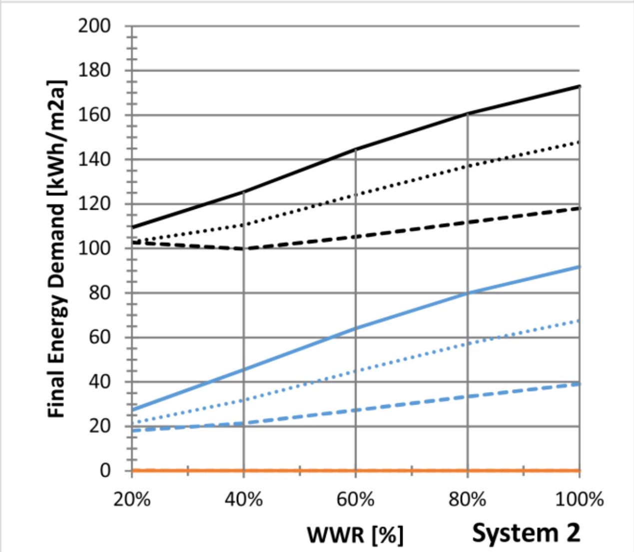
SOUTH - Glass type/No shading devices





Recommendations when System 1

WWR	GT1	GT2	GT3
20%	-	+	+
30%	0	-	+
40%	0	0	+
50%	0	0	+
60%	0	0	-
70%	0	0	-
80%	0	0	0
90%	0	0	0
100%	0	0	0

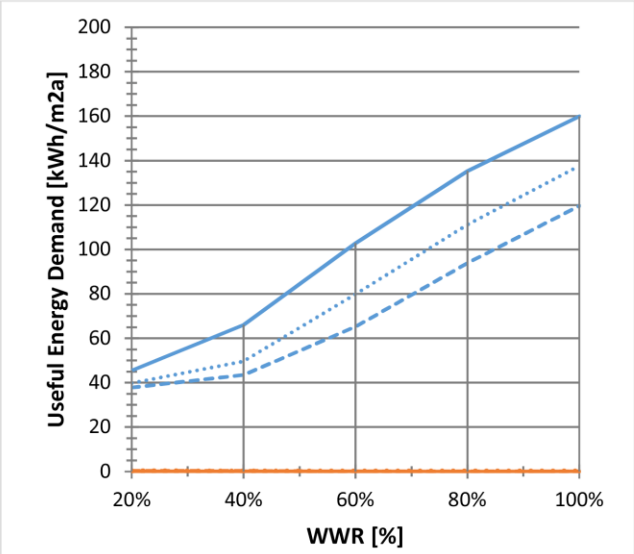


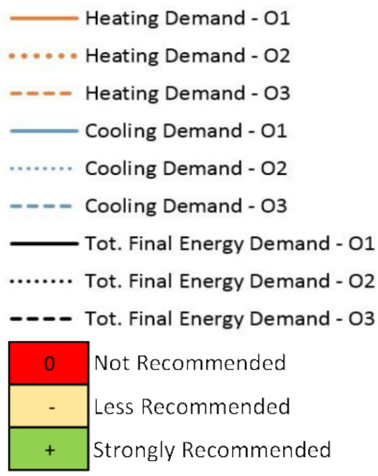
Recommendations when System 2

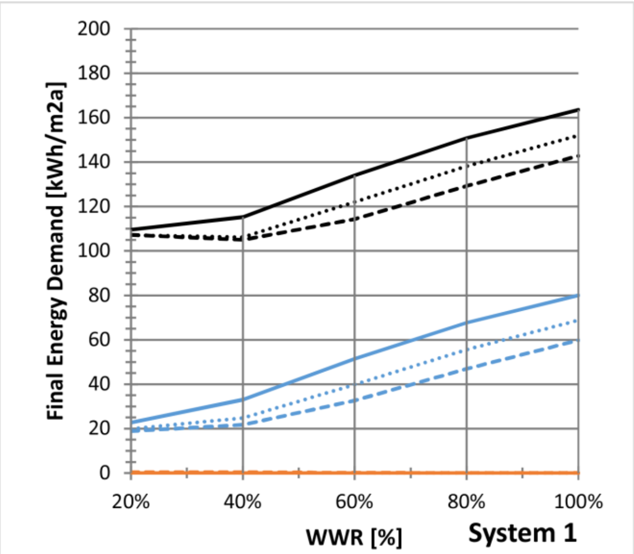
WWR	GT1	GT2	GT3
20%	-	+	+
30%	0	-	+
40%	0	0	+
50%	0	0	+
60%	0	0	-
70%	0	0	-
80%	0	0	0
90%	0	0	0
100%	0	0	0

Figure 5.50: Graphics and tables with recommendations for Palermo, South, Glass type

PALERMO
SOUTH - Overhangs

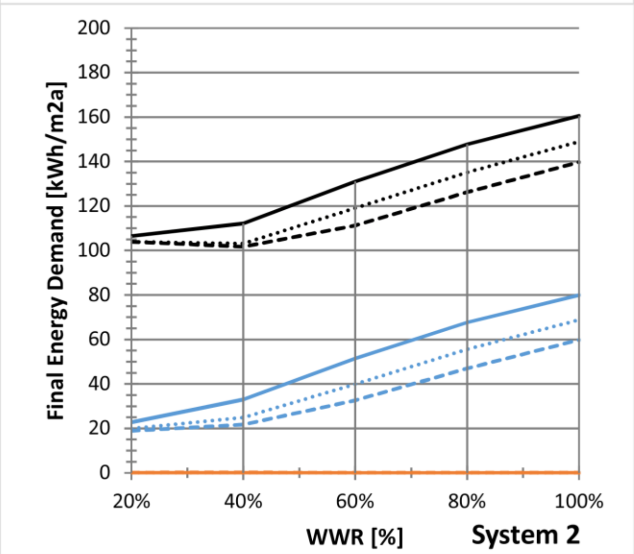






Recommendations when System 1

WWR	O1	O2	O3
20%	+	+	+
30%	-	+	+
40%	0	+	+
50%	0	-	+
60%	0	0	-
70%	0	0	0
80%	0	0	0
90%	0	0	0
100%	0	0	0



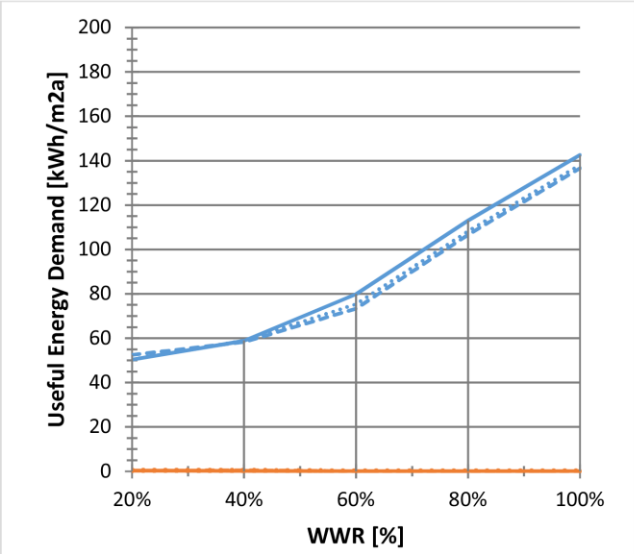
Recommendations when System 2

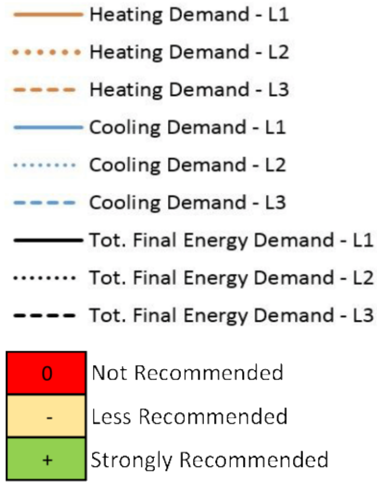
WWR	O1	O2	O3
20%	+	+	+
30%	-	+	+
40%	0	+	+
50%	0	-	+
60%	0	0	-
70%	0	0	0
80%	0	0	0
90%	0	0	0
100%	0	0	0

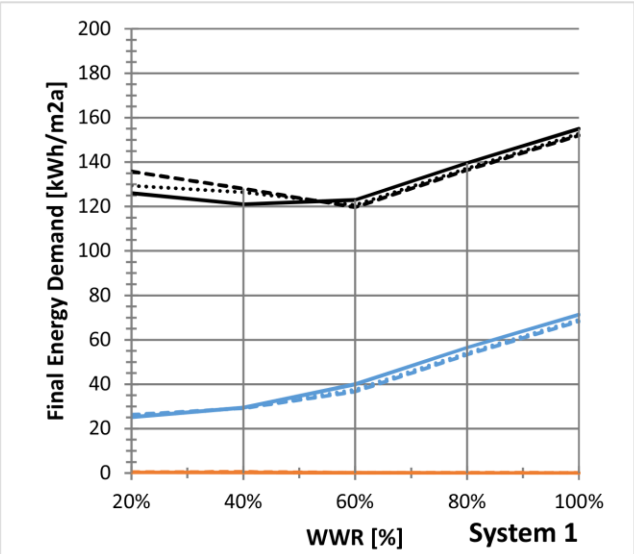
Figure 5.51: Graphics and tables with recommendations for Palermo, South, Overhangs

PALERMO

SOUTH - Horizontal Louvers

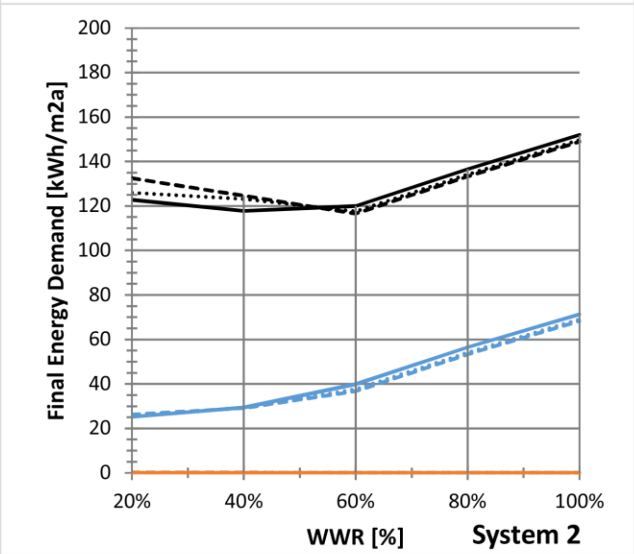






Recommendations when System 1

WWR	L1	L2	L3
20%	-	-	0
30%	+	-	0
40%	+	-	-
50%	+	+	+
60%	+	+	+
70%	0	-	-
80%	0	0	0
90%	0	0	0
100%	0	0	0



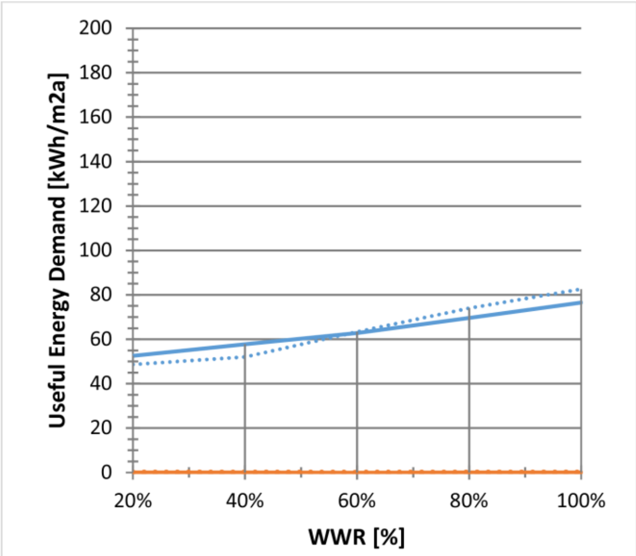
Recommendations when System 2

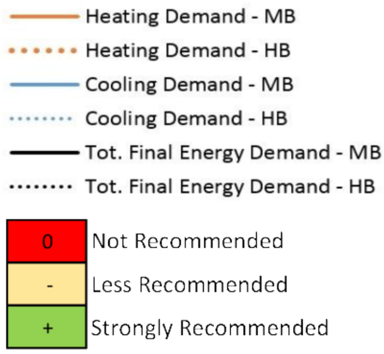
WWR	L1	L2	L3
20%	-	-	0
30%	+	-	0
40%	+	-	-
50%	+	+	+
60%	+	+	+
70%	0	-	-
80%	0	0	0
90%	0	0	0
100%	0	0	0

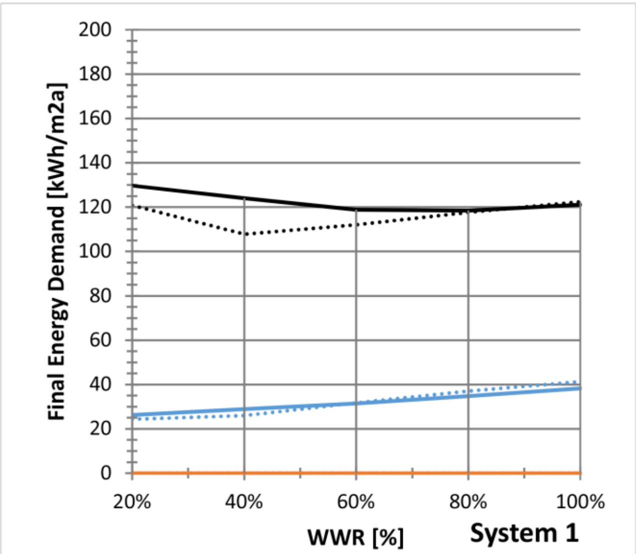
Figure 5.52: Graphics and tables with recommendations for Palermo, South, Louvers

PALERMO

SOUTH - Horizontal Blinds

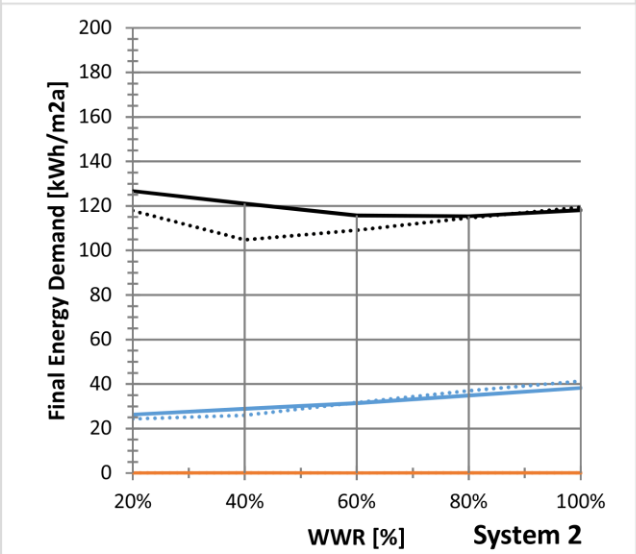






Recommendations when System 1

WWR	MHB	HHB
20%	0	0
30%	0	-
40%	0	+
50%	0	+
60%	0	+
70%	0	-
80%	0	-
90%	0	0
100%	0	0

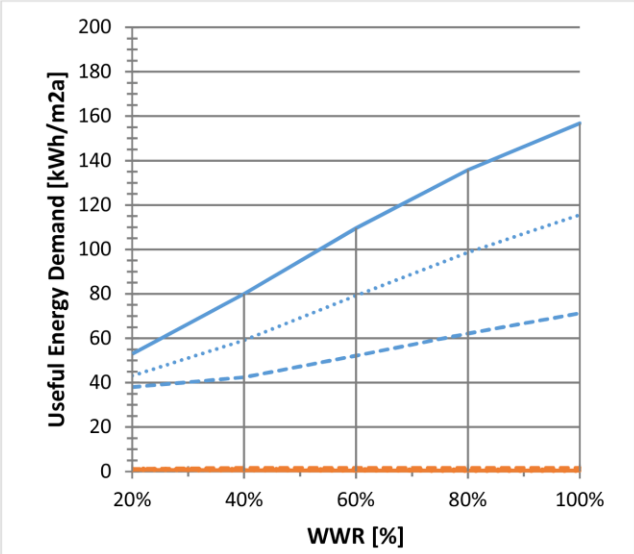


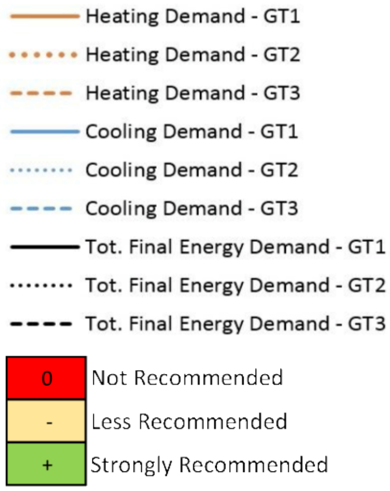
Recommendations when System 2

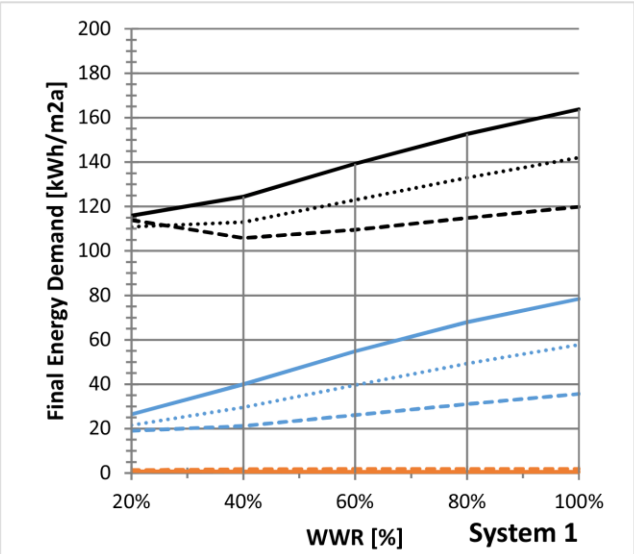
WWR	MHB	HHB
20%	0	0
30%	0	-
40%	0	+
50%	0	+
60%	0	+
70%	0	-
80%	0	-
90%	0	0
100%	0	0

