MSc Program
Wood Based Building Design for Sustainable Urban Development

Optimizing the thermal performance of a multi-storey wood based hotel building under Mediterranean climate conditions by means of bioclimatic techniques

A Master Thesis submitted for the degree of
"Master of Science"

supervised by
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PREFACE / ACKNOWLEDGEMENT

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Best Regards,

Miren Aurtenetxe

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1. ABSTRACT

This research project examines the feasibility of developing a functional muli-storey timber building in the Mediterranean. The climatic conditions of this region pose considerable challenges for the thermal performance of a building, especially the high temperatures in the summer. The central research question thus is how the thermal performance of a multi-storey timber building under Mediterranean climate conditions can be optimized?

For the optimization of the thermal performance of the wood based building project (a multi-storey hotel building located in Barcelona), this research project will rely exclusively on two different bioclimatic architectural techniques: the design of the building's geometric shape and the design of the façade.

To identify interesting ideas for façade solutions, this research project seeks to learn from the past and engages in a study of traditional Spanish architecture. In so doing, the concept of a double layer façade system (used in traditional wooden galleries, the so-called Solanas) is identified as a very useful design solution to improve the thermal performance of a wood based building in hot weather conditions.

The idea is then adapted to the purposes of the wood based hotel building project. A comparison with other construction materials shows, that by using a double layer façade system, the disadvantages wood has in terms of storage mass over alternative construction materials like concrete can be largely offset. As far as the geometric shape and orientation of the wood based hotel building is concerned, an oval shape with an internal courtyard has been selected as these characteristics satisfy the requirement of an exceptional thermal performance as well as other important design criteria.

Figure 1(a)

Model image of the thesis project

2. INTRODUCTION

2.1. Motivation

> "***start thinking about the concept of beauty, poetry and truth in wooden architecture****. To express the idea more simply, does a building always have to reveal its real structure? Its soul? Its truth? Can it not be a mirror of the cultural preservation of the way of building, but far from the exact effectiveness and logic of material behavior? Can it not be that the outer structure, like a cloth covering the skin, reveals a charming appearance whereas in fact the inner framework is made up of a completely different load bearing system and functional division? Is it always necessary to look for beauty in the rational composition of a building?*

During the industrial revolution wood became something of a "Cinderella" material for construction. And in the twentieth century, new materials, like concrete, glass and steel became the standard bearers of modern architecture. Still, some pioneer architects, like Gerrit Rietveld and Alvar Aalto, introduced innovative applications of wood to modern architecture by using thin plywood panels and gluing techniques for interior design. Since the early 1990's, when sustainability started to become a serious issue both in construction and in architecture, wood is experiencing a renaissance.[12]

Figures 2.1(a) Peter Zumthor (Expo 2002) Neuchatel, Equilibrimu pavilion

[1] Peter Zumthor said the following about the Equilibrium Pavilion at the Neuchatel Expo 2002. National Exhibition of Switzerland

[2]Author (2007): Wood, A10 New European Architecture, vol. 18.

During the industrial revolutionnability aspect that drives the current revival of wooden architecture. As pointed out by the Swiss architect Peter Zumthor "*All design work starts from the premises of this physical, objective sensuousness of architecture, of its materials. To experience architecture in a concrete way means to touch, see, hear and smell it, to discover consciously work with these qualities.*"[3]

This sentence synthesizes very well the principal idea of this research project. Peter Zumthor is right in emphasizing that architecture does not only consist on its design, shape and appearance, but also of what it offers to the senses, by means of its real geometry, material, structure, light and smell.

More generally speaking, wood, as construction material, possesses several positive characteristics and can consequently make a very valuable contribution to the development of a new modern architecture and to the construction of low energy consumption buildings. The following characteristics of wood are particularly noteworthy:

- Wood is an ecological material because it closes the energy cycle (stores the CO2), it is unlimited (as raw material) when its production and plantation is controlled adequately and it is a recyclable construction material.


1


2

Figures 2.1(b) 1 Gerrit Rietveld (1933) Zig-zag chair
2 Alvar Aalto, Pavilion for Agricultural exhibition (1938) Lapua

[3]Bertolini Cestari C., Marzi T., Seip E., Touliatos P. (editors) (2004): Interaction between Science, Technology and Architecture in timber construction, Elsevier, Paris.

- Wood can be fashioned to suit almost any building form, whether as planks, panels or shingles. Its prefabrication is easy and this provides savings of energy consumption for erection processes on site, also compared to other materials timber construction is faster and cleaner.

- Wood is a relatively light material, therefore saves energy consumption also for transportation.

- Wood used as construction, structure or facade element, avoids the existence of thermal bridges because of its insulating properties.

- Wood is the only material that can be used as load bearing, insulating structure and as auxiliary elements.

This said, it is important to bear in mind that wood lives with the conditions of the environment and also has some unfavorable or dislike aspects. It adjusts to the ambient humidity. Its properties are different if measured along or across the grain. It swells or shrinks with the variation of moisture content and temperature variations can result in deformations of the material.

When considering wood as a construction material it is thus essential to consider the environment of the building site and the particular challenges posed by it. Against the backdrop of the increasing interest new modern architecture is taking in wood, this research project examines how wood façade solutions can be applied to a multi-story building in the Mediterranean. For various reasons, the Mediterranean climate is posing considerable challenges to wooden architecture. Very importantly, energy demands for the cooling of buildings are great in the hot Mediterranean climate. And in comparison to other construction materials with a greater thermal mass, such as brick or concrete, the thermal performance of wood is clearly inferior.[4] Still, as this research project will show, disadvantages in the thermal performance of wood over other construction materials can be largely offset through a careful and smart application of building design strategies and envelop systems.

[4] Thanks to its insulating properties wood is especially suitable for building in cold and mild climates and if frequently used as main building material and as a main facade component.

2.2. Definition of the research project

The starting point of the research project is the question whether or not it is possible to build a modern, multi-story timber building that functions well under the hot Mediterranean climate conditions. In order to deal with the challenges posed by the summer heat in the Mediterranean, this research project examines how the thermal performance of a multi-storey timber building can be optimized by means of building design strategies and envelops systems.

The building design strategies will be based on bioclimatic methods. That means that the research will play exclusively with the design of the building (orientation, materials, openings of windows, etc.) in order to improve the building's indoor environment (rather than using complex mechanical systems)[5]. More specifically, this research project will rely on the following two construction-techniques to enhance the thermal performance of multi-story buildings:

- A **volumetric study** based on the solar radiation and the wind. These are two important external factors that interfere in the thermal-performance of the building envelope.

- A **façade study** that is divided in three different "scales":

  - Large scale: orientation of the building envelopes and design in section.
  - Medium scale: disposition of the building envelope layers.
  - Small scale: materials and composition of the building envelope layers.

Figure 2.2(a)

Project model photos

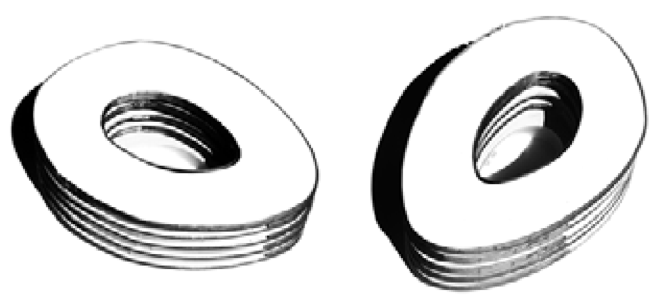
[5] ARQHYS: What is the bioclimatic architecture?, <http://architecture.arqhys.com/bioclimatic.html>.

The reason this research project pays great attention to facade solution is straight forward. The façade is the interface between the interior and the exterior environment and contributes significantly to the energy budget as well as the comfort level of a building. The better the facade's thermal insulation, the smaller the necessary heating elements have to be; the more effective the sun protection, the smaller the necessary cooling units have to be.

To optimize the thermal performance of my building project and to increase the comfort level in its indoor environment the mentioned factors have to be applied in a way that they offer sun protection and reduce the cooling demand of the building in the summer and reduce the heating demand in the winter. All these requirements have to be taken into account in order to optimize the buildings thermal performance.

As very specific external factors such as sun radiation and wind conditions that characterize a particular building site enter into my volumetric and in my façade study, the city of Barcelona has been selected as location for my building project. However, it is important to stress that Barcelona has very similar climatic conditions like other Mediterranean cities. Hence, the general findings of this project are also applicable to similar projects in the wider region, even though the specificities of the building will have to be adjusted to the alternative location. What is more, as the global warming is expected to continue at a significant pace this research project would also like to contribute new ideas for sustainable construction designs using would as principal building material and to promote the general idea of an environmentally sound architecture.

Last but not least, as any architectural project my building needs to serve a certain purpose. Due to the important role tourism plays in the Mediterranean, this research project has defined the purpose of the building to function as a hotel.



2.3. Outline of the main research questions

From the above described definition of my research project it is possible to formulate the following research questions:

Overarching research question: *How can the thermal performance of a multi-storey timber building under Mediterranean climate conditions be optimized?*

Specific research question 1: *In what ways can bioclimatic-architectural techniques help to optimize the thermal-performance of a wood based building envelope?*

Specific research questions 2: *Is it possible by means of bioclimatic architectural techniques to design a wood-based building envelope with an equal or even better thermal-performance than a building envelope based on a rubble wall, massive concrete, or brick-work?*

Specific research question 3: *Can wood substitute other greater thermal-mass materials thanks to the combination of bioclimatic-architectural methods?*

Figure 2.2(b)

Casa Rozes (1962) Girona
Jose Antonio Coderch

2.4. Hypothesis

In the Mediterranean wood has not been a widespread building material in the past and it is seldom used in the region's contemporary architecture. Instead, materials like steel, glass and concrete are the most popular construction materials and over time replaced traditionally used materials like stone, clay and wood.

However, as I will explain in more detail in the historical part of my research project, the fact that wood has not been used more frequently in the traditional Mediterranean architecture was not so much because of an incompatibility with the prevailing climatic conditions but rather owed to the fact that historically wood has been a scarce raw material in this region. In other Spanish regions with quite similar climatic conditions like the Mediterranean, wood has been used as a building material in the traditional architecture when it was readily available. What is more, the vernacular timber architecture of these Spanish regions applied interesting architectural techniques to improve the thermal performance of timber buildings, which will inform the façade study of my research project.

The fact that wood has not been used on a big scale in the vernacular Mediterranean architecture should therefore not lead us to believe that timber is an entirely unsuitable or impractical construction material in Mediterranean climatic conditions. And it might go without saying that due to technical innovation and low transportation costs would today is a readily available raw material for architects who are interested in using it in contemporary Mediterranean architecture.

The central hypothesis posed by this research project thus is: *Through the uses of bioclimatic architectural techniques the thermal performance of a multi-storey building under Mediterranean climatic conditions can be substantially improved.*

2.5. Structure of the thesis

This research project is structured in six main chapters. This introductory chapter has defined the research problem, the main research questions and central hypothesis as well as the motivation of my research project. It explained why this project is interested in studying ways to optimize the thermal performance of a wooden multi-storey hotel building under Mediterranean climatic conditions by means of bioclimatic architectural techniques and highlighted the benefits of such an analysis are.

In a next step, chapter two describes the research methods employed to answer the project's central research questions. To identify traditional timber façade solutions that offer potentially useful idea for modern wooden architecture this research project carries out a detailed study of the literature on the vernacular architecture in different Spanish regions. To specify the specific external climatic condition at the building site (sun radiation, wind, humidity external temperature) this research project will, among other things, rely on data offered by CTE Technique Code of Spain, NASA (Atmospheric Science Data Center Fabra Observatory) as well as data generated with the Solar Radiation Computer Simulation Program "SolRad3". To determine the building geometry in a way that optimizes its thermal performance, this research project once more uses the SolRad3 program. Finally, the study of the building envelope components is carried by using the computer simulation program Lider, administrated by CSIC (Instituto de la construcción Eduardo Torroja, Pamplona, Spain).

After the research methods have been specified, chapter three provides an historic overview of the use of wood in the traditional architecture in different Spanish regions. From this historical research, the design concept used in traditional wooden galleries, the so called "Solanas", is identified as an important architectural technique to improve the thermal performance of a timber building. In essence, the concept of a double layer façade system, that creates a space between the inner and the outer façade skin, prevents a building from overheating and allows the use of building materials like wood, that do not have a huge storage mass.

Subsequently, chapter four specifies the weather conditions (temperature, relative humidity, precipitation, wind and sun path/radiation) that characterize the

Mediterranean climate in general and the “micro-climate” of the city of Barcelona in particular. Furthermore, the effects of climate on a building and ways to cope with these effects through a building’s geometry and envelope will be delineated.

Chapter five then turns to the core of this research project, examining how the thermal performance of the multi-storey hotel building project can be optimized by defining the building’s geometry and through façade solutions. First, a volumetric study is conducted. Examining different geometric forms with respect to heat gains caused by solar radiation, it is concluded that the oval shape adopted by my hotel building project – that has also been taken due to architectural design considerations - is well suited to avoid heat gains. Moreover, an internal courtyard is introduced to the building that facilitates natural air movements that help to cool the building and the optimal orientation (in terms of thermal performance) of the building is determined.

The second part of chapter five consists of the study of façade systems. After briefly delineating the main purposes performed by a façade, this section examines how façade solutions can help to optimize the thermal performance of the wood based hotel building. It will do so by distinguishing three different phases of analyzing façade solutions (big, medium and small scale). At the big scale, it looks for individual façade solutions for the different sections of the building to reduce the solar radiation intensity on the building envelope (calculations with SolRad3). At the medium scale, the project examines the cooling demands in a reference room (calculated with the computer simulation program Lider) and looks at the room geometry and façade composition. For the reference room, a specific sun shading solution is developed to optimize its indoor environment. And at the small scale, this research project goes even deeper into the study of the building envelope, looking at functional façade materials and forms.

In the concluding chapter six, the main findings of this research project will be summed up.

3. DESCRIPTION OF THE METHODICAL APPROACH

From a methodological point of view, this research project can be divided in four main tasks, each of which requires the use of different research methods.

The first task (historical research) consists of identifying wood based envelope solutions by reviewing the literature on the vernacular architecture in the different regions of Spain. The aim of this literature review is to learn from the past (from the traditional Spanish architecture) to identify interesting design solutions and to adapt them to the necessities of modern architecture.

The second task consists of the specification of the external climatic conditions at the building site in Barcelona that have an effect on the indoor environment of a building. The different climatic factors that will be assessed are: sun (solar radiation), wind, ambient humidity, precipitations and exterior temperatures. The following methods are employed to determine the different climatic factors at the building site: the temperature, relative humidity, and precipitation levels are taken from the CTE Technique Code of Spain. The wind velocity is taken from data provided in the CTE Technique Code of Spain and by the NASA (Atmospheric Science Data Center Fabra Observatory). The sun radiation is determined by relying on data by the NASA (Atmospheric Science Data Center Fabra Observatory) and through own calculations based on SolRad3 (Solar Radiation Computer Simulation Program), developed by Tomasz Kornicki (1999, Vienna).

The third task consists of determining the geometry of the building based on two criteria. First, the buildings geometry should be functional in terms of heat gains/losses that occur at the different sections of the building’s façade due to solar radiation (that varies at the different sections of a building’s façade, depending on their orientation). Secondly, the buildings geometry will be subject to other important design criteria like architectural composition and the intent of the building. Pertaining to the first criterion, four different alternative floor plans and orientations are compared to the oval shape of this building project: a rectangular building with east/west orientation, a square building, a rectangular building with north/south orientation and a building with an octagon floor plan. The thermal performance of each of these architectural forms is compared by relying on calculations made with the computer simulation program SolRad3. The main finding of this comparison is that the oval shape selected for my wood based hotel building is the most functional in terms of reducing heat gains.

The forth tasks consists of developing design solutions for the different façade sections of the building. As pointed out earlier, the facade solutions are developed in three different work steps (big scale, medium scale, small scale). At the big scale, the building envelope is divided in different sections according to the orientation of the façade. This is necessary, as the orientation of a façade section results in different solar radiation intensity and angle. In total, three different design solutions (sun shading devices) for the façade of the building are developed, each of which is adapted to the special requirements of its particular location at the building envelope. Moreover, the idea of using a secondary façade skin (see the concept of wooden galleries or "Solanas" in the historic section) is applied to the façade of the wood based hotel building project.

At the medium scale, the different sun shading systems are analyzed in more detail and the thermal performance of a reference hotel room (36m2 including bathroom) is determined relying on the Lider computer simulation program administrated by CSIC (Instituto de la construcción Eduardo Torroja, Pamplona, Spain). These results are scaled taking into account the CTE-DB-HE (Código Técnico de la Edificación-Documentos Básicos-Ahorro Energético, March 2006) for energy demand limitation.. At the small scale, the thermal performance of different building materials for the chosen façade solution (double layer façade) is examined. Besides wood, concrete and glass are tested as alternative solutions for the inner façade skin of my building. Even though its thermal mass is lower than that of concrete, the results show that a inner façade skin made out of wood has a better thermal performance than a concrete wall.