Figure 5.53: Graphics and tables with recommendations for Palermo, South, Horizontal Blinds

PALERMO
EAST - Glass type/No shading devices

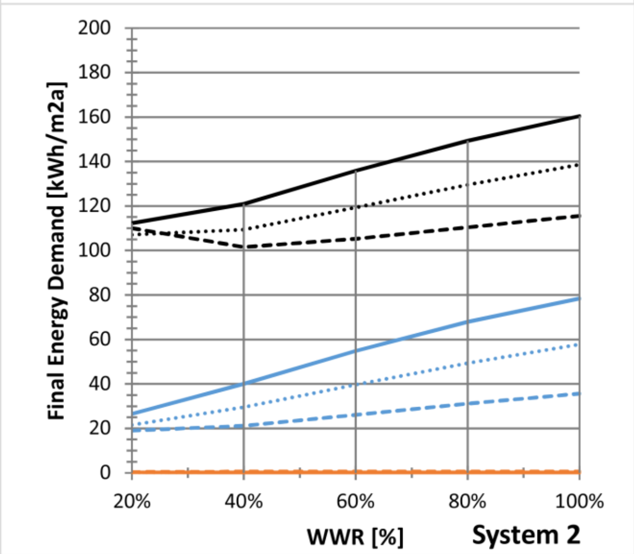






Recommendations when System 1

WWR	GT1	GT2	GT3
20%	0	-	-
30%	0	-	+
40%	0	-	+
50%	0	0	+
60%	0	0	+
70%	0	0	-
80%	0	0	-
90%	0	0	0
100%	0	0	0

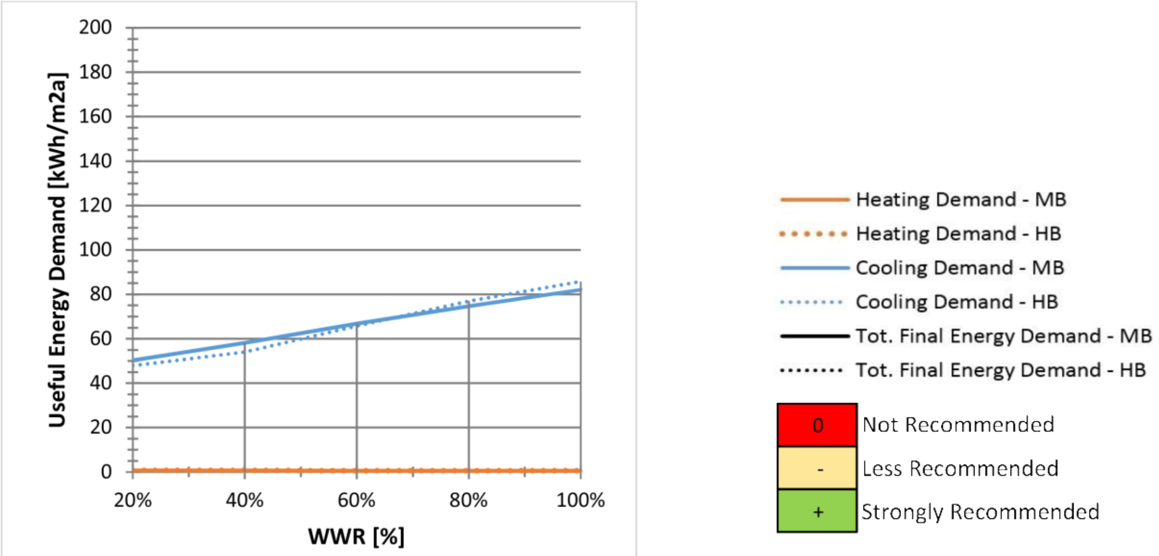


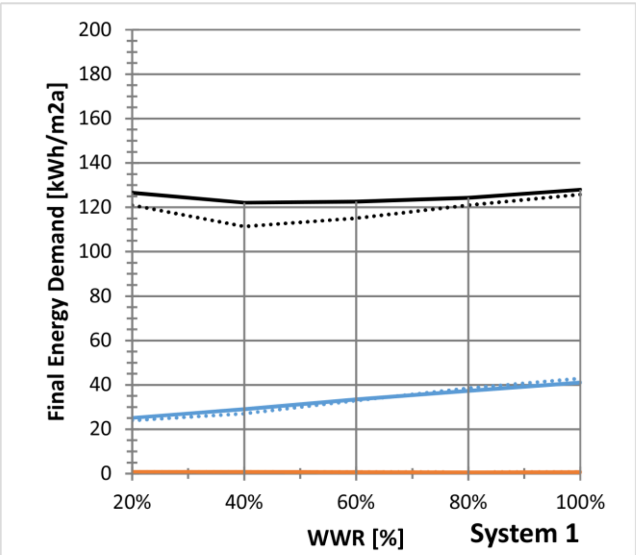
Recommendations when System 2

WWR	GT1	GT2	GT3
20%	0	-	-
30%	0	-	+
40%	0	-	+
50%	0	0	+
60%	0	0	+
70%	0	0	-
80%	0	0	-
90%	0	0	0
100%	0	0	0

Figure 5.54: Graphics and tables with recommendations for Palermo, East, Glass type

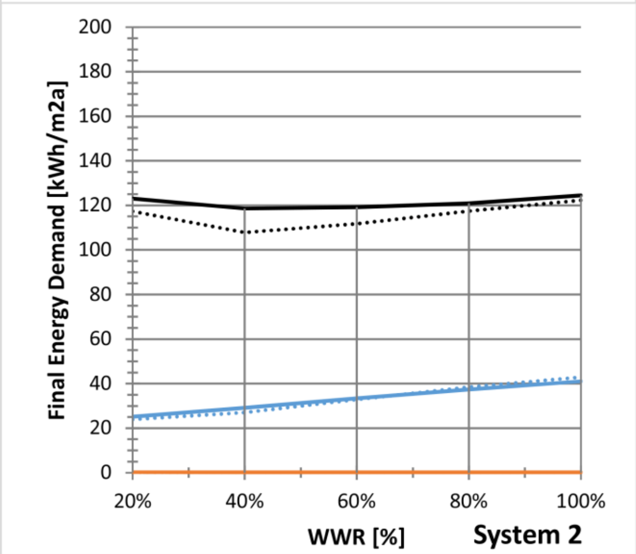
PALERMO
EAST - Vertical Blinds





Recommendations when System 1

WWR	MVB	HVB
20%	0	-
30%	0	+
40%	0	+
50%	0	+
60%	0	+
70%	0	-
80%	0	-
90%	0	0
100%	0	0



Recommendations when System 2

WWR	MVB	HVB
20%	0	-
30%	0	+
40%	0	+
50%	0	+
60%	0	+
70%	0	-
80%	0	-
90%	0	0
100%	0	0

Figure 5.55: Graphics and tables with recommendations for Palermo, East, Vertical Blinds

From the analyses of the pervious figures (from Figure 5.11 to 5.55), some considerations can be summarized:

- glasses even if nowadays can have low U-values (comparing to the past where U was around 2.7W/m^{2}K), isolate less than the opaque component (ex. U equal to 0.3W/m^{2}K). Hence, if the facade have big WWR, heat losses increase. This becomes more relevant in cities as Milano and Firenze where heating demand is more important;
- the difference of thermal transmittances (ΔU) between the transparent and the opaque parts, influences the energy behavior of the building. Specifically, in such case small ΔU[16] reduces heating demands (ΔU_{GT3});
- the most critical fronts are South, West and East for the hot climate that characterized the Italian territory. In Italy, in fact, the main problem is the reduction of cooling loads. For such reason glasses have to guarantee high values of visible transmittance VT more than 0.45 (in order to reduce the artificial lighting use) and be medium (SHGC equal to 0.4) or high spectral selective (SHGC between 0.27 and 0.24) to reduce cooling loads. Otherwise, high WWR have to be avoided or shading devices are necessary;
- transparencies require the adoption of shading devices not only to reduce overheating, but also for maintaining the indoor comfort (protection from glare).
  Shading devices can be placed differently (exterior/interior position) in relation to the window. For instance, the exterior solution is preferable when overheating has to be reduced. In fact, in such way, the shading system protects the window from direct radiation preventing a large part of the heat from getting in. On the other hand, this solution entails more investment and maintenance costs, more complexity of the technological systems, etc., if compared with interior shading devices;
- the length of the overhang influences both cooling demand (thanks to the shadow projection on the window) and lighting demand (constituting an obstruction to daylight). Specifically, longer is the overhang, higher is the energy for lighting, but minor is overheating. At the same time, increasing the size of the windows means increasing the length of the overhang to permit the appropriate shadowing.
  Despite, the use of overhangs is not a recurring solution in offices for the not flexible solution. Nevertheless, for the office typology, it is common that upper floors are in overhang respect to the ground one. In such case, it is recommended: the ground floor with the WWR equal to 100% with interior shading devices and the upper levels in projection (length equal to 1.5m, O3). Another design strategy is the adoption of horizontal louvers, with PV modules integrated, positioned in overhang;
- fixed exterior shading elements (horizontal louvers for the Southern facade) increase the lighting demand because the fixed angle not support the different inclination of the solar rays according to the season. This is the main disadvantage that encourage to prefer the use of movable shading devices or more performing glazing;
- considering blinds, higher reflectance entails the decrease of lighting demand privileging the reflection of the solar rays into the building. Specifically, the adoption of blinds combined with the basic glass (GT1+HB or GT1+VB) permits the decrease of the final energy demand for all the cities and orientations. On the other hand, it entails the increasing of both costs (investment and maintenance costs) and technology complexity. Hence, for small WWR values, high spectral selective glass (GT3) without

[16] $\Delta U = U_{glass} - U_{opaque}$. U_{op} = 0.31W/m^{2}K, U_{GT1}=1.70W/m^{2}K, U_{GT2}=1.37W/m^{2}K, U_{GT3}=1.01W/m^{2}K; ΔU_{GT1}=1.39W/m^{2}K, ΔU_{GT2}=1.06W/m^{2}K, ΔU_{GT3}=0.70W/m^{2}K.

exterior shading devices can permit a good compromise between energy saving and costs. Despite, exterior blinds (especially in combination with more performing glasses as GT2 or GT3) can be strongly recommended when large transparencies are adopted.

Considering the cities, the following considerations can be briefly summarized:

- in Milano, heating is predominant on North front independently by WWR and type of glass. While for West, East and South orientations, it depends by both glass and shading device types. Specifically, heating is predominant for low values of WWR; while cooling demand grows especially for the base glass (GT1 without shading devices). Vertical blinds on East/West fronts and horizontal blinds on South, contribute to maintain cooling demand below the heating one. For this city, the choice of the type of system influence importantly the window design since the adoption of the heat pump ("System 2") permit a great reduction of the heating demand. In such case, the heat pump increases the range of the recommended solutions;
- in Firenze and Roma, cooling is predominant for all orientations except for the North one where there is a balance between heating and cooling demands. West, East and South fronts can have important cooling demands especially when WWR grows;
- in Napoli and Palermo, cooling is predominant and transparencies have to be contained on West, East and South fronts.

Additional energy simulations have been made to investigate the relation between shading devices and glazing types.
Specifically, the results show the combination of the type of glass (GT1, GT2 and GT3) and the horizontal blinds (MHB and HHB) for the South orientation, for the cities of Milano and Palermo. It is possible to observe how in Milano (from Figure 5.56 to Figure 5.58) and in Palermo Figure 5.56 and Figure 5.59):

- high selective glass (GT3) in combination with shading devices (MHB or HHB) maintains constant and low the cooling demand that becomes independent by WWR (Figure 5.56). In such case, it is possible to increase transparencies on façade without influences the cooling demand for both cities;
- when WWR is more of 60% or 70%, in Milano, GT2 or GT3 can be preferably combined with blinds with high reflectance (HHB); while in Palermo is better GT3 combined with HHB;
- the use of exterior blinds with high reflectance permits to reduce lighting demand according to a better diffusion of daylighting.

Therefore, when WWR is more than 60% and 70%, the facade is big and oriented on West, East and South fronts, the recommendation is to combine GT2 or GT3 with exterior blinds for all the locations.

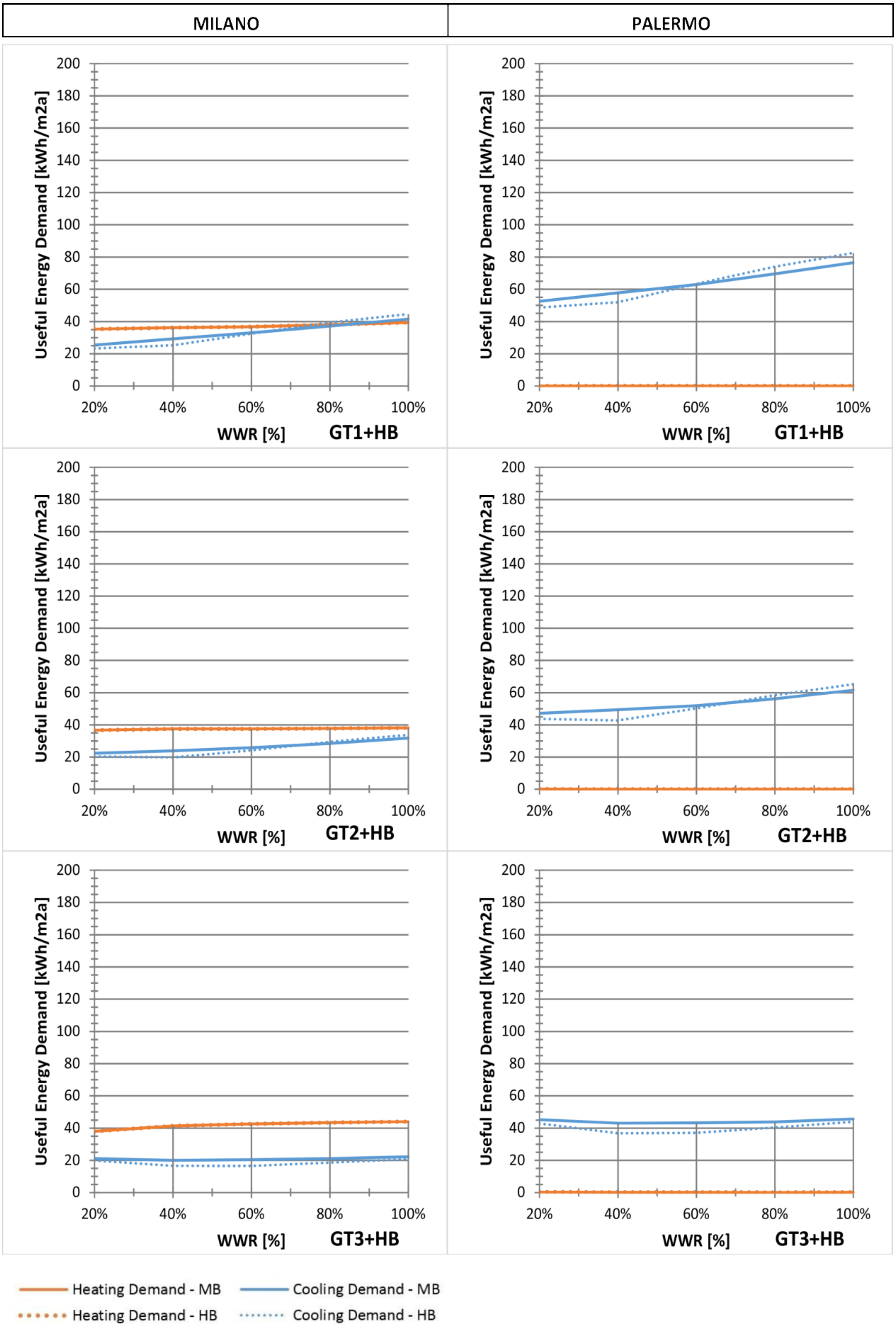
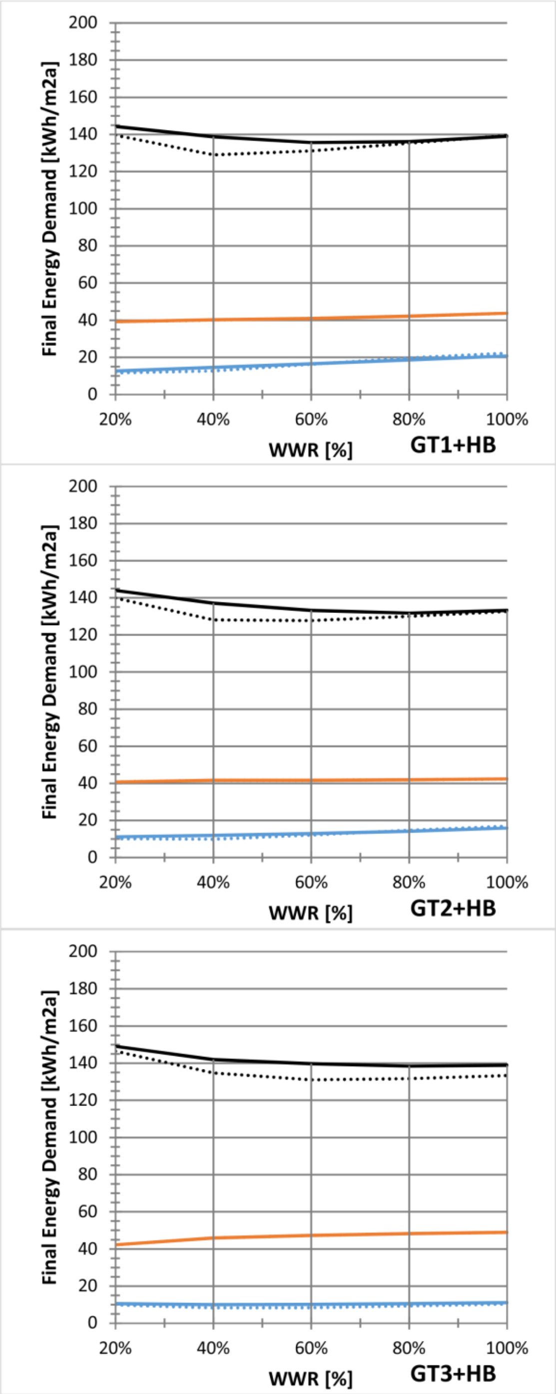
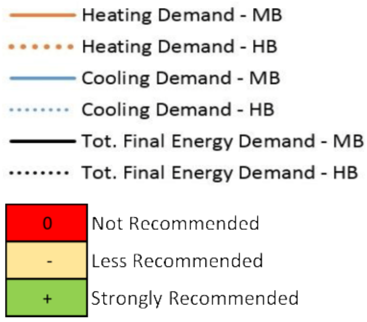