4. HISTORICAL STUDY OF TRADITIONAL WOODEN FACADES IN HOT CLIMATE REGIONS (SPAIN)

This chapter gives a brief overview of the use of wood in the traditional architecture of different Spanish regions. It would go beyond the scope of this project, however, to provide a detailed analysis of the historic development of wooden architecture in Spain or to offer a comprehensive description of the various construction techniques utilized in wooden building envelopes in traditional Spanish houses. Rather, this chapter identifies different timber façade-types and briefly delineates the way these façades are influenced by, and cope with, regional factors such as climatic-conditions and the availability of timber-resources. Its central purpose is to find out in which way traditional solutions for wooden façade-systems can inform and enrich my own research project, that is the optimization of the thermal-performance of a multistory building by means of wooden façade-systems.

4.1. Wood as enclosure material in Spanish vernacular architecture

Wood, stone and mud form together the three essential materials of traditional building construction in Spain. The utilization of wood in Spain's traditional vernacular architecture was inevitable due to the multiplicity of functions that this material can serve. Generally speaking, wood fulfills three main functions in buildings: structural, partition and auxiliary.

However, in the traditional Spanish architecture, wood is only used in rare cases as the essential or predominant element of a building. While it is possible to talk about stone and mud-made villages in Spain one can find hardly any wood-made villages.

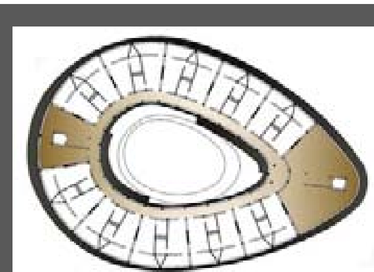
Unlike in Spain, houses where wood has been used as the main or nearly exclusive construction material are common in many villages and towns in Switzerland, Austria, Germany, Finland or Canada. Therefore, it is important to point out that when the term "wooden buildings" is used in this master thesis, it is referring to buildings in which wood plays an important role, even though in most cases wood is not used as the "only" building material.

More specifically, this research project looks at cases where wood has been used as enclosure material, that is as separation element between the exterior and the interior, as well as for other external elements of a building, such as balustrades, eaves or balconies. As regards to buildings with a massive presence of wood as enclosure material, it is assumed that timber is also used at great scale in the interior spaces of the building as structural, partition and auxiliary elements due to the advantages wood enjoys for these purposes over other basic traditional building materials such stone or mud.

In the traditional architecture of Spain, the use of wood in construction is limited almost exclusively to the *private* architecture, that is to family houses and auxiliary buildings, such as stalls or storage places. Only in view exceptional cases wood has been used as the main façade component in palaces and convents or monasteries.

4.2. Analysis of wood based façade typologies by Spanish territories

In many cases, the quantity of wood used as a construction material in traditional architecture is directly related to the availability and proximity of forestry resources in the surrounding area. Therefore, wooden architecture is generally found near the mountain chains of the Iberian Peninsula, where Spain's largest forests are located. Still, in some places it is possible to find rural houses that extensively use wood even though they are located in areas where timber is scarce. Examples of such timber houses can be found in the towns of Aragon and Leon, where no forests exist in the surrounding areas and architects selected wood as a construction material in spite of its high economic costs. At the same time, a high availability of forestry resources does not always imply that wood is also used as a major construction-material. In the Pyrenees, for example, wooden buildings are extremely rare even though there is no lack of forestry resources. The fact that in the Pyrenees stone is easy and cheap to obtain as well as the lack of an established culture of wooden architecture in this region seems to account for this particularity.



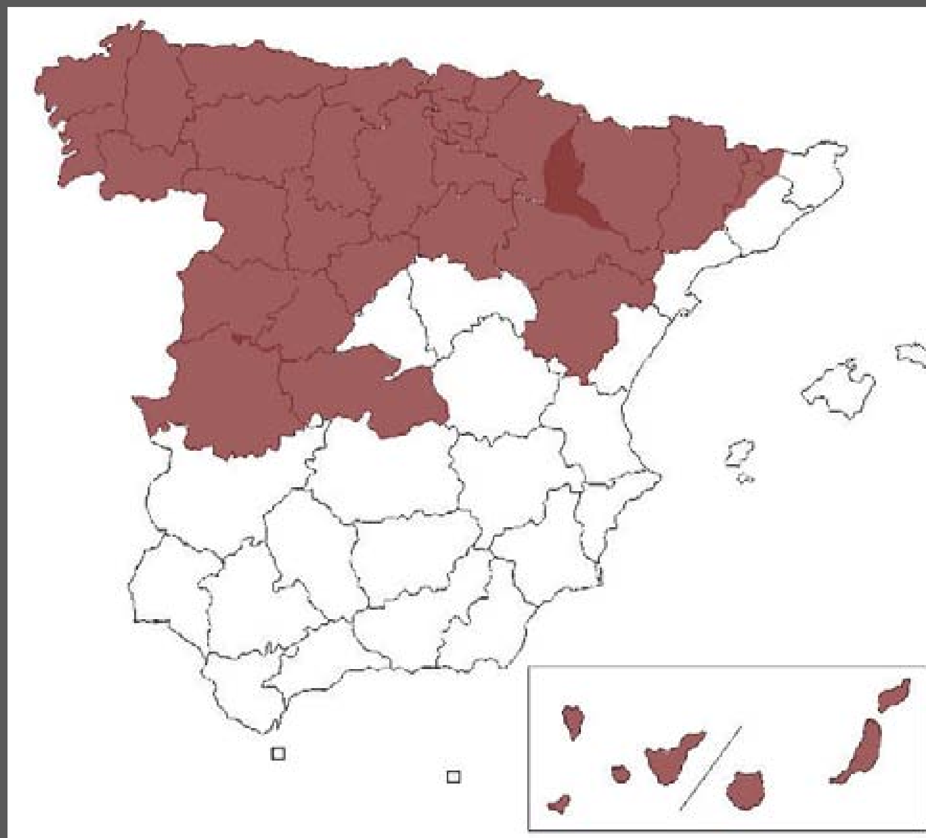


Figure 4.2 (a)
Spanish provinces where wood –base building facades can be found in the vernacular architecture

Northern regions
Cantabric climate

Central regions
Continental climate

A. Pyrenean zone

As described above, the traditional architecture in the Pyrenean zone generally does not make use of timber as the principal construction material and wood is rarely used as enclosure material. Still, timber is applied in the exterior of houses in the Pyrenees for auxiliary elements, such as window frames, doors, and the balustrades of balconies (Figure 4.2(b)). By and large, villages made up of stone houses, characterized by slate roofs and wall masonries thus dominate the landscape in the Catalonian Pyrenees. Yet again, there are some exceptions to the “rule” and a small number of towns and villages exist in Catalonian and Aragon Pyrenees – such as Orgaña, Rialp, Bosost, Las Bordas - where timber plays an important role in the traditional architecture.[6]

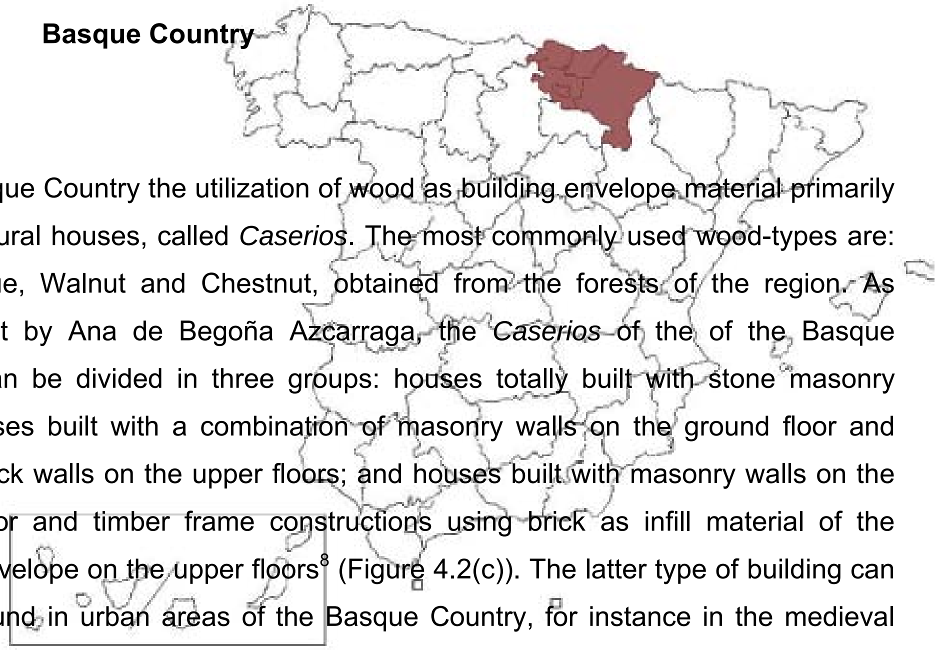
The closer you get from the Pyrenees to the Cantabric coast (the north coast of Spain) the more common becomes the use of timber as enclosure material. This trend can be observed very well in the northwestern regions of Navarra; in Arizkun, Maya, Lesaka, Arraioz, Goizueta and Vera de Bidasoa.[7]