Figure 5.56: Useful Energy demands for the cities of Milano and Palermo, South orientation, Combination between different types of glass and horizontal blinds

MILANO - SYSTEM 1



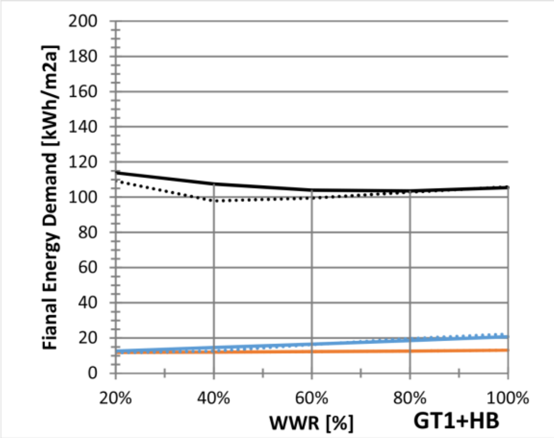


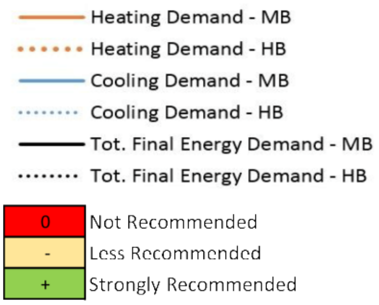
Comparison between different type of glass combined with horizontal blinds

WWR	GT1 + MHB	GT1 + HHB	GT2 + MHB	GT2 + HHB	GT3 + MHB	GT3 + HHB
20%	0	0	0	0	0	0
30%	0	-	0	-	0	0
40%	0	+	-	+	0	-
50%	-	+	-	+	0	-
60%	-	+	-	+	0	+
70%	-	-	+	+	0	+
80%	-	-	+	+	0	+
90%	-	-	+	+	0	+
100%	0	0	-	+	0	-

Figure 5.57: Final Energy demand, South orientation, Combination between different types of glass and horizontal blinds - Milano - “System 1”

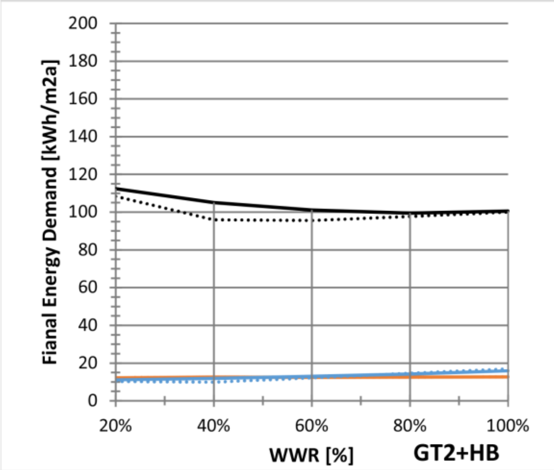
MILANO - SYSTEM 2





Comparison between different type of glass combined with horizontal blinds

WWR	GT1 + MHB	GT1 + HHB	GT2 + MHB	GT2 + HHB	GT3 + MHB	GT3 + HHB
20%	0	0	0	0	0	0
30%	0	-	0	-	0	0
40%	0	+	0	+	0	+
50%	0	+	-	+	0	+
60%	-	+	-	+	-	+
70%	-	-	-	+	-	+
80%	-	-	+	+	-	+
90%	-	-	-	+	-	+
100%	0	0	-	-	-	+



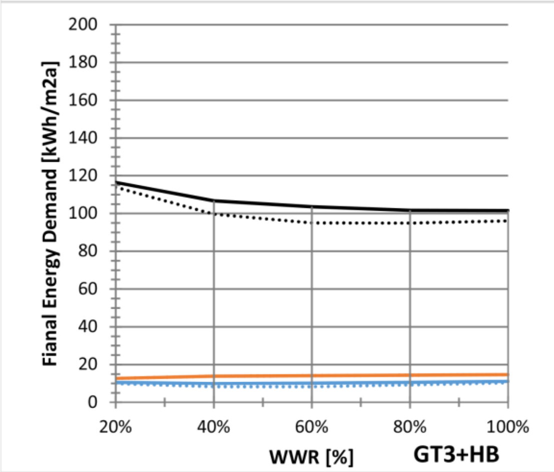
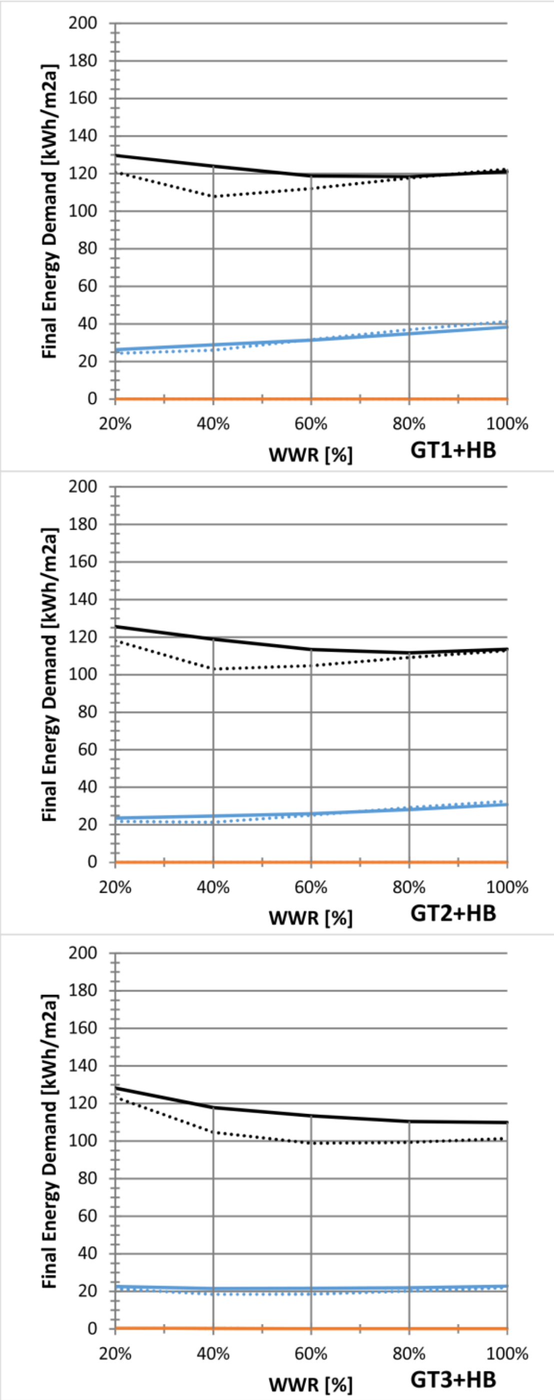
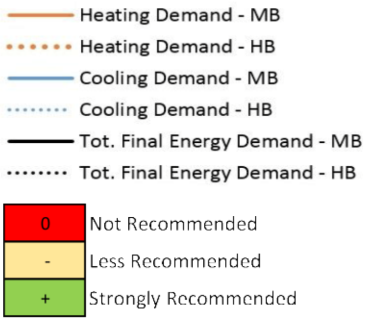


Figure 5.58: Final Energy demand, South orientation, Combination between different types of glass and horizontal blinds - Milano - “System 2”

PALERMO - SYSTEM 1





Comparison between different type of glass combined with horizontal blinds

WWR	GT1 + MHB	GT1 + HHB	GT2 + MHB	GT2 + HHB	GT3 + MHB	GT3 + HHB
20%	0	0	0	0	0	0
30%	0	0	0	0	0	0
40%	0	-	0	+	0	-
50%	0	0	0	-	0	+
60%	0	0	0	-	0	+
70%	0	0	0	-	0	+
80%	0	0	0	0	0	+
90%	0	0	0	0	0	+
100%	0	0	0	0	0	+

There is no difference between the results obtained for System 1 and System 2. Hence, the same recommendations are valid in both cases.

Figure 5.59: Final Energy demand, South orientation, Combination between different types of glass and horizontal blinds - Palermo - "System 1"

5.3 VENTILATION STRATEGY

Different ventilation systems can contribute to reduce strongly the cooling demand of the building, adopting various techniques and control strategies [6].

Specifically, the present paragraph shows the results of the application of the mixed mode ventilation[17] to the same model[18] of the previous paragraphs (dimensions of the floor plan equal to 12m and 5.25m, WWR equal to 20%, GT1, etc.). Specifically:

- the first tranche of simulations entails the application of natural ventilation (NV) during night (night cooling, NC) from 23.00 to 7.00 [7] and from May to September for all cities;
- the second tranche entails the application of natural ventilation during summer nights (as the previous part) and during the working hours (from 8.00 to 16.00) of the mid-seasons (April, May and October).

The air change rate (ACH) is varied for both cases, from 0 1/h to 10 1/h in order to investigate the influence on the cooling demand. The results are presented in Figures from 5.60 to 5.68. The results when night cooling (NC) is activated show that:

- NC is a strategy that permits the reduction of the cooling demand without increasing the heating one. This is valid for all the orientations (Figures 5.60 and 5.66) and for all the cities (from Figure 5.60 to 5.68);
- cooling demand decreases rapidly (biggest inclination of the line) from 0 1/h to 2 1/h while the trend is reduced for ACH bigger than 2 1/h. Specifically, the decrease of the cooling demand changes according to the cities and to the orientation. For instance, in Milano the potential of the energy saving is bigger on South than on North part (from Figure 5.60 to Figure 5.62). In the last case, when ACH is more than 2 1/h, there is not a substantial reduction of the cooling demand. On the other hand, in Palermo, all fronts have benefits and the energy saving is major than in Milano (from Figure 5.66 to Figure 5.68).

The results of the adoption of the natural ventilation (NV), during both summer nights and the working hours of the mid seasons, show that:

- NV during mid-seasons does not increase the heating demand of the building having a general benefit in the reduction of the cooling demand that is different according the location.

  Specifically, in Milano, NV during mid seasons does not affect importantly the results. In fact, for the North front, the trend of the cooling demand is almost the same of the case with only NC activated (Figure 5.61). The benefits are also contained for the South orientation (Figure 5.62). For the other cities (Figures from 5.63 to 5.68), the potential of this strategy acquires importance. In Palermo it is maximum; in fact cooling demand is reduced until to 54% when ACH is equal to 10 1/h.

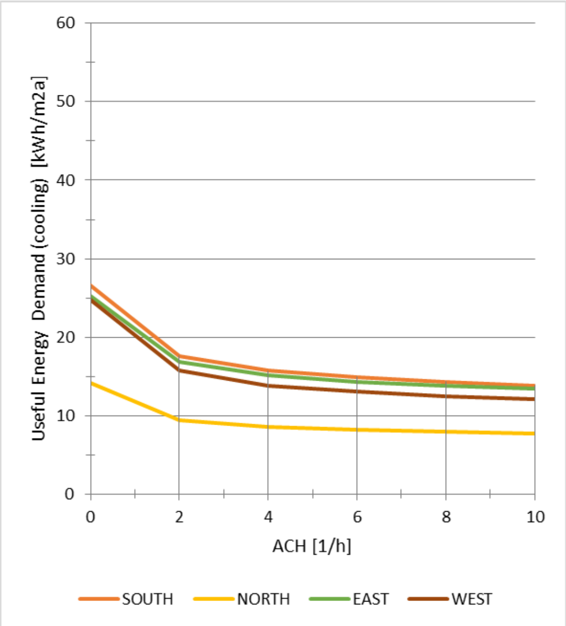


Figure 5.60: Milano - NC - All orientations

[17] The hybrid approach of the mixed mode encloses NV combined with mechanical ventilation. In the present research, NV is used to cool the building naturally in specific periods; while the mechanical one provides the minimum requirements during all the year (indoor air quality).

[18] The model is single side ventilated.