Figure 4.2(b)

Popular architecture in Navarra (Pyrenees)

[6] Flores, Carlos (1990): Arquitectura regional Española: pueblos y lugares de España, Espasa-Calpe, Madrid.
[7] Ibid

B. Basque Country



In the Basque Country the utilization of wood as building envelope material primarily occurs in rural houses, called *Caserios*. The most commonly used wood-types are: Oak, Hague, Walnut and Chestnut, obtained from the forests of the region. As pointed out by Ana de Begoña Azcarraga, the *Caserios* of the of the Basque Country can be divided in three groups: houses totally built with stone masonry walls; houses built with a combination of masonry walls on the ground floor and exterior brick walls on the upper floors; and houses built with masonry walls on the ground floor and timber frame constructions using brick as infill material of the building envelope on the upper floors[8] (Figure 4.2(c)). The latter type of building can also be found in urban areas of the Basque Country, for instance in the medieval part of Vitoria (Figure 4.2(d)).

In Basque rural houses (*Caserios*), the most common type of wooden façades are timber frame constructions that are also predominant in Central European, Finnish, and North American vernacular architecture. This façade type frequently occurs in *Caserio*s that are located in towns and villages in the Basque region of Biscay: Abadiño, Durango, Amorebieta, Etxebarri, Orozko, Villaro, Zeberio and Alava. In the Basque province of Gipuzkoa, on the other hand, most of the rural houses generally do not have much timber in their façade. Still, houses with wooden building envelopes can be found in some of the province's coastal towns like Hondarribi, Getaria and Ondarroa.

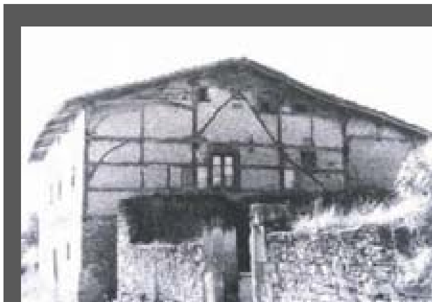


Figure 4.2(c)
Timber frame on the upper floor

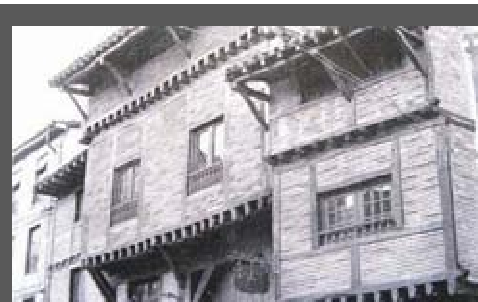


Figure 4.2(d)
Use of timber framing in urban areas

[3] Ana de Begoña Azcarraga (1986) Arquitectura doméstica en la llanada de Alava: S. XVI-XVIII, Diputación Foral de Alava, Vitoria.

A special type of wooden *Caserio* that has nowadays almost disappeared in the Basque Country was made up of load carrying masonry walls resting on the ground floor and supporting two more stories. The upper level was the attic, which's front and back façades were composed of vertical wooden planks; and timber frame construction made up the attic's side facades. (Figure 4.2(e) and Figure 4.2(f)). These wooden plank façades only appear in small and medium seized rural buildings (*Casas Populares)* while larger Caserios (*Casas Señoriales)* for the most part use timber frame façades at the upper floors.[9]

Even though in the traditional architecture in Basque urban areas wood has been rarely employed at the exterior of buildings, it is possible to find houses with a glazing façade combined with wooden window frames that are commonly painted, using diverse

colors, such as red, blue and green. This type of traditional houses is present in the whole northern coastal area of the Iberian Peninsula and it is especially popular in La Coruña, with its beautiful houses with white painted Galeries.

It is moreover important to point out that many of the rural and urban houses mentioned in this chapter have roof eaves built in timber frames. Besides their decorative purpose, these elements serve as a prolongation of the roof, protecting the building and its façade from the rain and sun.

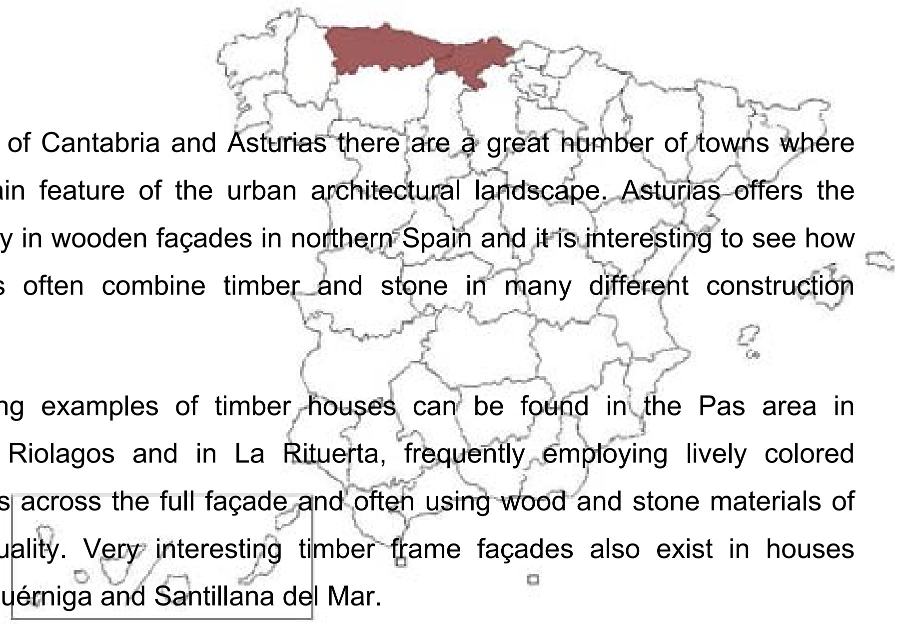
Figure 4.2(e) and (f)
Rural houses in Biscay. Use of wooden planks in the upper floors

[9] For the distinction between *casas populares* and *casas señoriales* see: Ana de Begoña Azcarraga (1986) Arquitectura doméstica en la llanada de Alava: S. XVI-XVIII, Diputación Foral de Alava, Vitoria.

In summary it can be said that the most common traditional construction materials used in Alava and consequently also in the Basque Country are[10]:

- Stone: Sandstone and white Limestone.
- Ceramic: in order to produce brick blocks and tiles.

C. Cantabria and Asturias



In the regions of Cantabria and Asturias there are a great number of towns where wood is a main feature of the urban architectural landscape. Asturias offers the greatest variety in wooden façades in northern Spain and it is interesting to see how these façades often combine timber and stone in many different construction solutions.

Very interesting examples of timber houses can be found in the Pas area in Cantabria, in Riolagos and in La Rituerta, frequently employing lively colored wooden planks across the full façade and often using wood and stone materials of exceptional quality. Very interesting timber frame façades also exist in houses located in Cabuérniga and Santillana del Mar.

Another widespread wood-made feature in the traditional architecture of Cantabria and Asturias, that is also very common in the rest of Spain, is the balcony. Balconies used to fulfill multiple functions, serving as a place to dry maize cobs and other food stuff as well as a place to sit and enjoy the evening. In the XVIII and XIX, the construction of the so-called seafront galeries, or "*Solanas*" as they are called in Cantabria and Asturias, Century marked an historic high-point in the development of balconies (Figure 4.2(g)).

Seafront gallleries can be described as an early example of a façade-system using a combination of glass and wood. The building skin of traditional glass fronted houses consisted of two different envelope layers: a glazing layer and a masonry or brick wall with window and door openings. More often than with glass, these openings in the thick masonry walls were traditionally filled with transparent pig-skins or with a

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[10] Ana de Begoña Azcarraga (1986) Arquitectura doméstica en la llanada de Alava: S. XVI-XVIII, Diputación Foral de Alava, Vitoria

simple wooden shutter.[11] The glazing served as secondary skin of the building façade and protected the building and its primary façade-skin from adversary weather conditions (mainly from the coastal wind and rain). In addition to providing a meeting area for people, the spaces between the two façade-skins fulfilled important isolation functions and allowed to direct air currents. The seafront galleries thus distributed important functions performed by a façade – such as the protection against adversary weather conditions, isolation and solar-shading – among the different façade layers (i.e. the primary and secondary façade skins) and the spaces enclosed between them.

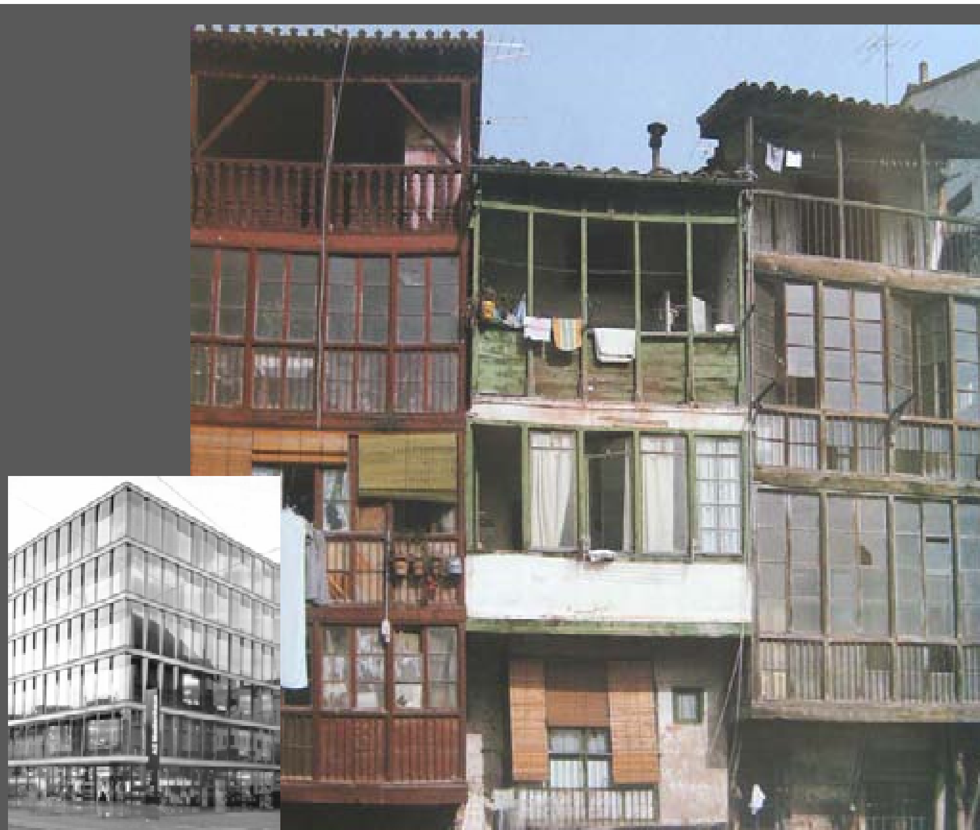


Figure 4.2(g)

Early secondary skin (glass front), primary skin (masonry wall)

Double function: - penetration of natural light

- protection of the main envelope from sea spray rainfall and wind. Generally used in sea fronts

[11] Laws, Bill and Castells Benosa, Joaquim (1995) Traditional Houses of Rural Spain, Abbeville Press, New York.

In traditional Spanish architecture, there are very interesting variations of wooden balconies; some are placed at the main building façade, others are running along the façades of inner-courtyards. In the latter case, the balcony does not function as a zone where people stay or as an additional "room", but rather as a corridor. The rooms of the house are opened to the balcony facing the courtyard, which serves a the connecting element for the different rooms of the building.

A good example of a building with a balcony running along its internal courtyard is the monastery of Teverga, in Asturias (Figure 4.2(h)). The architecture of this monastery follows a very traditional Spanish building typology, where the cloistral courtyard constitutes a principal element of the building. A garden of Palm trees is located in the center of the courtyard and the balcony's timber posts, beams and eaves create a small arcade system on the ground floor, where the pillars are made of limestone pieces[12].

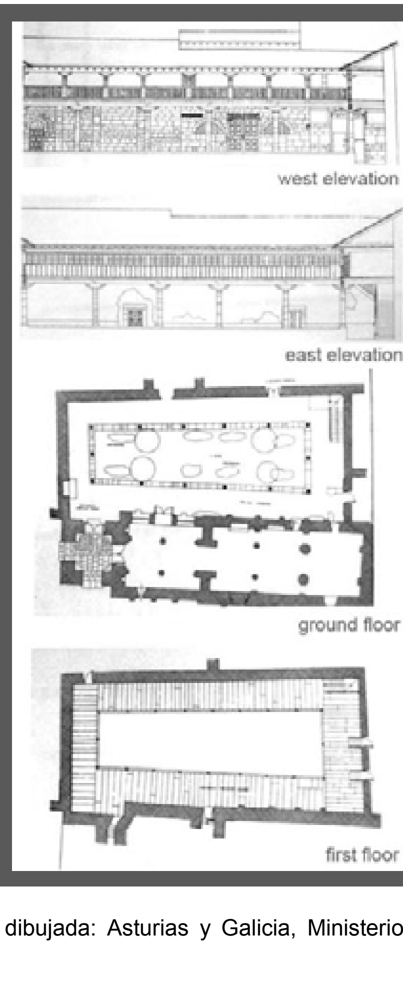


Figure 4.2(h)

Monastery-church of Teverga
Wood-base cloistral courtyard

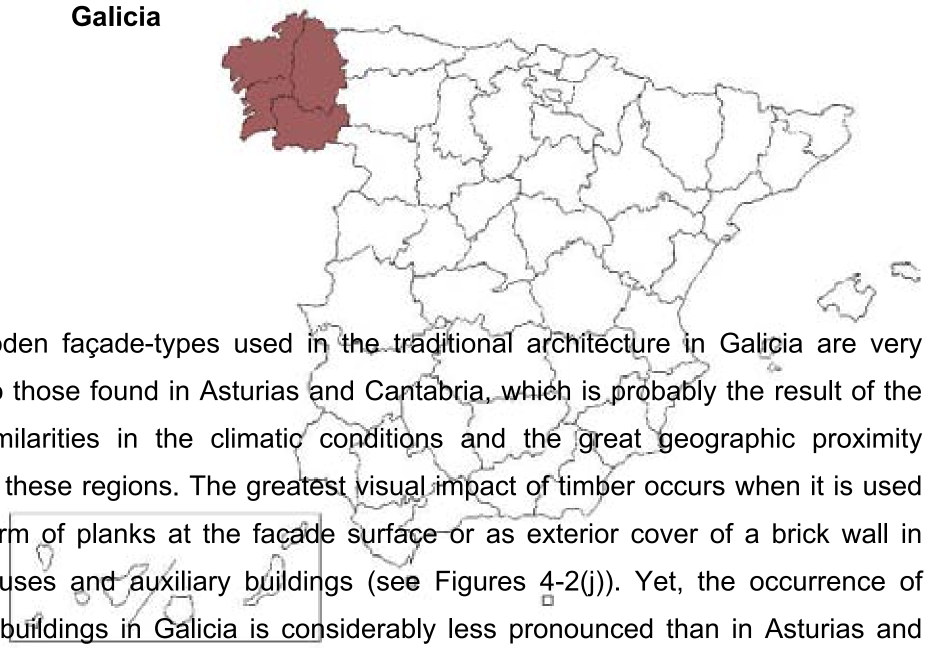
[12] Garcia Fernandez, Efrén y Jose Luis (1975) España dibujada: Asturias y Galicia, Ministerio de Vivienda, Madrid.

To complete this brief overview of traditional wood-building types in the northern part of Spain, it is necessary to also mention the antique building typology called *Hórreos* found in Asturias and in Galicia. The floor shape of these buildings differs among regions; they can have rectangular, linear-curved or elliptic floors. The *Hórreos* were mainly used as storage places for cereals. They were erected on stone columns in order to avoid the direct contact with the ground, making it difficult for mice to enter and allowing for the ventilation of the floor.