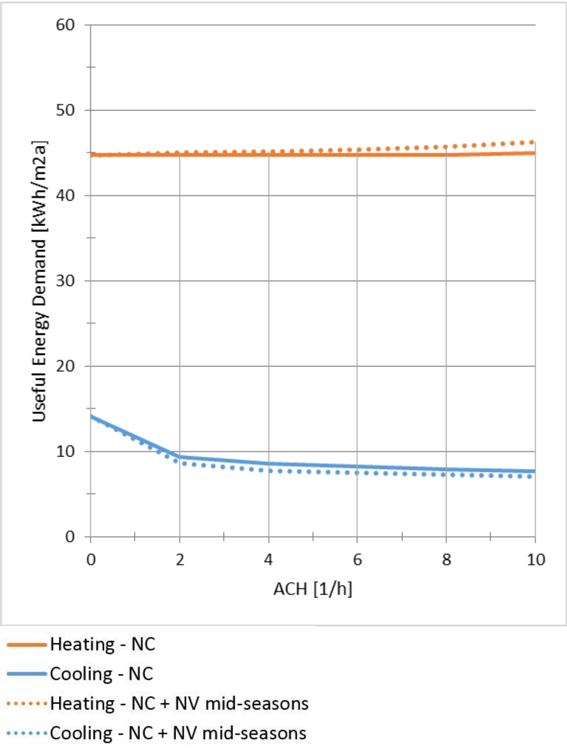


Figure 5.61: Milano - North - NC and NC + NV mid-seasons

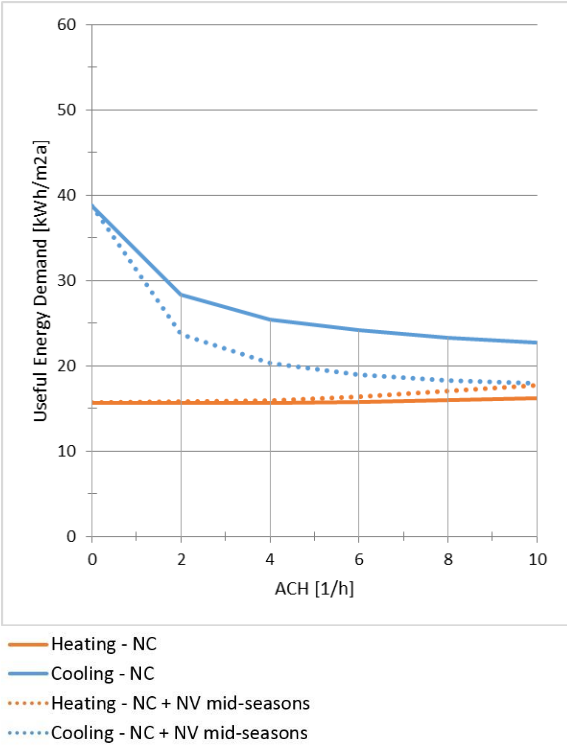


Figure 5.63: Firenze - South - NC and NC + NV mid-seasons

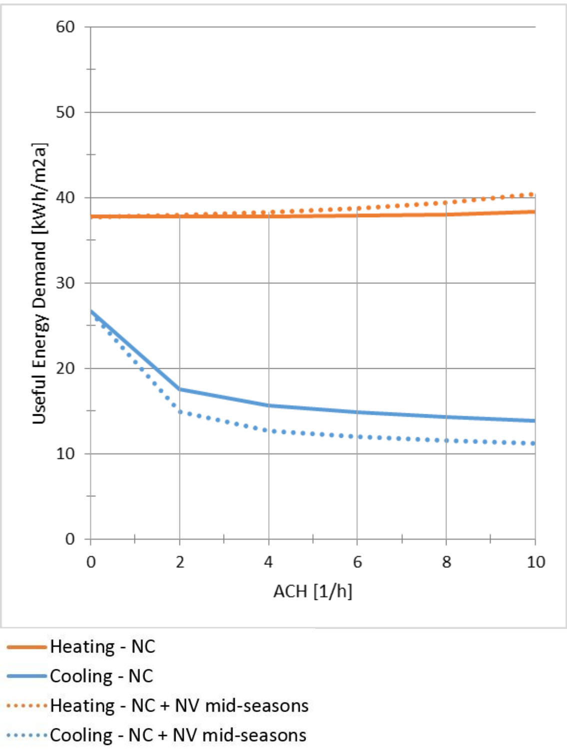


Figure 5.62: Milano - South - NC and NC + NV mid-seasons

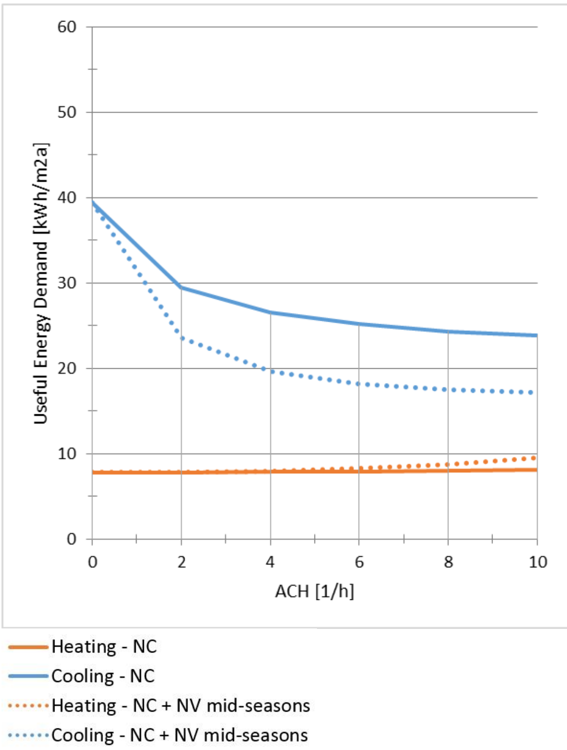


Figure 5.64: Roma - South - NC and NC + NV mid-seasons

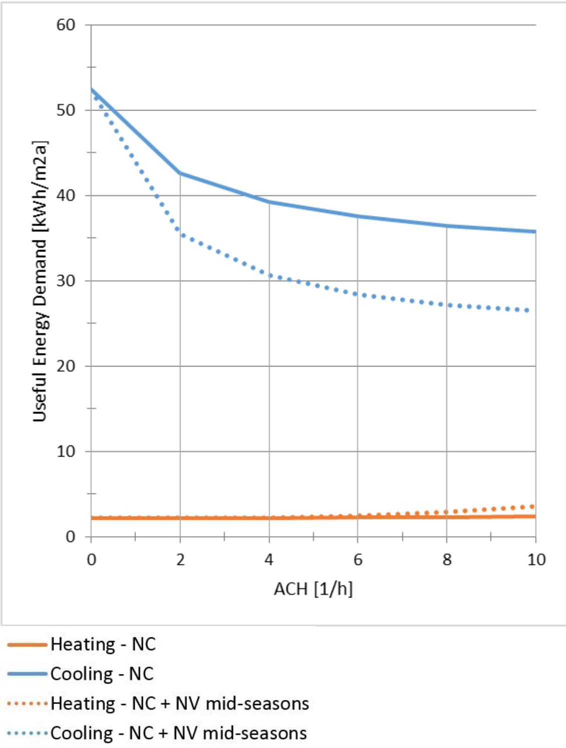


Figure 5.65: Napoli - South - NC and NC + NV mid-seasons

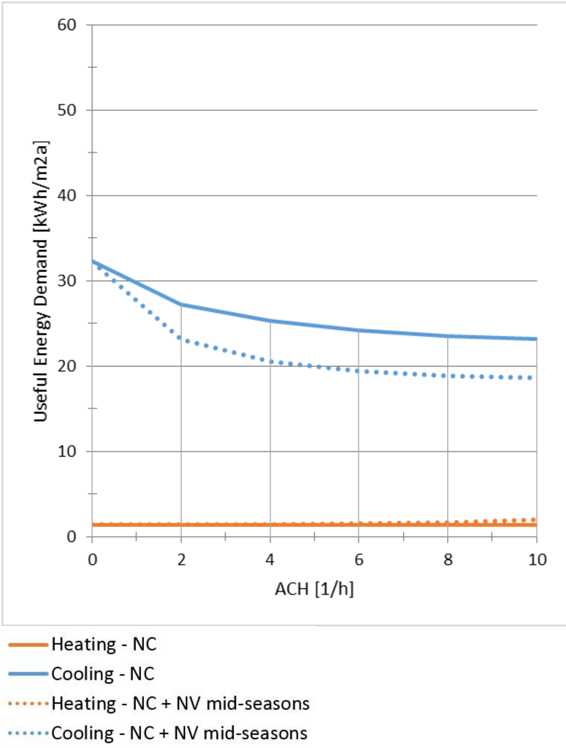


Figure 5.67: Palermo - North - NC and NC + NV mid-seasons

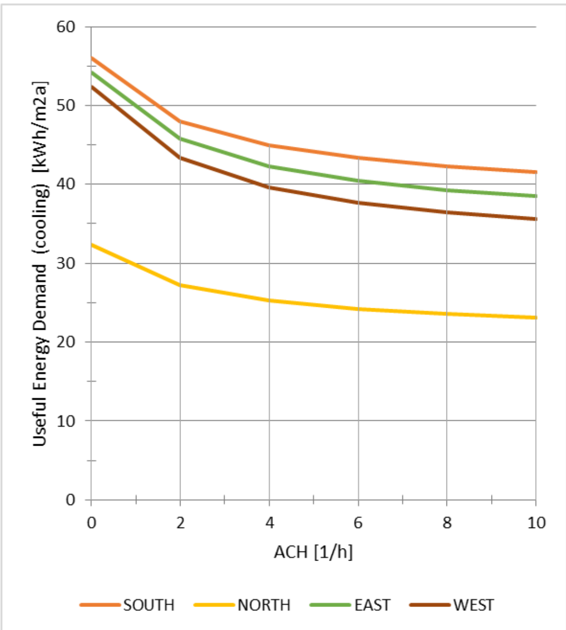


Figure 5.66: Palermo - NC - All orientations

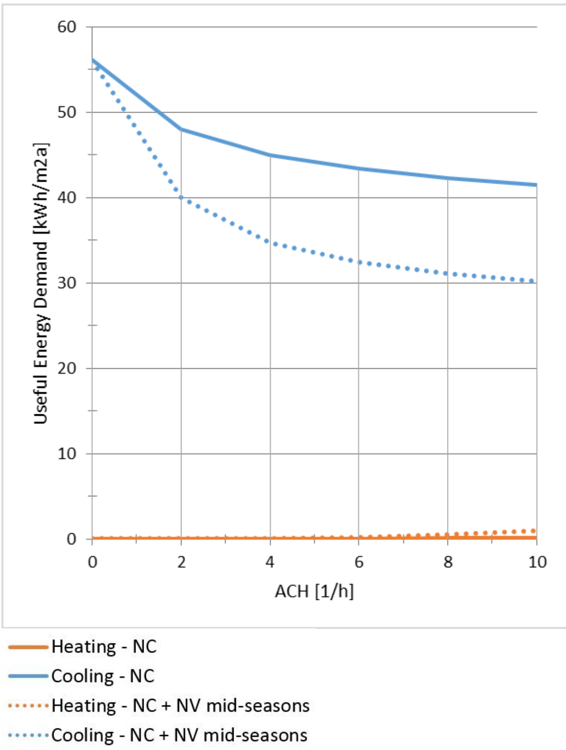


Figure 5.68: Palermo - South - NC and NC + NV mid-seasons

5.4 STRATEGIES FOR RENEWABLE ENERGY SUPPLY: PHOTOVOLTAICS

This part investigates the potential of producing electricity from renewables thank the integration of photovoltaic modules into the building (Figure 5.71).

The study analyzes the influence that some design criteria have on the performance of the PV systems. The parameters are the location (five cities), the shape of the buildings (cases A, B, C) and the shape of some elements of the envelope. For ex.: flat roof with a mounting system of PV and PV integrated into the sloped roof; PV integrated into the façades with different geometries, etc.

Specifically, some architectural parameters investigated are the following:

- **tilt angle of PV (β):** it influences the performance of PV module. The best value depends by the latitude and the position of the sun during the year. Generally, for a specific location, the small tilt angle is preferable during summer period while the bigger one in winter season. For Italy, the average value is approximately 30° (Figure 5.69);
- **minimum distance between modules (X_{min}):** it guarantees no mutual shading between panels. It depends by latitude and dimensions of the PV panel (ex. Figure 5.72);
- **$A_{PV,max}/A_{facade}$ ratio or $A_{PV,max}/A_{roof}$ ratio:** they represent the ratio between the max. area covered by PV modules and the total area of the roof or façade. The percentage depends, for example, by the minimum distance to maintain between PV panels, the relation with the transparent parts in the facade, etc.

The energy output are the following: PV output [kWp]; Energy produced [kWh]; Annual yield [kWh/kWp] and Final energy [kWh/m^{2}a].

The software adopted to simulate PV systems is “PV*SOL Expert 5.5”.

For the energy simulations, it is adopted the PV module type “BP 3235T” by BPSolar (Figure 5.70).

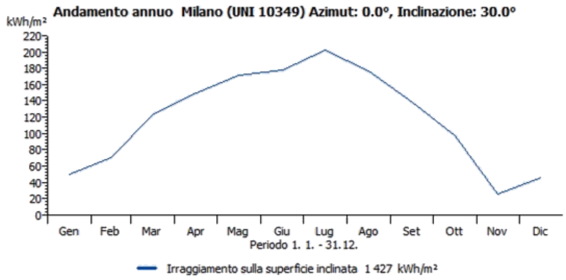


Figure 5.69: Solar radiation - Milano - PV with β=30°

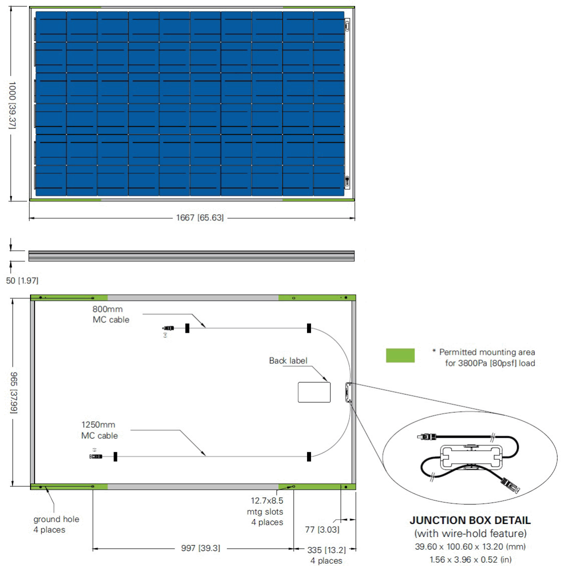


Figure 5.70: PV module (BP 3235T) by BP Solar **[8]**

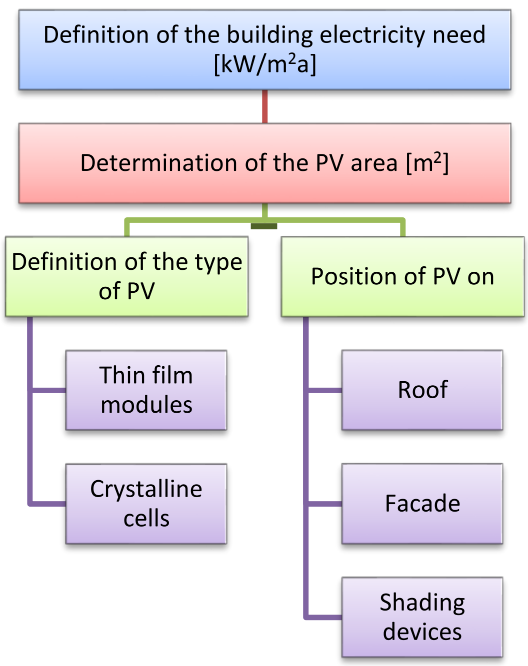


Figure 5.71: Phases of the BIPV design

5.4.1 ROOF

As described in the previous chapters, the exploitation of the roof surface to dispose PV modules is the strategy most common and most recommended (Paragraph 3.3.7). Despite all, if for low-rise buildings this should be valid since the huge area available on the top; high-rise buildings require the installation on the south-facade.

Looking at the disposition of PV panels on the roof of the building, the choice between flat roof with a mounting system or the integration into a pitched roof influences the design of the building in terms of esthetic, morphology, technology, etc. as also in terms of energy performance.

Some design solutions related to the allocation of PV modules are covering the roof on its entirety or partially; disposing them above the roof of the offices or integrating into the transparent surfaces of corridors, staircases and atria[19].

5.4.1.1 FLAT ROOF

Standard panels south oriented (β equal to 30° for all cities) could be disposed on a flat roof with a mounting system (no BIPV). In this case, in order to have not mutual shading (Figure 5.72), PV need to be separated by a space (X_{min}) that depends by the inclination of sunrays (latitude) and the geometry of the panels.

For instance, it goes from 1.58m for Palermo until 2.23m for Milano (Table 5.7). For the same reason, also a minimum distance from the parapet is necessary to guarantee (ex. i_{min} equal to 0.5m).

For this solution, it is not possible to exploit totally the area of the roof for the alternation with the empty spaces. Hence, for the same roof, the number of modules change depending by the location.

Equation 5.5 permit the calculation of the maximum area of modules (A_{PV}) varying the shape of the roof and the location. The different shapes are those belonging to the base cases (square, rectangle and rectangle with core atrium). Specifically, the equations are obtained dividing the roof into strips, which enclose the panel projection and the empty area (Figure 5.73).

It is possible to observe, applying the previous considerations, that for the three cases:

- the number of panels, for each case, increases from the North to the South of Italy depending by latitude and the consequent decrease of the distance between modules (Figure 5.76);
- there is no difference between the cases A and B because they have almost the same floor plan area. On contrary, preferring a low-rise building (case C), means having more available area ($N_{PV,C} \approx 3N_{PV,A}$) with the consequent triple of energy production (Figure 5.75);

EXAMPLES	- Horizontal roof with mounting systems; - South facing sloped-roof; - Curved roof with thin modules; - Shed roof for the atrium.
ADVANTAGES / DISADVANTAGES	more performing than facade; *PV mounting system:* - best angle of panel; - easy to install; - possibility to install on existing buildings; - waste of the space between PV. *PV integrated into sloped roof:* - more investment cost; - more economic subsidy; - optimization of space; - expectation since the early design phase. *Thin film modules:* - less performing; - permit curved surfaces and free design.

Table 5.6: Summary of PV on roof

[19] Glazed roof that covers the atrium can have a shed geometry with openings on one-side and PV modules integrated. This solution guarantees at the same time natural ventilation and production of electricity. The angle of the shed is determined by the solar radiation (β equal to 30°), but it is important to define the way of shadowing the interior space.

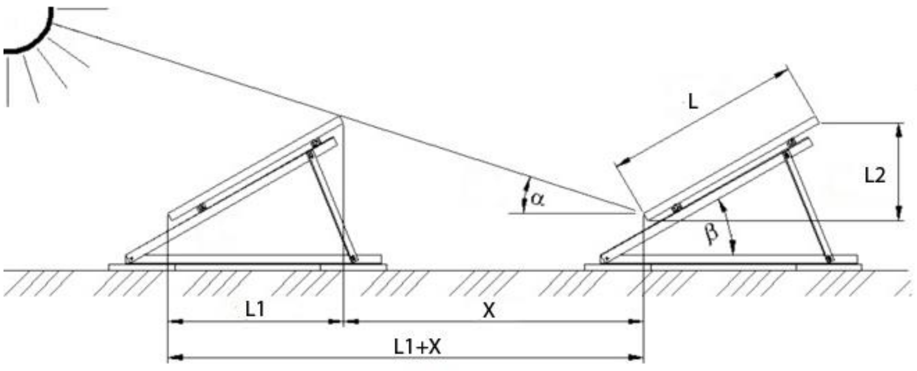


Figure 5.72: Sketch for the calculation of X_{min}

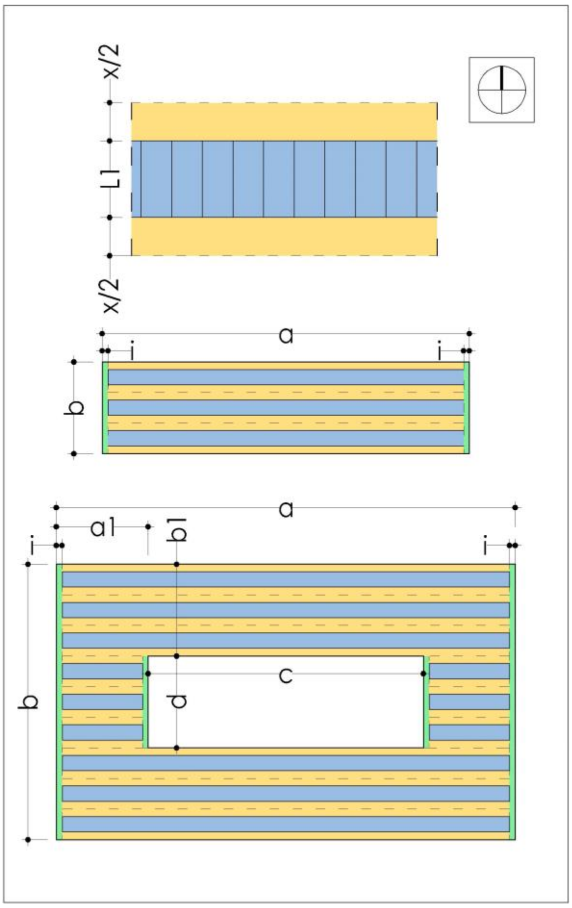


Figure 5.73: Sketch for the calculation of the area max of PV panels according to the geometry of roof

α	Inclination of solar rays [°]
β	Angle of the PV [°]
L	Length of the PV [m]
L_1	= L·cosβ PV projection on horizontal plane [m]
L_2	= L·senβ PV projection on vertical plane [m]
X_{min}	Minimum distance between PV [m]
a,b,a_1,b_1,c,d	Dimensions of the floor plan [m]
i	Minimum distance from the parapet [m]

Square and rectangle geometry of the roof (case A and B):

$$A_{PV,max} = \frac{b}{(L_1 + X_{min})} \cdot (a - 2i) \cdot L$$

Rectangle with a core empty space (case C):

$$A_{PV,max} = 2 \cdot \frac{b_1}{(L_1 + X_{min})} \cdot (a - 2i) \cdot L + 2 \cdot \frac{d}{(L_1 + X_{min})} \cdot (a_1 - 2i) \cdot L$$

Equation 5.5: $A_{PV,max}$ for PV mounting system on flat roof according to different geometries of the roof

CITY	LATITUDE [°]	α [°]	β [°]	L [m]	X_{min} [m]
Milano	45.62	20.80			2.23
Firenze	43.80	22.7			2.03
Roma	41.80	24.7	30	1.7	1.85
Napoli	40.85	25.65			1.77
Palermo	38.18	28.32			1.58

Table 5.7: Minimum distance between PV according to the cities analyzed

- $A_{PV,max}/A_{roof}$ ratio depends by location and not by the case. It goes from 45% to 55% with an increase at maximum of 10% from the coldest city to the hottest (Figure 5.74);
- in Palermo the same roof (ex. case A) produces the 43% more than in Milano; while there is no big difference between Roma and Napoli (they produce respectively the 17% and the 15% less than Palermo). In Firenze, it produces the 25% less than Palermo and the 17% more than in Milano (Figure 5.75);
- kilowatt-peak is between the range 32kWp and 43kWp for the case A and B (with the minimum value for Milano and the maximum for Palermo); while for the case C the range is between 94kWp and 129kWp (Figure 5.77);
- the result in terms of final energy[20] is that the high-rise building produces on roof around 5.7kWh/m^2 in Milano and 9.9kWh/m^2 in Palermo; while the low-rise building, that have the same volume, produces 15.6kWh/m^2 in Milano and 30.1kWh/m^2 in Palermo (Table 5.10).

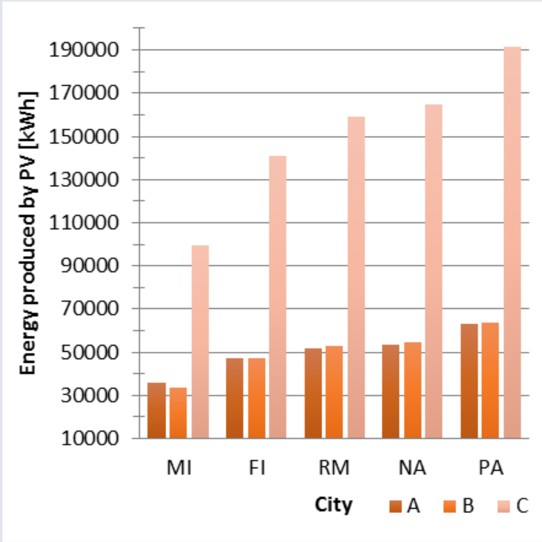


Figure 5.75: Energy produced by PV - All cases and cities

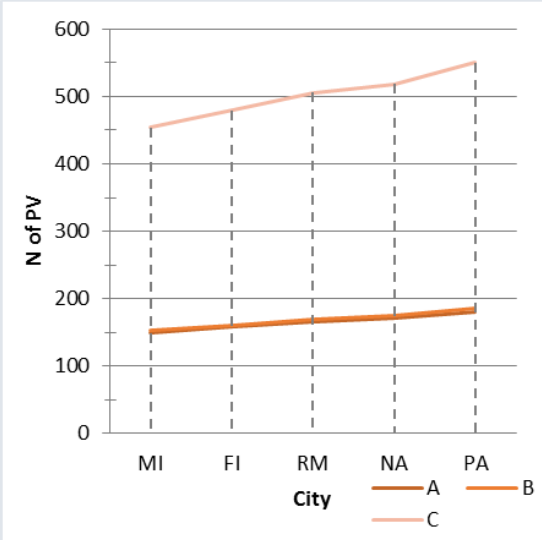


Figure 5.76: Number of PV panels - All cases and cities

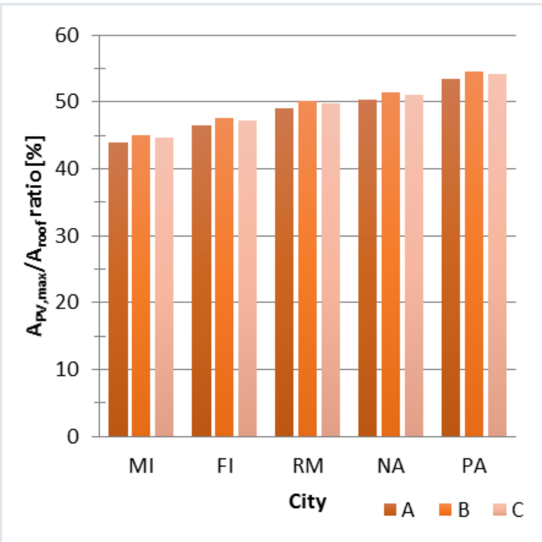


Figure 5.74: $A_{PV,max}/A_{roof}$ ratio - All cases and cities

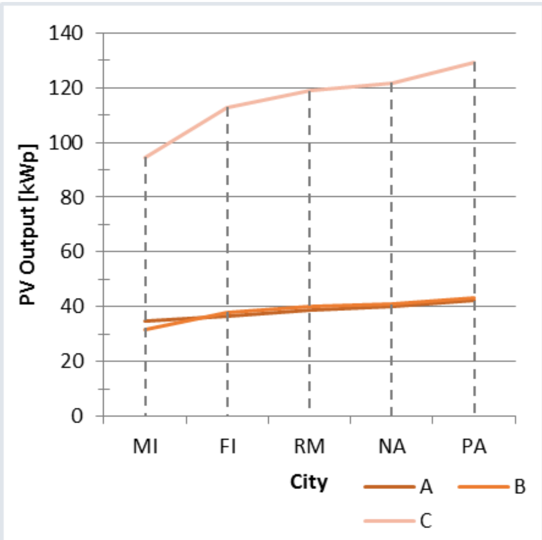


Figure 5.77: PV Output - All cases and cities

[20] kWh are divided for the total net area of the building. Specifically: $A_{net} = A_{gross} - 8\% \approx 6359m^2$ for the three cases.

5.4.1.2 SLOPED ROOF

Sloping the roof entails the possibility to integrate PV panels as component on the south-face oriented part (BIPV). The angle of PV, following the inclination of the roof (β equal to 30%≈17°), differs from the optimum one reached in mounting systems (β≈30°). On the other hand, this permits the exploitation of the area eliminating the minimum distance to maintain between panels. Hence, the number of panels is independent by the location (X_{min}=0 for all cities) and it depends only by the roof-geometry.
Equation 5.6 permits the easy calculation of the $A_{PV,max}$ according to various geometries of the roof (Figure 5.79). Specifically, choosing a pitched roof (case A.1 and B.1-B.2) implies a A_{PV}/A_{roof} ratio value of 50%, while hip roof (case A.2) A_{PV}/A_{roof} ratio of 25% (Figure 5.80).
Figures from 5.81 to 5.83 show the comparison of the results of PV disposed with the mounting system and PV integrated into the sloped roof. It appears evident how the second solution is more convenient: in fact, sloping just half roof means producing more energy.[21] This is valid for all the locations, except for the city of Palermo. In this city, the distance between PV allocated on the flat roof is the lowest for the high inclination of solar rays.
Anyway, the potential of BIPV is also increased by the economic subsidy.
An example is the new office for Marché International Support (Beat Kämpfen, Kemptthal ZH-CH, 2007, Figure 5.78). In such case, thin film modules are installed on the sloped roof with an angle of 12°. The system has an output of 44.6kWp, the covered surface is 485m² and the energy production is 40000 kWh/year [9].

5.4.1.3 CURVED ROOF

The design of a curved roof requires the application of thin film modules that are less performing than the crystalline one[22].
The relation is approximately:

$$\mathbf{A_{p.Si} = 2A_{a\text{-}Si}} \text{ for 1kWp}$$

Hence, if the will is the adoption of curved geometries for the roof, the area on top should be maximize.

Figure 5.78: Marchè International Support Office, Kemptthal (CH) **[9]**

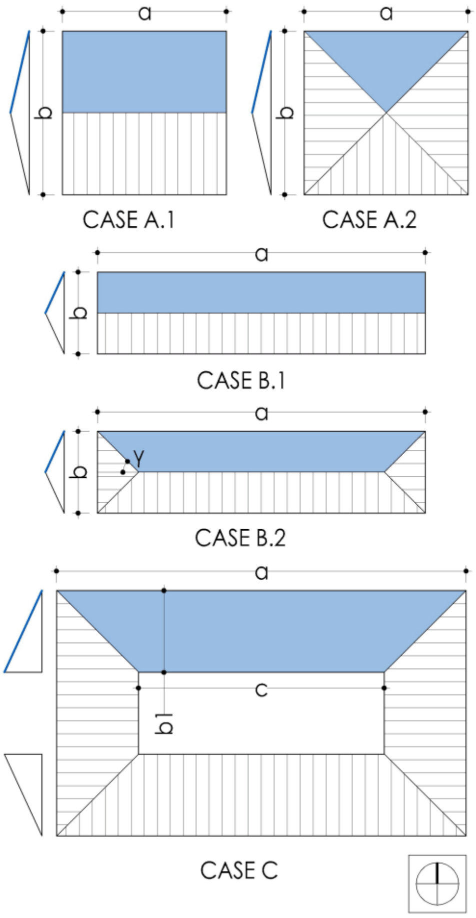


Figure 5.79: Various geometries of roof with PV

[21] Sloping the entire roof implies double the energy production. Despite, this solution could be not applicable in some cases since there would be an excessive waste of interior space (for instance, big depth of the building can influence the choice).

[22] Required PV module area for 1 kWp depending on type of solar cell, page 124 [13]:
Mono-Poly Cristallyne Silicon: 1kWp=6-8m²;
CIS = Copper Indium Selenide: 1kWp=8-12m²;
a-SI = Amorphous Silicon: 1kWp=12-16m².

CASE A.1 AND B.1:

$$A_{PV,max} = \frac{a \cdot b}{2cos\beta}$$

CASE A.2:

$$A_{PV,max} = \frac{a \cdot b}{4cos\beta}$$

CASE B.2:

$$A_{PV,max} = \frac{(2a - b \cdot tg\gamma) \cdot b}{4cos\beta}$$

(γ=45°)

CASE C:

$$A_{PV,max} = \frac{(a + c) \cdot b_1}{2cos\beta}$$

Equation 5.6: $A_{PV,max}$ for PV integrated in sloped roof according to different geometries of the roof

γ	Angle of the roof on horizontal plane [°]
β	Angle of the PV [°]
X_{min}	Minimum distance between PV [m]
a,b,c,d	Dimensions of the floor plan [m] (Figure 5.79)

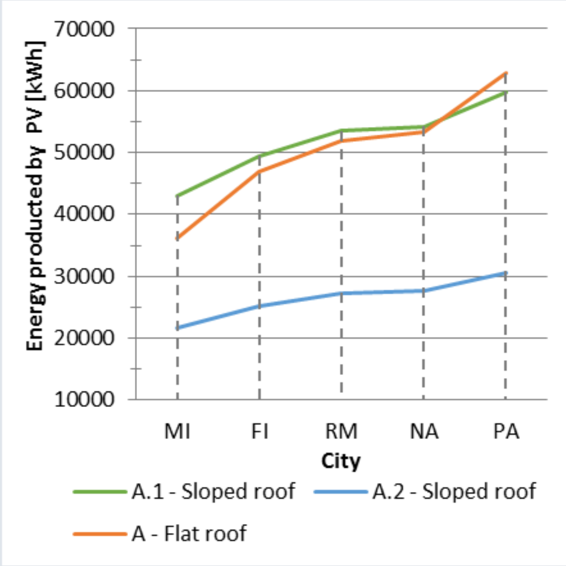


Figure 5.81: Energy produced by PV - Case A - All cities

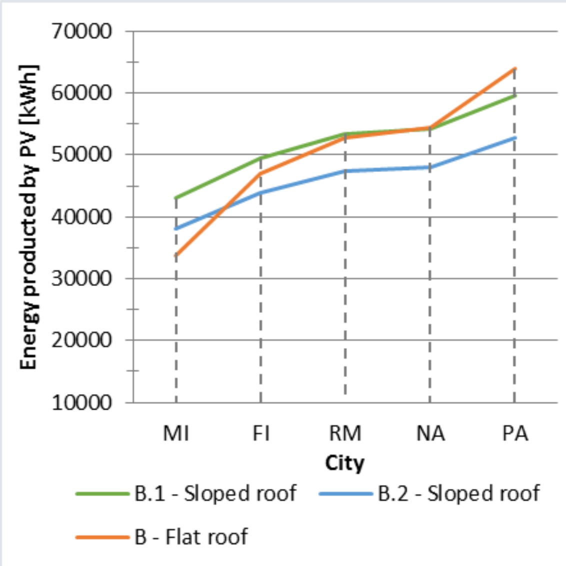


Figure 5.82: Energy produced by PV - Case B - All cities

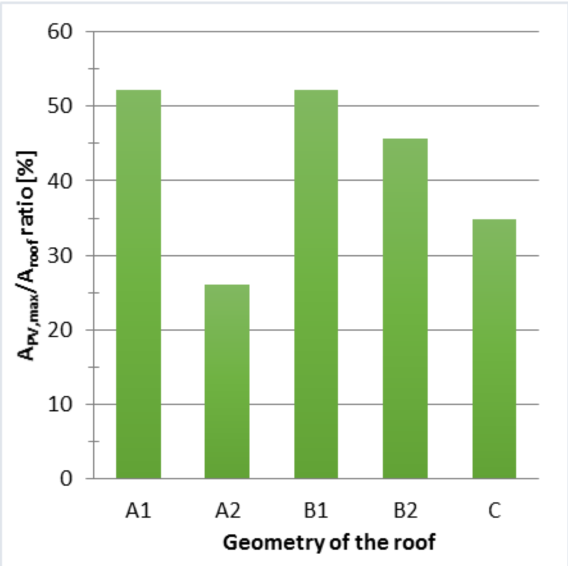


Figure 5.80: $A_{PV,max}/A_{roof}$ ratio - All cases and cities

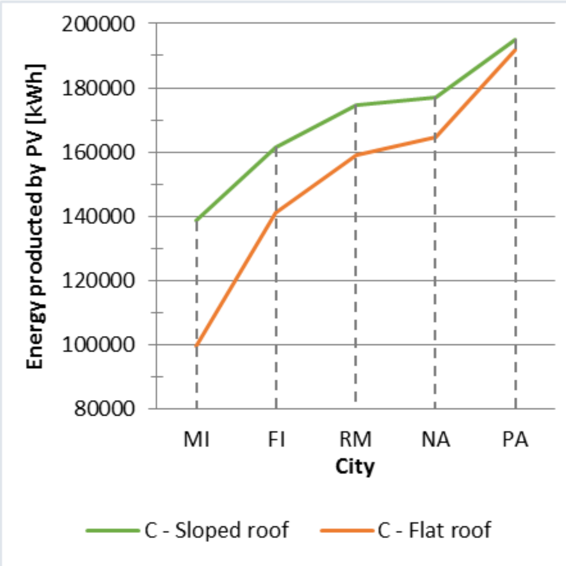


Figure 5.83: Energy produced by PV - Case C - All cities

5.4.2 FACADE

The integration into the façade south-oriented has high potential especially in high-rise buildings (Table 5.8).
In such case, the facade satisfies contemporary the typical recommendations for the design of the façade (ex. relation with wind loads, durability, water thigh) and of PV.
In correspondence to each office module, the facade should be divided into three horizontal and vertical strips. This in order to define:

- percentage of opaque, semi-transparent and transparent surfaces (Figure 5.84);
- position of openings and photovoltaic modules;
- relation with the structure;
- relation with the interior layout.

The thesis investigates only some solutions related to integration of photovoltaics on façade. The solutions are:

- PV integrated into the vertical façade (parameters: location, WWR, building shape);
- PV integrated into the façade that is sloped on its entirety (parameters: location, WWR, building shape);
- PV integrated into the parapet of the façade that is sloped of an angle (parameters: location, building shape, angle of PV).

EXAMPLES	- Ventilated façade; - Curtain wall; - Double skin façade.
ADV/DISADV	more surface available to dispose PV than roof; less performing than roof; optimization of the space;
DESIGN STRATEGY	sloping the entire façade if the building is low-rise; sloping just the parapet of the façade to improve the energy performance;

Table 5.8: Chart of PV on façade

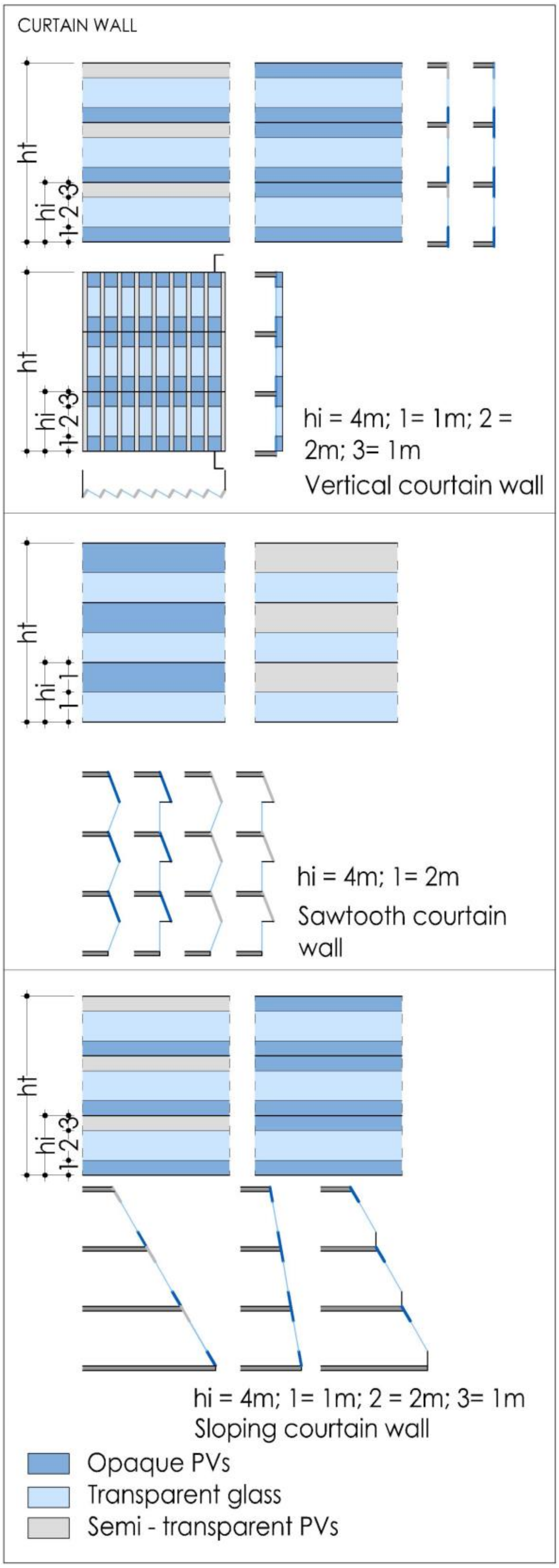


Figure 5.84: Sketch of PV integrated in the facade

5.4.2.1 VERTICAL FACADE

The location, the shape and the WWR are some of the factors that influence the positioning, the numbers and the performance of PV on vertical façade (Figure 5.85).
For instance, considering the three cases (A, B, C) with equal WWR, the number of PV is independent from the location and it depends only by the shape. Specifically, the B case is more recommended since it has the major numbers of panels for its big façade on south front. The relations for the numbers of panels and the cases are:

$$N_{PV,B}= 2N_{PV,A} \qquad N_{PV,C}=1.2N_{PV,A}$$

Figure 5.86 shows the results of the energy production for the three cases (South façade with $A_{PV,max}/A_{facade}$ ratio equal to 80% and WWR equal to 20%, Table 5.9). The energy produced increases from Milano to Palermo at maximum of the 21% for the three cases.
The B case have the highest values, while there is no a big difference between C and A.
The $A_{PV,max}/A_{facade}$ ratio depends by the WWR as following: $A_{PV,max}/A_{facade}$ ratio = 100-WWR.