Figures 4.2(i) Asturian Horreos

Figures 4.2(i) show traditional *Hórreos* in Asturias. The wooden enclosures of the *Hórreos* are generally made of timber planks, placed vertically one next to the other, leaving a view centimeters of space between them to permit a better ventilation. They also have a timber roof structure covered with small slate stone plates. The roof leaves wide eaves at the four sides of the building, thereby protecting the timber façade from the rainfall to prevent the planks from absorbing too much humidity.

D. Galicia



The wooden façade-types used in the traditional architecture in Galicia are very similar to those found in Asturias and Cantabria, which is probably the result of the great similarities in the climatic conditions and the great geographic proximity between these regions. The greatest visual impact of timber occurs when it is used in the form of planks at the facade surface or as exterior cover of a brick wall in living houses and auxiliary buildings (see Figures 4-2(j)). Yet, the occurrence of wooden buildings in Galicia is considerably less pronounced than in Asturias and Cantabria. Primarily because of the region's richness in natural granite stone, stone-made villages dominate the rural architecture in Galicia and many construction details in traditional rural houses are executed in stone.

In the traditional Galician architecture, the most common application of wood in façade-systems is found in the above described seafront galleries (*Solanas*). The seafront galleries in Galicia appear much more frequently in an urban context than in Cantabria or the Basque Country and are mostly used in multistory buildings (Figures 4.2(k)). Cloistral-courtyards, surrounded by a wooden gallery and by buildings with a wooden structure, are also very typical for the Galician region. The wooden galleries are commonly supported by columns and ensure a good natural lighting to the rooms. At the same time, the wooden gallery protects the living spaces from heat (shading effect) and coldness (isolation effect).

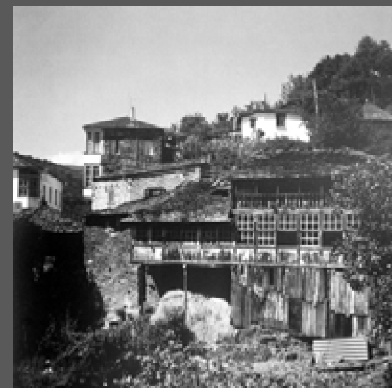
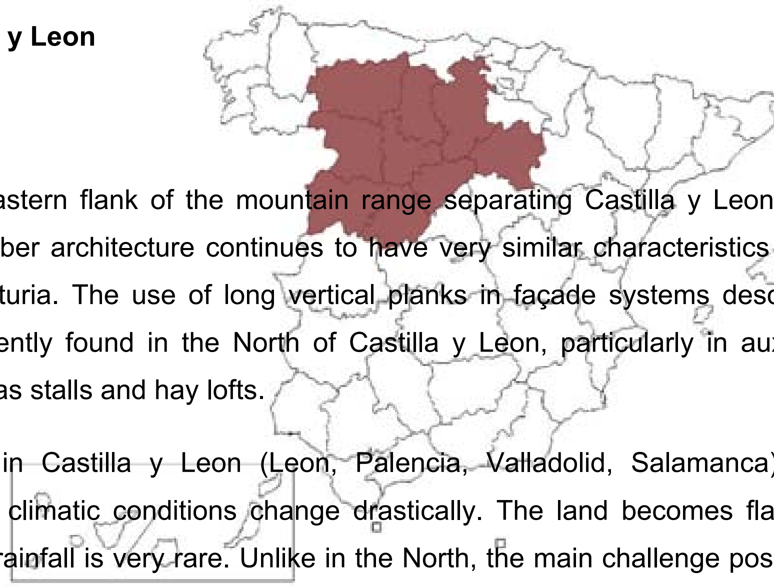


Figure 4.2(j) Facades composed with wooden planks

Figure 4.2(k)
Galeries in La Coruña
Sea front glass facades, white painted

E. Castilla y Leon



At the south-eastern flank of the mountain range separating Castilla y Leon from Galicia, the timber architecture continues to have very similar characteristics as in Galicia and Asturia. The use of long vertical planks in façade systems described above is frequently found in the North of Castilla y Leon, particularly in auxiliary buildings such as stalls and hay lofts.

Further south in Castilla y Leon (Leon, Palencia, Valladolid, Salamanca), the landscape and climatic conditions change drastically. The land becomes flat and desolated and rainfall is very rare. Unlike in the North, the main challenge posed by the weather conditions in this dry region for the (traditional) architecture is thus not the protection against rain but the protection against the extreme variation in temperature, as it gets very cold in the winter and very hot in the summer.

In the traditional architecture of southern Castilla y Leon, straw, mud and wood constituted the principal building materials and were frequently applied in combination with each other. A very common traditional construction technique in this region, which one still can find today, is called *Trulla*[13]. This technique combines a kneaded mix of mud and straw with a timber framework that serves as the structure of the building.

Figure 4.2(l)
Rural environments in Castille, yellowish exterior renders

[13] Iñiguez Almech, Francisco (1957) Geografía de la arquitectura Española, Dirección de Bellas Artes, Madrid

Due to the use of straw, the exterior render layer has a very nice, shiny yellowish color (Figure 4.2(l)). Unlike in other parts of Spain, lime is not used as a protection layer in this dry region. As Castilla y Leon was a poor region, decorative elements in its traditional architecture are not very common.

The greatest density of wooden villages in Spain is located on the slopes of the *Sistema central* mountain chain in the provinces of Avila and Segovia. Very noteworthy examples are the towns of Somosierra, Riaza and Robregard. Besides these towns, we can find very admirable wood construction works in La Vera and Del Jerte, in Extremadura, and a complex of different villages called *Del Valle,* situated in the province of Avila[14].

Figure 4.2(m)

Rural houses in Castilla
Timber framing, infill of stone and render of mud and straw, called "Trulla"

[14] Flores, Carlos (1990): Arquitectura regional Española: pueblos y lugares de España, Espasa-Calpe, Madrid.

These regions offer a great variety of timber façades. Typically, timber frameworks in traditional houses of this regions are applied in the upper floors (first and second floor) of the buildings. The front part of the ground floor often consists of an arcade with timber columns carrying the upper part of the house. Such houses exist in urban areas, for instance in Soria and Leon (Figures 4.2(m)).

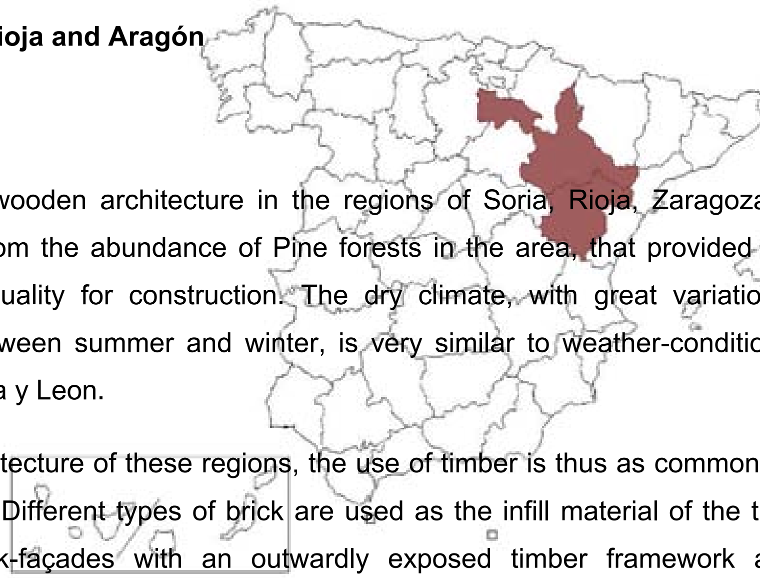
Between the regions of Burgos and Sória (Lerma, Calatañazor, Gallinero) another house typology, called *Casa Pinariega,* can be found. The name of the house is derived from the pine logs used in the building, which are taken from the large Pine forests located in the area. The *Pinariega* house is characterized by its circular chimney, composed of independent wooden logs joined together on the vertex and filled with stone crowed, adobe and sometimes brick. The façades of these houses are composed of a softwood log construction that reinforces the structure in the ground floor (usually the only floor of the building). Extraordinarily far prolonged roof eaves are another special characteristic of the architecture in this region[15].

Figure 4.2(n)

Timber framing, infill composed of brick work or clay blocks

[15] Flores, Carlos (1990): Arquitectura regional Española: pueblos y lugares de España, Espasa-Calpe, Madrid.

F. Rioja and Aragón



The traditional wooden architecture in the regions of Soria, Rioja, Zaragoza and Soria befitted from the abundance of Pine forests in the area, that provided Pine-wood of high quality for construction. The dry climate, with great variations in temperature between summer and winter, is very similar to weather-conditions in Southern Castilla y Leon.