5.4.2.2 SLOPED FACADE (ENTIRETY)

Sloping either the entire façade (Figure 5.87) or only a portion of it, means increasing the performance of the PV system. Specifically, in this paragraph, the entire south-façade of the three cases is sloped of an angle (θ) equal to 20° and PV with β equal to 70° (Equation 5.7).
Equation 5.7 permits the calculation of the number of panels for photovoltaics panels disposed on a sloped façade. Figure 5.88 shows the results in terms of energy produced for such solution for the three cases; while Figure 5.89 presents the results of PV systems integrated both in vertical and sloped facades (WWR equal to 20%). In such case, as expected, the second solution is more performing. For the case B, sloping the entire façade entails a gain of 30.7% to 35.0% (from Milano to Palermo). Anyway, this solution affect considerably the design of the building: for instance, the net area of the floor plan is reduced. Hence, sloping the entire south front is recommended for low-rise buildings.

Figure 5.85: Example of building with PV on the vertical façade, CIS Tower **[10]**

VERTICAL FAÇADE (θ=0°)	CASE A	CASE B	CASE C
A_{facade} [m²]	1152	2304	960
WWR [%]	**20**	**20**	**20**
$A_{PV,max}$ [m²]	922	1843	768
N_{PV}	576	1152	480
$A_{PV,max}/A_{facade}$ ratio [%]	80	80	80
WWR [%]	**60**	**60**	**60**
$A_{PVI,max}$ [m²]	461	922	384
N_{PV}	288	576	240
$A_{PVI,max}/A_{facade}$ ratio [%]	40	40	40

Table 5.9: A_{PV}/A_{facade} ratio and $A_{PV,max}$ varying WWR and cases - Vertical façade

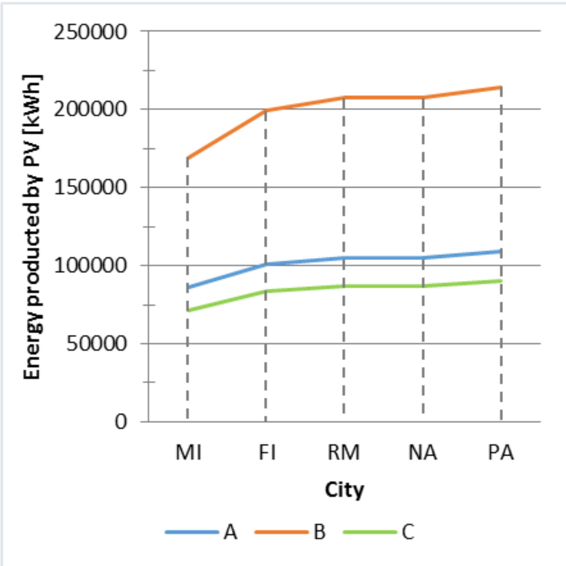


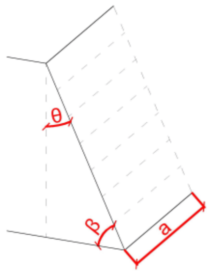
Figure 5.86: Energy produced by PV - All cases and cities (WWR=20% and $A_{PV,max}/A_{facade}$ ratio=80% - Vertical façade)

Figure 5.87: Example of BIPV into the sloped facade [11]

$$A_{facade} = a \cdot \frac{h}{cos\theta}$$

$$A_{PV,max} = A_{facade} - (WWR \cdot A_{facade})$$

a Length of the façade [m]
h Height of the façade [m]
θ Angle of the façade [°]
WWR Window-to-Wall Ratio [%]



Equation 5.7:
$A_{PV,max}$ for PV integrated in sloped facade

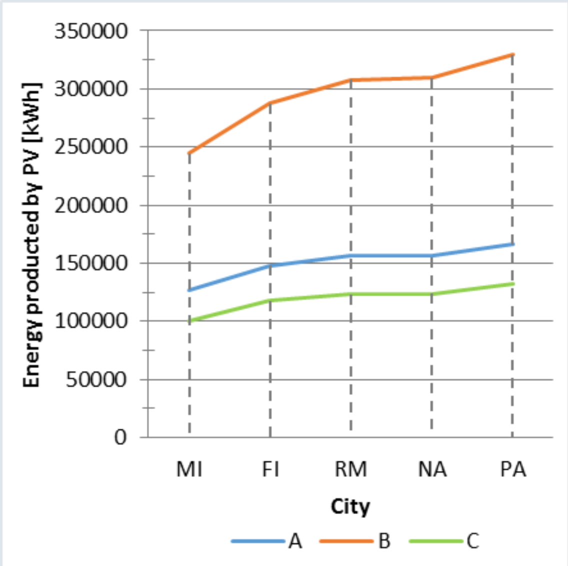


Figure 5.88: Energy produced by PV disposed on sloped façade with WWR=20%

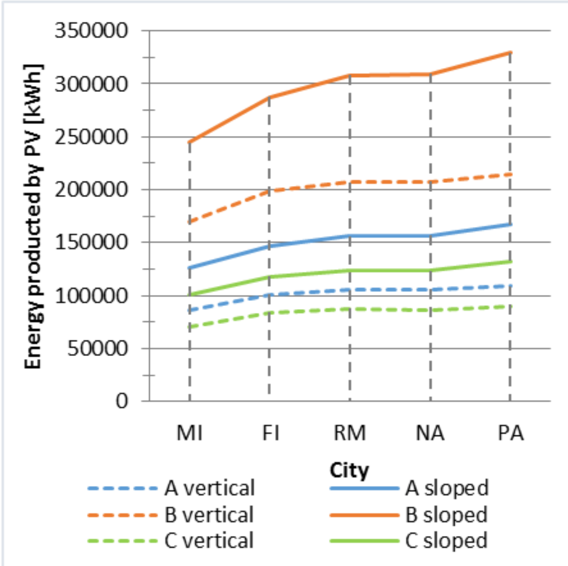


Figure 5.89: Comparison between the energy produced by PV into façade (vertical and sloped position)

5.4.2.3 PARTIALLY SLOPED FACADE

Sloping the parapet entails increasing the performance of the PV system and maintaining the verticality of the façade. In such way, the area of the floor plan is preserved for every level. In this solution, the facade is divided in two main strips: the lower part with integrated PV that constitutes the parapet and the upper part with transparent and opaque portions (WWR is maximum equal to 50%).
The strategy has also the advantage that the sloped PV naturally shadow (as overhang) the windows below (Figure 5.91).
Moreover, the same considerations on the minimum distance to maintain between panels have to be made in order to have no mutual shading (Figure 5.90).

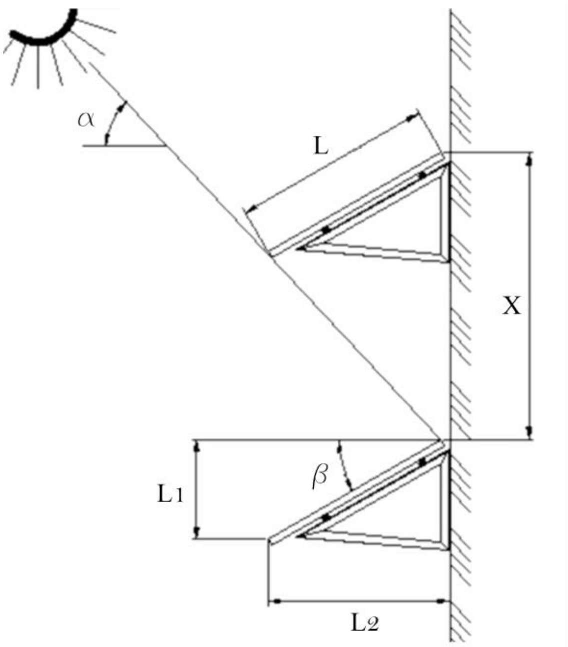


Figure 5.90: Sketch of the study for sloping just a part of the façade (the parapet)

Figure 5.92 shows the minimum distance to maintain between panels (X_{min}) varying the orientation of the panel (vertical or horizontal position) and the angle according to the location. Considering the acceptable floor-height, the good choice is the disposition of the panel vertically with an angle of β equal to 60°. In such case, A_{PV} depends by the length of the south front and the number of levels as following:

$$A_{PV,max} = a \cdot N_L \cdot L$$

a	Length of the façade [m]
N_L	Number of levels
L	Length of the PV [m]

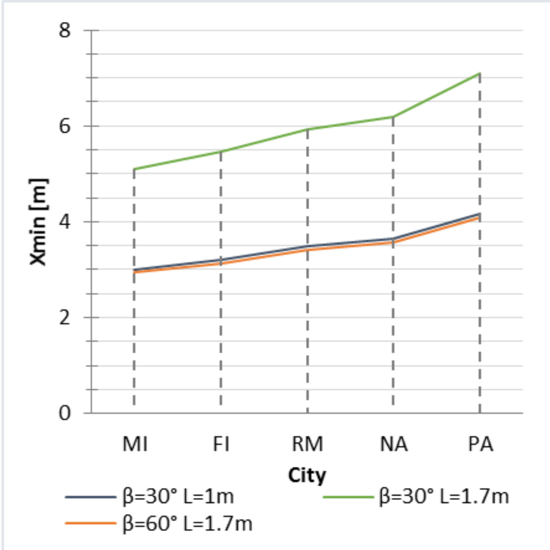


Figure 5.92: X_{min} according to the location

Figure 5.93 presents the results in terms of energy for the three cases.

Figure 5.91: Example of sloped parapet with PV **[11]**

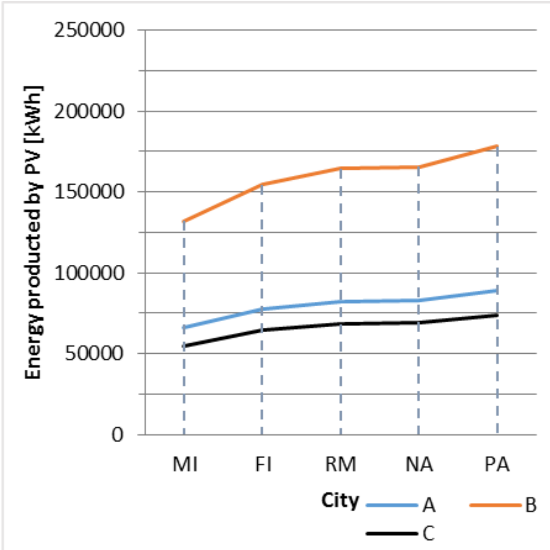


Figure 5.93: Energy produced by PV on the sloped parapet

CASE	CITY	ROOF Flat	ROOF Sloped	FAÇADE (SOUTH) Vertical	FAÇADE (SOUTH) Sloped	FAÇADE (SOUTH) Sloped
A	Milano	5.7	6.8	13.6	19.9	10.4
	Firenze	7.4	7.8	15.9	23.2	12.2
	Roma	8.2	8.4	16.6	24.6	12.9
	Napoli	8.4	8.5	16.5	24.7	13.0
	Palermo	9.9	9.4	17.1	26.3	14.0
B	Milano	5.3	6.8	26.6	38.5	20.8
	Firenze	7.4	7.8	31.4	45.2	24.3
	Roma	8.3	8.4	32.7	48.4	25.9
	Napoli	8.6	8.5	32.6	48.7	26.0
	Palermo	10.0	9.4	33.7	51.8	28.0
C	Milano	15.6	21.8	11.2	15.8	8.7
	Firenze	22.2	25.4	13.2	18.5	10.1
	Roma	25.0	27.5	13.7	19.4	10.8
	Napoli	25.9	27.9	13.7	19.5	10.9
	Palermo	30.1	30.7	14.1	20.8	11.7

Table 5.10: Summary of results in terms of Final Energy Demand [kWh/m²a] - All cases and cities

5.5 ENERGY EFFICIENT BUILDINGS

This paragraph shows the application of the previous considerations through the presentation of some examples.
These buildings constitute just an exemplification since many are the combinations of the parameters analyzed.
In addition, the examples do not want to be a "must" to follow because the design process has to be carried on also by a component of creativity that permits to obtain an original building.
The previous paragraphs have explained some ways to save energy (Paragraph from 5.1 to 5.3) and to produce it (Paragraph 5.4). Despite, to reach the goal Net Zero or looking towards the EnergyPLUS, other additional measures could be adopted. For examples, lighting and appliances demands can be further reduced both through the adoption of more efficient equipment and trough the installation of sensors. Specifically, for the last tranche of the energy simulations, these considerations are followed:

- use of high performance T8 lamps and electronic ballasts. In such way, the light power density (LPD) for office spaces is considered to be equal to 8W/m^2 ;[23]
- use of ENERGY STAR–rated equipment. Table 5-6 of ASHRAE Guidebook [12] demonstrates a reduction of 30% adopting advanced equipment instead the basic one.[24] Hence, a minor value equal to 6W/m^2 is adopted for all cases;
- automatic daylight harvesting controls and occupancy sensors that regulate when daylight and users are present (Light On/Off).

5.5.1 EXAMPLES

Considering five different locations and all the previous qualitative and quantitative recommendations, some examples are presented. For the definition of them, it has been applied both passive and active strategies analyzed. Moreover, it is tried to choose the solutions that both minimize the energy and find a compromise between costs, technical and technological feasibility, etc.
The design criteria adopted are briefly summarized in the Paragraph with also the results.

Milano:

The case adopted is the B one (high-rise building with a linear shape). This occurs since a tall building well insert into the urban pattern (ex. Isozaki tower) and in combination with the reversible heat pump ("System 2") it has a better energy performance for the predominance of heating demand in the city (Paragraph 4.3). Hence, the optimum thickness of the insulation material that meets a cost convenience is equal to 10cm (Table 5.3).
Windows are avoided on small fronts West/East oriented (WWR equal to 0%). This is made because the linear shape entails two main facades North/South facing that, with their openings (WWR on North equal to 40% WWR on South equal to 60%), guarantee already adequate daylighting. In addition, no transparencies on West/East sides permit a better thermal insulation thanks the lower U-value of the opaque part.
The use of high performing glass more than the adoption of exterior shading devices is privileged. This because the high-rise type generally avoids exterior shading devices (for wind loads, etc.) and is lower the investment and maintenance costs. Despite, to guarantee good level of daylighting and to protect from glare, it is recommend the use of interior

[23] ASHRAE [12] suggests as average value for the entire building LPD=0.75W/ft^2≈8W/m^2; while for corridors LPD=0.5W/ft^2 ≈ 5.4W/m^2.

[24] Instead 0.75W/ft^2 (≈8W/m^2) is adopted 0.55W/ft^2 (≈5.9W/m^2). They are average values distributed on a medium office building of 53600ft^2.

shading devices, easier to control and to maintain.

Natural ventilation is introduced during summer nights and mid seasons days with an intermediate value of air exchange rate (ACH equal to 5 1/h), in order to not increase heating demand also in relation to the importance of the North-front.

In addition, PV are integrated into the entire sloped roof (the building depth is contained) and into the South vertical façade (A_{PV}/A_{facade} ratio in equal to 40%) that is a long front.

Table 5.11 shows the summary of the previous considerations, Figure 5.94 the sketches of the variation of the two buildings; while Figures 5.96 and 5.97 present the results in terms of Q_U and Q_P demands.

The results show how cooling, lighting and appliance are diminished in comparison to the Base Case (left side) while heating demand is increased. This occurs for the use of huger glass surfaces that reduce the average U-value of fronts.

Anyway, the primary energy demand (Q_P) is reduced from 180.8kWh/m^{2}a to 119.6kWh/m^{2}a and, thanks to the electricity production equal to 81 kWh/m^{2}a, the building has a total primary energy equal to 38.6kWh/m^{2}a. Hence, the energy is reduced of the 77.6%.

Firenze:

The case is the B in combination with "System 2" as for Milano since it is more convenient in terms of energy saving.

The optimum insulation thickness is 8cm.

For the transparent envelope, it is adopted the recommended WWR equal to 40% combined with the GT2 in order to meet a compromise between costs and energy efficiency (except for the South front where GT3 is used).

For the same reason as in Milano, no exterior shading devices are introduced (but it has been required the adoption of the interior ones).

In order to cool the spaces, NC and NV during mid seasons are combined with ACH equal to 8 1/h.

PV are integrated into the sloped roof and in the vertical façade with A_{PV}/A_{facade} ratio of 60%.

Table 5.12 shows the summary of the previous considerations, while Figures 5.98 and 5.99 present the results in terms of useful and primary energy demands. Comparing to the base case, the advanced one has a primary energy of 14.9kWh/m^{2}a (with 85.3kWh/m^{2}a produced by PV) with a reduction of the 91.4% comparing to the base case.

MILANO	
Case	B;
Opaque part	10cm;
Transparent part	N: WWR=40% + GT2; W: WWR=0%; S: WWR=60% + GT3; E: WWR=0%;
HVAC	"System 2"; NC+NV midseason; ACH=5 1/h;
PV	Roof: Entire sloped roof; Façade: A_{PV}/A_{facade}=40%;

Table 5.11: Summary of design choices for Milano

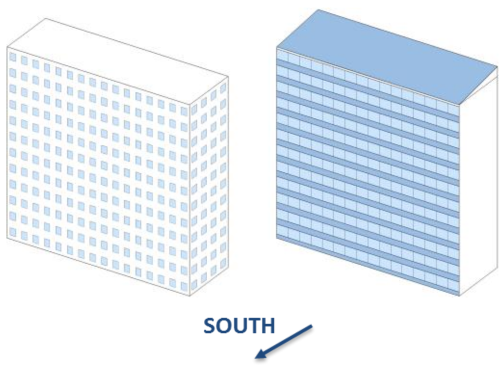


Figure 5.94: Sketch with the two buildings: the base case and the energy efficient case in Milano

FIRENZE	
Case	B;
Opaque part	8cm;
Transparent part	N: WWR=40% + GT2; W: WWR=40% + GT2; S: WWR=40% + GT3; E: WWR=40% + GT2;
HVAC	"System 2"; NC + NV midseason; ACH = 8 1/h;
PV	Roof: Entire sloped roof; Façade: A_{PV}/A_{facade}=60%;

Table 5.12: Summary of design choices for Firenze

Roma:

The low-rise type (case C) is preferred because it appears the most energy efficient in combination with the reversible heat pump ("System 2") and it does not represent a contrast with the recurring and traditional shape, typical of the buildings in such city. Hence, the optimum thickness of the insulation layer is 7cm. Many fronts (court included) have the WWR equal to 40% combined with the GT3 (only the North side is combined with GT2) with no exterior sun shading elements to reduce costs. The South side is different with a WWR equal to 60%.

Despite, to reduce overheating, night and day natural ventilation is permitted with an ACH equal to 10 1/h.

In addition, PV are allocated on the flat roof with a mounting system because the court shape bad-faces with sloped roof, the surface on top is generally quite big and the façade can also allocate modules (vertical facade with A_{PV}/A_{facade} ratio equal to 40%). Table 5.13 shows the summary of the design choices. The results are presented on Figures 5.100 and 5.101. It is possible to observe how the primary energy demand of the advanced case is 13.2kWh/m^{2}a (69.4kWh/m^{2}a from PV system) with an energy saving of 91.6%.

ROMA	
Case	C
Opaque part	7cm
Transparent part	N: WWR=40% + GT2; W: WWR=40% + GT3; S: WWR=60% + GT3; E: WWR=40% + GT3; Court N,W,S,E: WWR=40% + GT3.
HVAC	"System 2"; NC + NV midseason; ACH=10 1/h;
PV	Roof: Mounting system; Façade: $A_{PV}/A_{façade}$ =40%;

Table 5.13: Summary of design choices for Roma

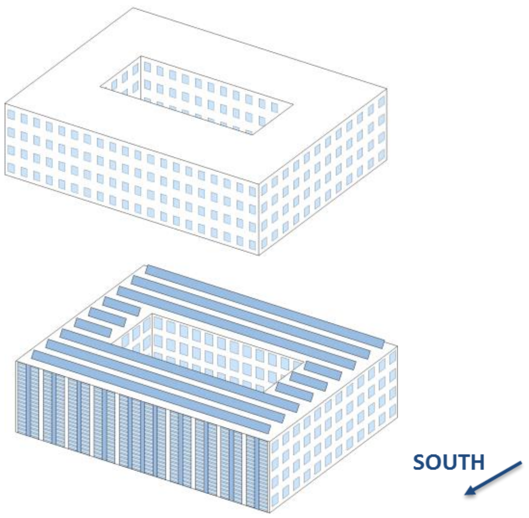


Figure 5.95: Sketch with the two buildings: the base case and the energy efficient case in Napoli

Napoli:

The case C is preferred in combination with "System 2". The optimum thickness for the insulation layer is 7cm. For the longest fronts (North and South) a WWR equal to 80% is used in combination with GT3 (for the South also horizontal blinds are introduced); while for the court is used a WWR equal to 40% with the GT3. As in Rome, the ACH is 10 1/h. PV are allocated on the flat roof and into the vertical facade with A_{PV}/A_{facade} ratio equal to 20%.

Figures 5.102 and 5.103 show the results where the advanced case has a primary energy demand of 3.5kWh/m^{2}a with an energy saving of 97.8%; while Figure 5.95 shows the sketches of the two buildings.

NAPOLI	
Case	C
Opaque part	7cm;
Transparent part	N: WWR=70% + GT3; W: WWR=30% + GT3; S: WWR=70% + GT3 + HHB; E: WWR=30% + GT3; Court: N,W,S,E=40% + GT3.
HVAC	"System 2"; NC + NV midseason; ACH=10 1/h
PV	Roof=Mounting system; Façade: A_{PV}/A_{facade} =30%;

Table 5.14: Summary of design choices for Napoli

Palermo:

The case C is chosen in combination with "System 1"; therefore, the optimum thickness for the insulation layer is 6cm. Big transparencies are adopted with shading devices and specifically: North and South fronts have respectively WWR equal to 70% and to 80% with GT3. South façade has in addition horizontal blinds with high reflectance. The court has WWR equal to 40% combined with GT3 as the West and East sides. As in other cities, the NC is combined with NV during midseason with ACH of 10 1/h. PV are allocated on the flat roof and into the vertical façade with A_{PV}/A_{facade} ratio of 20%. The results (Figures 5.104 and 5.105) show the reduction of the primary energy demand of 98.1%.

PALERMO	
Case	C
Opaque part	6cm
Transparent part	N: WWR=70% + GT3; W: WWR=40% + GT3; S: WWR=80% + GT3 + HHB; E: WWR=40% + GT3; Court: N,W,S,E=40% + GT3.
HVAC	"System 1" NC + NV midseason; ACH=10 1/h
PV	Roof=Mounting system; Façade: A_{PV}/A_{facade} =20%;

Table 5.15: Summary of design choices for Palermo

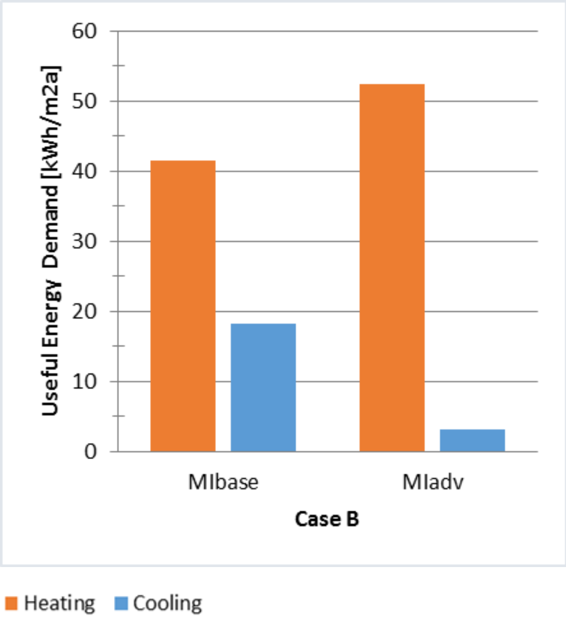


Figure 5.96: Useful Energy Demand - Comparison between the Base case and the Advanced case - Milano - "System 2"

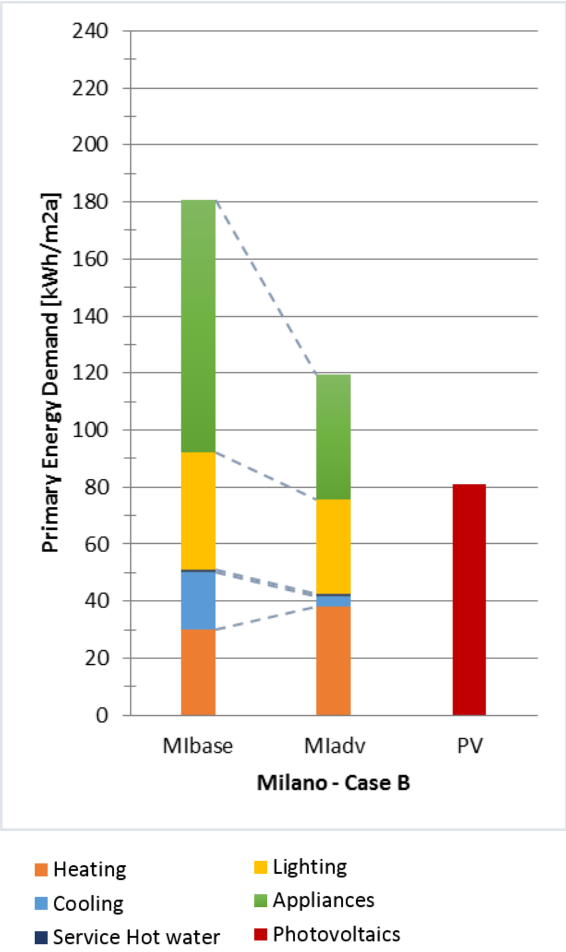


Figure 5.97: Primary Energy Demand - Comparison between Base case and Advanced case - Milano - "System 2"

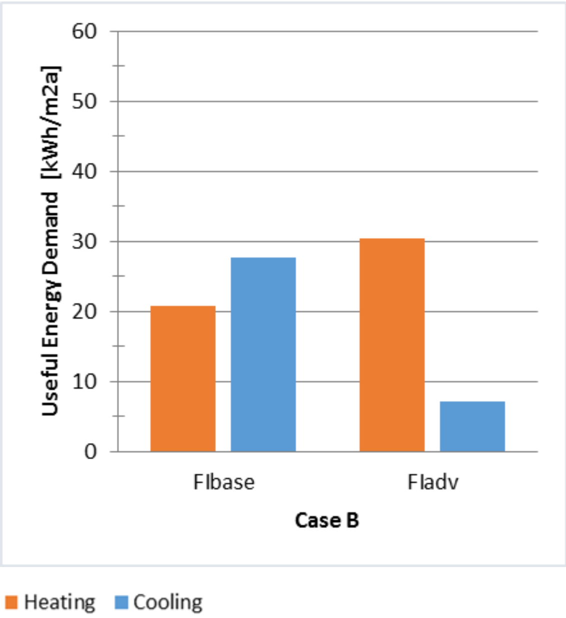


Figure 5.98: Useful Energy Demand - Comparison between the Base case and the Advanced case - Firenze - “System 2”

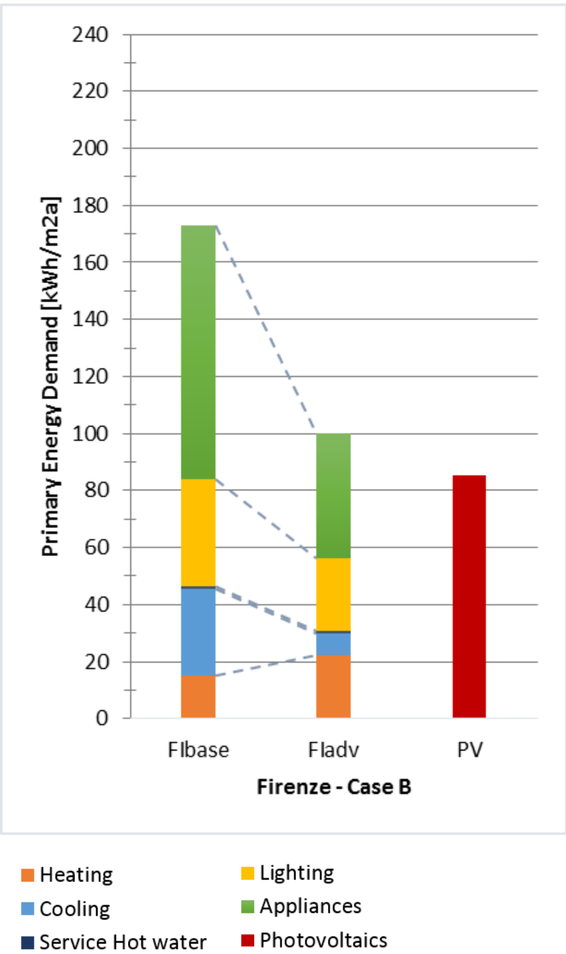


Figure 5.99: Primary Energy Demand - Comparison between Base case and Advanced case - Firenze - “System 2”

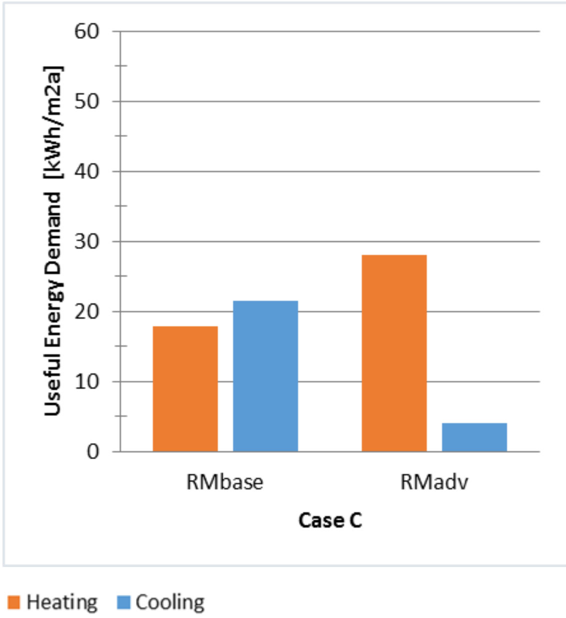


Figure 5.100: Useful Energy Demand - Comparison between the Base case and the Advanced case - Roma - “System 2”

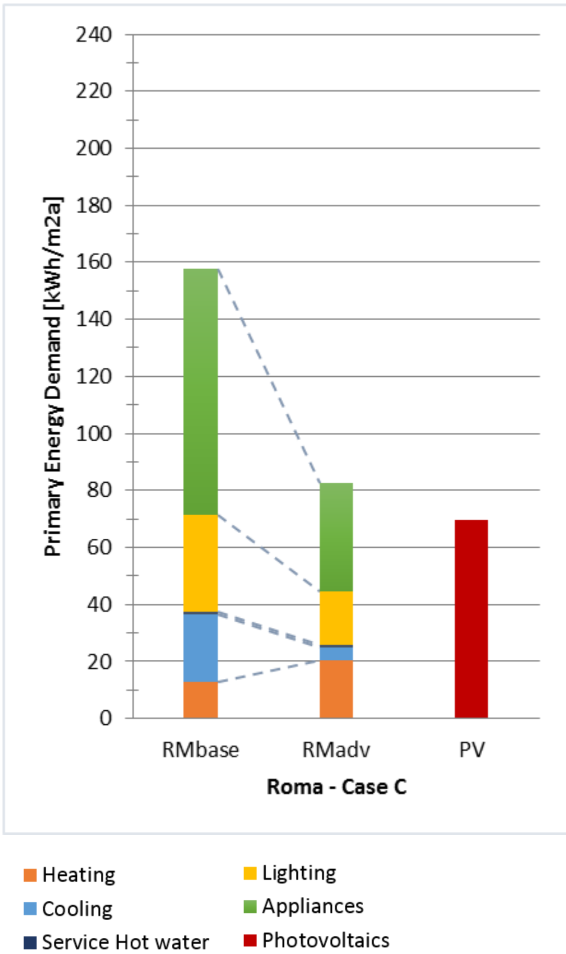


Figure 5.101: Primary Energy Demand - Comparison between Base case and Advanced case - Roma - “System 2”

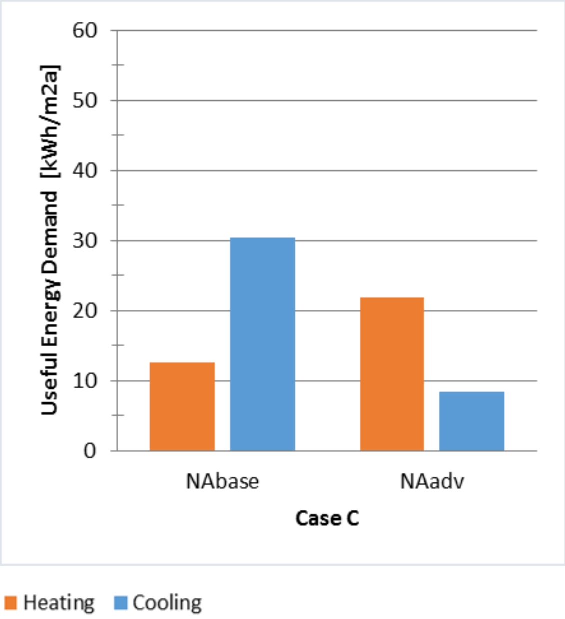


Figure 5.102: Useful Energy Demand - Comparison between the Base case and the Advanced case - Napoli - “System 2”