In the rural architecture of these regions, the use of timber is thus as common as in Castilla y Leon. Different types of brick are used as the infill material of the timber frame and brick-façades with an outwardly exposed timber framework are a common feature of the traditional architectural landscape (Figure 4.2(o)).

In other areas, especially the province of Teruel located at the fringe of the Albarracín mount range, the construction solutions resemble those applied in the *Casa Pinariega* in Southern Castilla y Leon. Important characteristics of these houses are timber frameworks, composed of vertical and horizontal wooden-elements and structural trusses that are filled with adobe or stone as well as long roof eaves made of timber.

Figure 4.2(o) Timber frame work and brick-work façade, sometimes rendered with lime

G. Castilla La Mancha, Andalucia and Levante

In the southern region of Madrid, Castilla La Mancha, Murcia and Baleares, the examples of wooden villages are very rare. In Andalucia, however, timber is frequently used for various decorative elements in balcony-bridges, as it is shown in the Figure 4.2(p).

H. Canary Islands

The Canary Islands are rich in forest resources and timber is frequently used in the archipelago ‘s vernacular architecture. It is common to find traditional houses with wooden exterior façades as well as with wooden façades facing an internal courtyard. The traditional wooden architecture is also influenced by the nearly tropical climate conditions.

Figure 4.2(p)

Andalusian Wooden balcony-bridges

Figure 4.2(q)

Wood is used for building structure, roof, shutters and other enclosure elements
The vernacular architecture in Canary island is characterized by long balconies along the facades and big window openings, to facilitate the ventilation and the cross circulation of the air

4.3. Conclusion of the historical analysis

The aim of this chapter was to gain a better understanding of the use of timber as a façade element in traditional Spanish architecture and to abstract fundamental ideas of façade solutions that can be applied by this research project (multi-storey hotel building). Based on this historical analysis of the use of timber in the vernacular architecture in different Spanish regions three very common façade typologies can be identified:

A. Wood framed glass galleries or *solanas*
B. Timber plank facades
C. Timber framework combined with ceramic, stone or clay material

Yet, as it will be explained in more detail below, the main traditional façade idea that will inform this research project is derived from the wood framed glass galleries. It therefore suffices for the purpose of this study to focus some more on this façade typology (category A).

The category A is usually found in the zones near the Cantabric coast where the weather conditions are mild. In these regions there are no great temperature variations between winter and summer and the climate is quite humid, with a relative humidity up to 80% and abundant rainfall. The traditionally adopted solution of the *solanas* considers the following aspects:

- To provide adequate ventilation to the building (because of the high moisture content of the air caused by plentiful rainfall).
- To use solar radiation to warm the air in the interior space of the *solana* and to store the gained heat in the wall next to the glazed façade. In this way, balconies can be used also in winter seasons.
- To create shades in the summer by diminishing solar radiation through the use of cantilever balcony floors in each story.
- Avoid possible overheating through the use of operable windows in the glazed façade (in summer, the heated space between the masonry wall and the glazing can be properly ventilated).

5. ANALYSIS OF THE CLIMATE OF THE SITE AND ITS EFFECTS IN THE ARCHITECTURAL DESIGN

5.1. Climatic conditions in of the site (Barcelona)

No specific building-site has been selected for this hotel-project inside the city of Barcelona. Consequently, the building's immediate urban surrounding does not need to be considered during the design-process. Rather, the geometry and orientation of the hotel-project as well as the proposed façade-solution are primarily concerned with optimizing the thermal performance of the building under the constraints imposed by Mediterranean climate conditions and the more specific weather conditions prevailing in the city of Barcelona.

The Mediterranean climate, as defined by EULEB (European High Quality Low energy Buildings), is characterized by mild winters and dry and hot summers. To examine the performance of façade-solutions under Mediterranean climate-conditions it is helpful to distinguish between the following four different aspects of climate: humidity, precipitations, wind and sun path, and solar radiation.

Figure 5.1(a) world map

A. Temperature and relative humidity

The information is based by the Spanish Technique Code (CTE) approved in March 2006 and Nasa Langley Research Center Atmospheric Science Data Center.

Appendix B Climatic Data contains the following data tables and figures:

- Figure B.1 Maximum air temperature
- Table B.1 Minimum exterior temperatures
- Figure B.2 Winter climatic zones
- Table B.2. Monthly average air temperatures
- Table B.3 Average daily temperature rage
- Table B.4 Monthly average cooling degree days above 18ºC
- Table B.5 Monthly average heating degree days below 18ºC
- Table B.6 Monthly average temperatures and relative humidity

In Barcelona, the maximum daily temperatures with an average of 28ºC are reached in the month of August and the minimum daily temperatures with an average of 4.4ºC occur in January. The main challenges for the thermal performance of a building located in Barcelona are thus posed by the hot temperatures and the high degree of sun radiation in the summer. The mild winters, on the other hand, do not necessitate an elaborate façade-solution to ensure a comfortable indoor environment. Therefore, this project does not attribute further attention to the winter situation and focuses instead on façade-solutions to optimize the building's thermal-performance in the hot summer.

In the figure B.1 it shows the map of Spain differentiating with colors the maximum temperature intervals. Barcelona is marked in light green color, which means that the maximum temperatures of the zone are registered between 40 and 42ºC.

In comparison with other zones in Spain, it can be said that the temperatures of this Mediterranean zone are very similar to the ones registered in the Cantabric Coast, but a little milder in winter and hotter in summer.

B. Precipitations

Table B.7 (See Appendix B climatic Data) indicates the annual average of precipitation for every month (mm/day). The precipitation data shows that a slight increase in the amount of rainfall in spring and autumn that reaches its peak in the month of October.

Based on the information given by the Spanish Technique Code (CTE) approved in March 2006, DB-HE, Figure A.3 shows a map of Spain indicating different pluviometric-areas. The area of Barcelona is part of the zone III, which furthermore includes Catalonia, the central areas of Castile, Estremadura, and Andalusia. Like in most of Spain, with the exception of the Cantabria and some isolated areas, the amount of rainfall in the pluvioumetric-zone III is rather low.

C. Wind

The Figure B.3, in Appendix B, shows the basic values of wind velocity in Spain. The north part of the Iberia peninsula is classified as Zone C, has a basic value of wind velocity of 29m/s.

This value is given in the CTE-DB-SE AE Technique code. The Dynamic Pressure (P_s) of wind in a building is calculated by using the formula[16]:

$P_s = 0.5 \cdot \rho \cdot V_b^2$ where ρ is the density of air and V_b is the basic wind velocity.

The Dynamic Pressure of the C Zone is 0.52KN/m²

Based on the data obtained from the NASA (*Atmospheric Science Data Center*) the predominant wind direction at the geographical location of Barcelona (at 41.50º Latitude and 1.5º Longitude) oscillates during the year between 306º and 313º degree.That means that the winds in the area of Barcelona come primarily from the direction North-West.

The Tables B.8 and B.10, obtained from the NASA data tables, indicate the average wind speed during every month of the year (measured from a height of 10 and 50m above the surface of the earth) and the difference in the minimum and the maximum

[16] See: CTE-DB-SE AE, Technique code, Structural Safety, page 27.

from the monthly wind speed average (at 50m above earth surface) indicated in percentage data.

D. Sun path and Radiation

The diagrams in the Figures B.5 show the yearly sun path in Barcelona. In these figures we can see the sunrise and sunset time for every day of the year and the sun daily hours and the Sun Path Diagram indicating the azimuth of the sun and the inclination of the sun with respect to the horizon.[17]

In June 21, summer solstice, the sunrise occurs at 06:18 and the sunset at 21:28, while the length of sun hours amounts to 15 hours and 7minutes. In December 21, winter solstice, the sunrise and sunset take place at 08:14 and at 17:25, respectively, and the length of sun hours consist of 9 hours and 12 minutes. In the equinoctials, the sunrise is at 07:42 and the sunset occurs at 19:43. The total sun hours in March 21 are 12 hours and 1 minute.

[17] The azimuth of the sun, as measured here, is defined as the angle from due north in a clockwise direction. Another, frequently used definition of the azimuth of the sun ist he angle between the line from the observer to the sun projected on the ground and the line from the observer due south.