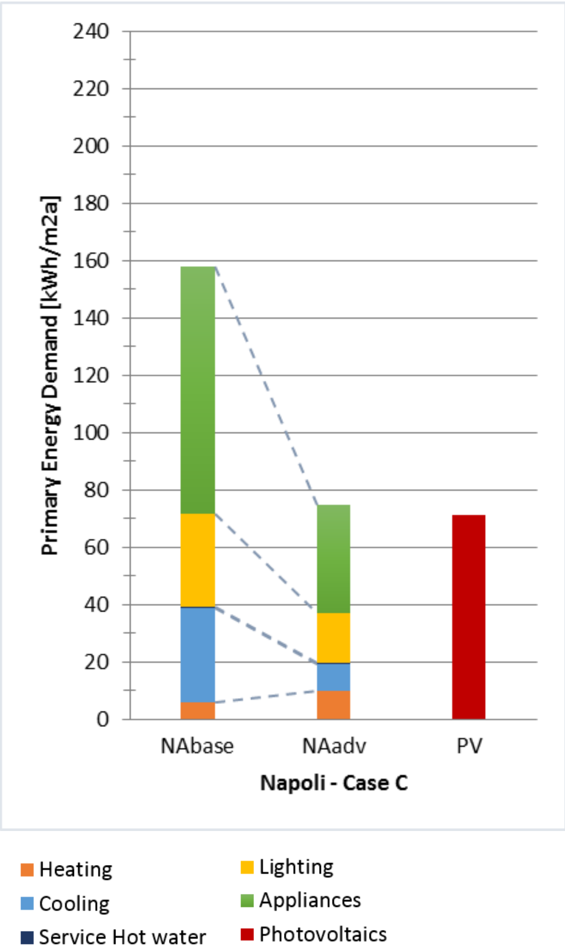


Figure 5.103: Primary Energy Demand - Comparison between Base case and Advanced case - Napoli - “System 2”

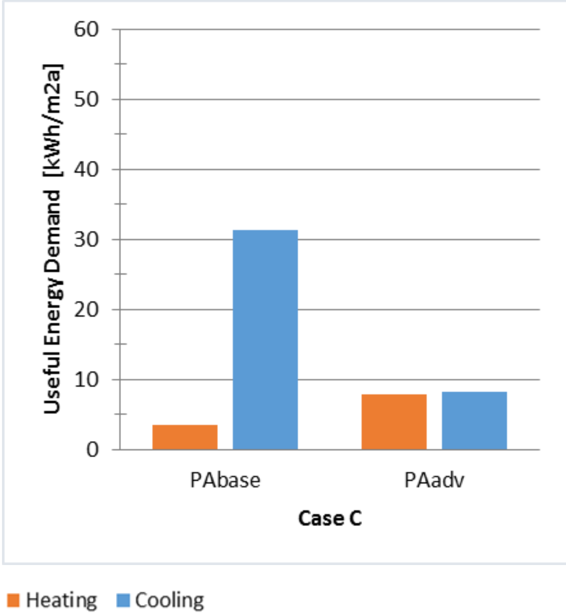


Figure 5.104: Useful Energy Demand - Comparison between the Base case and the Advanced case - Palermo - “System 1”

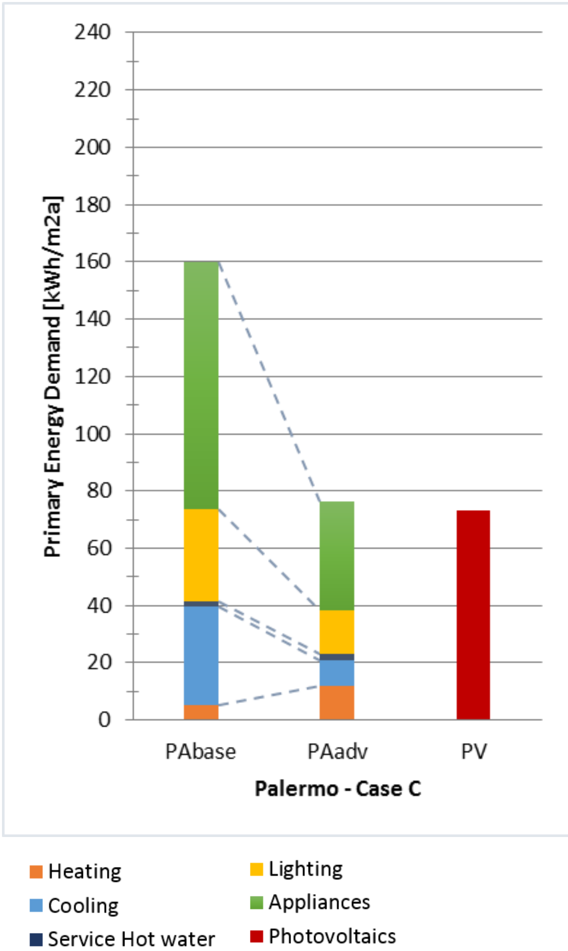


Figure 5.105: Primary Energy Demand - Comparison between Base case and Advanced case - Palermo - “System 1”

REFERENCES

1. **ZHU, P.** *Energy Efficient Multi-story Residential Buildings in China.* Braunschweig, PhD thesis, Supervisors: Univ. Prof. Dr. -Ing. M. N. Fisch, 2014.

2. **COMAKLI, K. and YUKSEL, B.** *Optimum insulation thickness of external walls.* Applied Thermal Engineering 23, Elsevier, pag. 473–479, 2003.

3. **www.climateconsulting.it.** [Online]

4. **CTI,** (Comitato Termotecnico Italiano Energia e Ambiente). **www.cti2000.it.** [Online]

5. **UNI10339:1995.** *Impianti aeraulici a fini di benessere - Generalità, classificazione e requisiti.* 1995.

6. **AKLAN, A.** *Design of Low Energy Office buildings in Yemen.* Braunschweig, PhD thesis, Supervisors: Univ. Prof. Dr. -Ing. M. N. Fisch, Prof. P. Krusche, Der Andere Verlag, 2012.

7. **UNITS11300-1:2008.** *Prestazioni Energergetiche degli edifici. Parte I.* 2008.

8. **www.bp.com.** [Online]

9. **www.bipv.ch.** [Online]

10. **www.tritec-energy.com.** [Online]

11. **www.en.wikipedia.org.** [Online]

12. **www.cifgroup.it.** [Online]

13. **ASHRAE.** *Advanced Energy Design Guide for Small to Medium Office Buildings. Achieving 50% Energy Saving Toward a Net Zero Energy Building.* 2011.

14. **FISCH, M. N., WILKEN, T. and STAEHR, C.** *EnergyPlus.* Leonberg, Univ. Prof. Dr. -Ing. M. Norbert Fisch, 2013, ISBN:978-3-00-041246-2.

15. **DEI,** *Prezzi informativi dell'edilizia. Recupero Ristrutturazione Manutenzione.* Tipografia del GenioCivile, DEI, Aprile 2012.

16. **www.dowxenergy.eu.** [Online]

17. **RONCHI, E., BARBABELLA, A. and REFRIGERI, L.** *I costi dell'Energia in Italia.* Roma, Fondazione per lo sviluppo sostenibile, 2013.

18. **D.P.R. 26/08/1993, n.412.** *Regolamento recante norme per la progettazione, l'installazione, l'esercizio e la manutenzione degli impianti termici degli edifici ai fini del contenimento dei consumi di energia, in attuazione dell'art. 4, comma 4, della legge 9 gennaio 1991, n.10.*

19. **D.Lgs. 29/12/2006, n.311.** *Disposizioni correttive ed integrative al decreto legislativo 19 agosto 2005, n. 192, recante attuazione della direttiva 2002/91/CE, relativa al rendimento energetico nell'edilizia.* Gazzetta Ufficiale n. 26, 1 febbraio 2007, Supplemento ordinario n. 26/L.

6. SUMMARY AND CONCLUSION

The research investigates design criteria for energy efficient office buildings in Italy giving qualitative and quantitative recommendations in order to guide designers at an early stage of the design process.
The thesis is structured in five chapters briefly summarized in the following:

CHAPTER 1: The Chapter introduces the field of interest, the aim and the methodology of the research. It underlines the urgency of actions on themes such as Nearly Zero Energy Building imposed by the deadlines (2018 for new public buildings and 2020 for all new ones) of the European Union. In addition, it shows the importance of adopting a multidisciplinary approach that considers the energy performance since the early design phase.

CHAPTER 2: The Chapter summarizes the literature review. It shows the terminology; some international studies that follow various approaches in order to reach the low-energy goal; an example of design guidebook made by ASHRAE for USA; some passive and active recurring strategies for the design of sustainable buildings.
This Chapter demonstrates how different approaches to the problem exist without a univocal way for the definition of high performance buildings.

CHAPTER 3: The Chapter analyses some offices that are located in Europe as examples.
Sheets of analysis and a summary with some design criteria (qualitative recommendations) are presented according to the macro-classification into low-rise buildings with a wide floorplan and high-rise buildings with a narrow floorplan. For every example, design strategies and technological solutions are made on evidence together with a list of goals in order to understand how different design teams have reached same goals.

CHAPTER 4: The Chapter shows the energy performances of three base cases (A, B and C) in five cities (Milano, Firenze, Roma, Napoli and Palermo) representatives of the Italian climate.
The features of cases have been defined trough the analyses of both literature review and examples (previous chapters).
Cases A and B are high-rise buildings differing only for the geometry of the floor plan; while the case C is a low-rise building with a core atrium.
In this part, only shape and type of system are varied. In fact, cases have same volume, total area, building features, internal loads, etc.
The systems adopted are two: the first one is a condensing gas boiler with an air conditioning system (System 1); while the second one is a reversible heat pump (System 2).

CHAPTER 5: The Chapter presents in the first part (Paragraphs from 5.1 to 5.4) some parametric studies; while in the second part (Paragraph 5.5) some examples of energy efficient office buildings (one for each city) obtained applying the optimized parameters to one of the base cases defined in Chapter 4. This is made in order to demonstrate the effectiveness of the recommendations. Specifically, parametric studies involve the following aspects:

- <u>the optimum thickness of the thermal insulation layer of the external wall</u> (Paragraph 5.1) finding a balance between the annuity of investment for thermal insulation layer and the real costs of space heating and cooling (minimization of the equation of costs varying the location and the type of system);
- <u>the optimum window design</u> (Paragraph 5.2) in relation to the Window-to-Wall Ratio, the glazing type, the shading devices, the orientation, the location and the type of system. The results are summarized in

tables and graphics that demonstrate the influence of the variation of the parameters on the energy demand and give recommendations easy to consult for designers;

- the adoption of hybrid ventilation (Paragraph 5.3) aimed at reducing cooling demand. Natural ventilation is firstly introduced during summer nights; secondly, during both summer nights and working hours of the mid-seasons. The air change rate is varied for all the cities;
- the potential of photovoltaics in order to cover the electricity need of the building (Paragraph 5.4). The parameters of this part are location and shape. Specifically, the second one entails the variation of either the shape of the entire building (the shape of the three base cases) and of some parts of the envelope (various morphology of roof and façade). For instance, flat roof with mounting PV system; PV integrated into sloped roof; PV integrated into vertical façade or into sloped façade. The energy output are in terms of PV output, energy produced, annual yield and final energy. The results show the high potential of such solutions and present how different design choices can affect the energy performance.

The main recommendations for the design of energy efficient offices in Italy are briefly summarized in the following:

- IN RELATION TO THE BUILDING COMPLEX

- stand-alone position of the building for a better control of the solar radiation;
- car parks on basement to reduce the heat island effect;
- North/South orientation of the main front with offices;
- adoption of paving materials with high reflectance coefficients to reduce overheating in summer;
- maximization of green areas and adoption of local plants that have less water need;
- promotion of public transports through either new bus lines or tube lines, low-emission and electric cars through car parks dedicated and new pedestrian and bike routes;
- etc.

- IN RELATION TO THE BUILDING TYPE

- in low-rise buildings with a wide floor plan, the creation of a core atrium, involving the height of the entire block, appears to be one of the main recurring strategy (Paragraph 3.3.6.1) and it is recommended in order to improve daylighting and natural ventilation. A wide range of technical and technological solutions characterizes such buildings as also many passive and active strategies can be applied. For example: thermal mass (ex. ceiling or interior partitions made by concrete directly exposed to solar radiation); double skin facades positioned on South front; night cooling trough specific openings; exterior and interior shading devices; photovoltaics positioned on the top of the roof and integrated into the transparent roof of the atrium with a shed shape;
- in high-rise buildings with a narrow floor plan, the exploitation of wind forces is overriding and drives many design solutions (ex. orientation and envelope technology). Transparent facades with high performance glazing are common, generally with interior shading device (ex. blinds into the cavity of the double skin facades). Other recurring strategies are thermal mass (ex. exposed concrete ceiling); buffer spaces (ex. created by double skin facades or sunspaces disposed helicoidally along the perimeter of the building); photovoltaics integrated into both the south-facade and the sloped roof.

- IN RELATION TO THE BUILDING

- best orientation of offices approximately North/South while vertical connections and service spaces preferably disposed on West, East, North sides or in core position;
- depth of the building between 12m and 13m to permit daylighting and cross ventilation (internal layout with double strip of offices and central corridor);
- the variation of the shape (Paragraph 4.3) affects the primary energy demand at maximum between 4% and 5% (maximum value 10kWh/m^{2}a). Specifically, the high-rise building with the linear shape (case B) is preferable in Milano and Firenze; while the low-rise building with the core atrium (case C) is preferable in Roma, Napoli and Palermo. Despite, the influence of the shape on the energy demand is further reduced when the reversible heat pump is applied;
- the adoption of the heat pump entails the reduction of the heating demand if compared with the condensing gas boiler (Paragraph 4.3). In such case, the maximum energy saving is in Milano where the primary energy demand is reduced of the 17% (approximately 39kWh/m^{2}a). Hence, it is strongly recommended the adoption of such solution especially for the cities where heating is important (ex. Milano, Firenze and Roma). Despite, the reversible heat pump should have a huge potential also in hot cities according to the possible integration with renewables (ex. free cooling);
- the optimum thicknesses of the thermal layer minimizes costs and it depends by the type of system and the energy source adopted (Paragraph 5.1). Specifically, when there are the condensing gas boiler and the air conditioning system, the optimum thicknesses are approximately for Milano 12cm; Firenze 10cm; Roma 9cm; Napoli 8cm and Palermo 7cm. If the reversible heat pump is used, the thicknesses should be reduced. Despite, in such case, the following thicknesses are suggested: in Milano 10cm, Firenze 8cm, Roma 7cm, Napoli 7cm and in Palermo 6cm;
- it is important the diversification of the transparent part according to the orientation in terms of Window-to-Wall Ratio, glazing type and shading devices. From the results (Paragraph 5.2), it is possible to underline how for all Italian cities, the most critical fronts are South, West and East with the main problem of controlling the increasing of the cooling demand. For such reason, glasses need values of visible transmittance higher than 0.45 (in order to reduce the use of artificial lighting) and should be medium (Solar Heat Gain Coefficient approximately equal to 0.4) or, preferably, high spectral selective (Solar Heat Gain Coefficient between 0.27 and 0.24).

  The optimum windows design depends by the type of glass, the Window-to-Wall Ratio, the type of shading devices and the type of system. Specifically, the variation of the system (condensing gas boiler versus heat pump) affects the window design in the cities where heating demand is predominant (ex. Milano). In fact, in such case, the reversible heat pump permits to increase the Window-to-Wall Ratio (more than 40%), for all orientations, since the heating demand is strongly reduced. For instance, big transparencies should be adopted on North front, for the cities of Milano, Firenze and Roma, adopting the heat pump and glasses with low U-values (minor of 1.4W/m^{2}K).

  When Window-to-Wall Ratio is major or equal to 40%, for East, West and South fronts, high selective glasses are necessary mainly in all cities, providing interior shading devices to protect from glare. Otherwise, either medium selective or basic glasses should be combined with exterior shading devices. In such case, exterior horizontal blinds (for the South fronts) and vertical blinds (for East and West sides) are the most recommended with a high reflectance index equal to 0.8.

  If the Window-to-Wall Ratio is more than 60% and 70%, it is strongly recommendable the adoption of high selective glass with exterior blinds for South, West and East fronts in all cities but especially in Napoli and Palermo;

- natural ventilation has a high potential for cooling the interior spaces and the benefits increase from Milano to Palermo (Paragraph 5.3).
  This should be made combining mechanical ventilation with natural one (hybrid ventilation) using the natural ventilation during both summer nights and working hours of the midseason. Specifically, it is strongly recommended for all cities the air change rate between 5 1/h and 10 1/h. The air change rate should be preferably 5 1/h for the city of Milano;
- photovoltaics integrated into the building are fundamental especially for offices where electricity needs are important and for the Italian territory where their energy potential is high (Paragraph 5.4). For instance, the annual yield in Milano is approximately equal to 1040kWh/kWp and in Palermo is 1480kWh/kWp. In addition, the example of energy efficient office building in Napoli (Paragraph 5.5) shows that PV modules cover the 95% of the primary energy demand of the building.
  Despite, design choices (the shape) influence the energy performance of the PV systems and some strategies could be adopted to increase it.
  The priority is disposing photovoltaics on roof and then into the façade that is less performing.
  For instance, sloping only half roof (angle of PV approximately equal to 17°) integrating PV modules in the part south-oriented is more convenient, in terms of energy performance, than cover the entire flat roof with a PV mounting system (best angle of PV equal to 30°). This is valid for all cities except for Palermo where there is no big difference between two solutions. However, it is strongly recommended sloping the entire roof especially in high-rise buildings where the surface on roof is quite contained.
  In addition, PV can be disposed also in the South facade where many solutions are possible.
  In fact the façade should be: vertical (the numbers of PV panels depend by the Window-to-Wall Ratio); sloped on its entirety with a PV angle, from the horizontal plane, equal to 70° (this is recommended especially for low-rise buildings) or, otherwise, vertical with only the parapet sloped (PV angle equal to 60°). This last solution permits to maintain the verticality of the façade, improving the energy performance of PV.

Recommendations are applied to some examples in the last Paragraph (Paragraph 5.5) and the results of this part show how the primary energy demands of the high performance buildings are strongly reduced in all cities.

The thesis constitutes the first step toward a wider research that can be further developed in many parts. For instance, some outlooks should be:

- additional parametric analyses related to the morphology (ex. atrium), the technology (ex. double skin facades), passive strategies (ex. solar chimneys, buffer zones, thermal mass) and the integration with renewable energies (ex. geothermic and wind turbines);
- total cost analysis to evaluate the influence of the design choices;
- analysis of the influence of the surrounding on the energy performance of the building (ex. building inserts into the urban area).