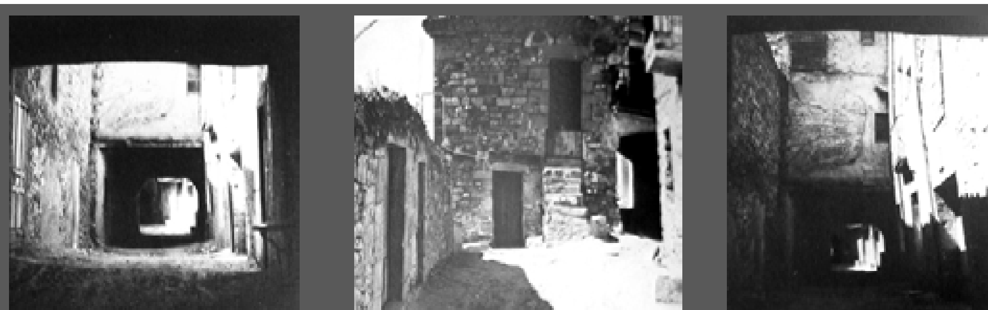
5.2. Effects of climate on the architectural form and the building envelope

Climate has a profound effect on the form of the vernacular architecture in Spain, that seeks to adapt to its natural environment. In the Mediterranean climate zones architectural forms are often designed to meet problems caused by the summer heat and wind.

The vernacular architecture in the Balearic Islands, Catalonia and Alicante responds to these challenges with courtyards, shadowing spaces, deep loggias, projecting balconies and overhangs, casting long shadows on the walls of buildings. Such arrangements characterize the architecture of the Mediterranean zones and evoke comfort as well as aesthetic satisfaction.

Fountains in courtyards and ceramic materials as covering of wall and floor constructions have been frequently used in the traditional architecture in hot Spanish regions. And so have gabled roofs, which decrease in pitch as the rate of precipitation decreases.

It can be said that the configuration of a building, its orientation and its arrangement in space creates a specific microclimate for each building site. To this must be added the building materials, surface textures and colors of exposed surfaces of the building and the design of open spaces, such as streets, courtyards, gardens, and squares. These man-made elements interact with the natural microclimate that characterizes the building site such as: light, heat, wind, and humidity.



Figures 5.2(a) Images of Catalonian traditional rural areas
Narrow streets and shadowed spaces are characteristic of vernacular architecture

There can be no doubt that certain configurations create better microclimates than others. For the micro-climatic conditions of a building site, there are optimal arrangements in space that can serve as a reference point in the process of deciding the design of an architectural project.

The main task is to establish the optimum orientation of a building with regard to the sun and the prevailing wind.

A. Sun radiation

It probably goes without saying that hot regions the sun is the major source of heat. Smart design strategies thus emphasize the need to protect the building primarily from isolation. On principle, the building should be compact and the ratio of enclosure (surface) area to volume (S/V) needs to be small, protecting the compact building from exposure and solar gains.

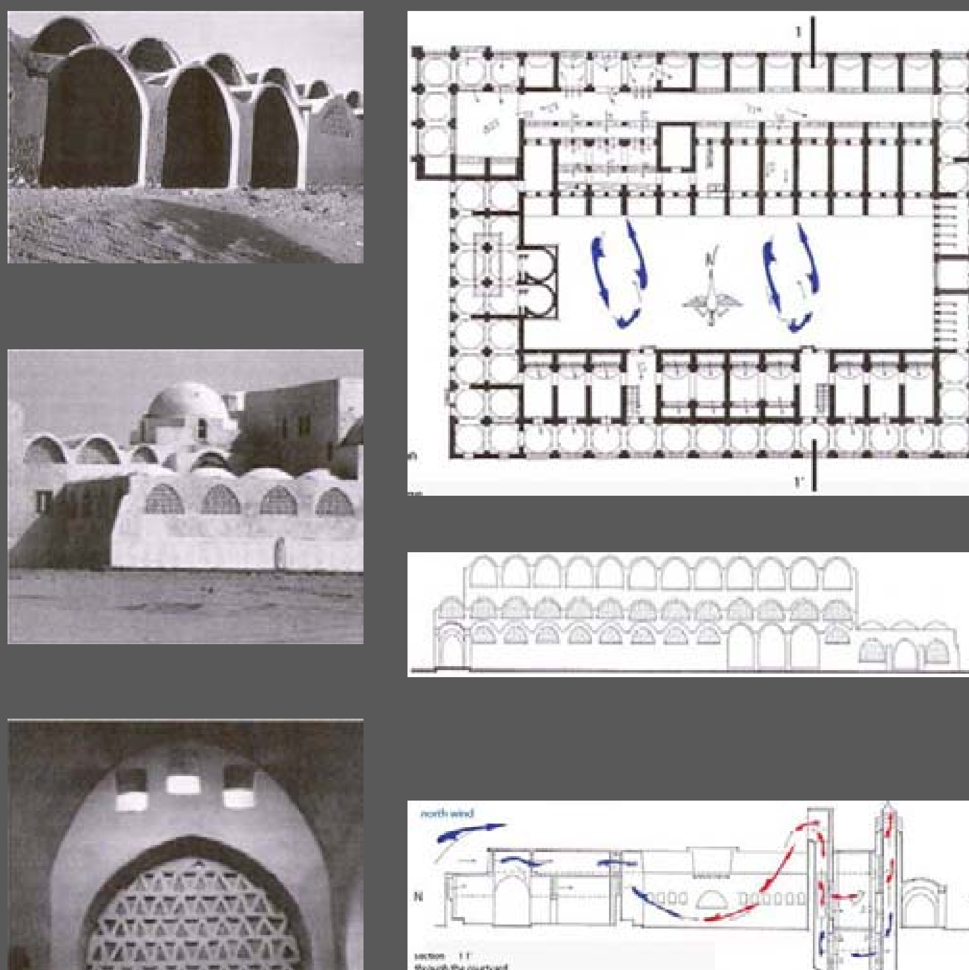
The orientation of the building needs to be carefully considered. The “sun factor” is complex, so it is helpful to begin the design process by considering the simple case of a block consisting of a single row of buildings. In comparison to this simple architectural form, more complex cases can be understood.

It is important that for reasons of simplification, this research project abstracts from additional factors that contribute to the specific environment of a particular building site, such as the reflection from the adjacent buildings.

Figures 5.2(b) Can Lis house, Mallorca (1972) Jørg Utzon

B. Natural ventilation, thermal currents and governing of wind

Currents of air in the atmosphere (wind), the interaction via openings linking inside with outside and thermal effects in the boundary air layers are phenomena that affect every building. Ventilation, therefore, is a vital factor to enhance the comfort levels of a building through the façade design. The façade design should aim to enable natural ventilation of a building whenever possible. This approach can solve several problems (posed by Mediterranean climate) such as too high interior temperatures in summer, unwanted draughts in the building, too low interior humidity, etc.



Figures 5.1(c) Hassan Fathy, Cairo (1900-89)
Shows the thermal current produce by interactions via openings

6- THERMAL PERFORMANCE OF THE BUILDING ENVELOPE PROJECT DEVELOPMENT

6.1. Volumetric study

This volumetric study is based on a solar radiation study of the building's façade and a study of the wind that flows through the building opening. Both factors contribute to a specific microclimate of the building. Wind movement and humidity are important to be considered simultaneously with the direct and indirect effects of the sun. These three external factors impact on the thermal-performance of the building envelope.

Again it is important to point out that no specific building site has been selected for this hotel project in the city of Barcelona. For this reasons design decisions concerning the building's geometry do not need to take its urban environment into consideration. In that way, it is possible to pay primarily attention to optimizing the building's thermal performance when deciding its orientation and geometry.

Figure 6.1(a) St Christopher's Hostel, Paris (2008) Chaix & Morel architects

As pointed out above, for an optimal thermal performance in hot regions a building needs to be compact, reducing as much as possible its exterior enclosure surface. At the same time, it is necessary to provide natural ventilation and to control air currents, for instance through the incorporation of a courtyard. Generally speaking, a building orientation is optimal when the larger enclosure surfaces are looking in a North-South direction and when the surfaces facing East-West – which provide the largest heat gains - are kept as small as possible.[18]

A. Solar radiation study

A.1. Description of the location Barcelona:

Latitude: +41.4 (41°24'00"N) Longitude: +2.17 (2°10'12"E) Altitude: ~20 m

Time zone: UTC+1 hours Local time: 09:47:57

Country: Spain Continent: Europe Sub-region: Southern Europe

Minimum and maximum medium temperatures in January: 4.4 ºC and 13.4 ºC

Minimum and maximum medium temperatures in August: 19.3 ºC and 28 ºC

Medium Relative Humidity per month: 73% in January, 70% in June and 72% in August

Figure 6.1(b) Hotel del Empordá Golf H&R, Gualta, Lleida (Catalonia), 2007
Carlos Ferrater and Martí – Sardá architects

[18] Façades facing East-West provide the greatest heat gains because the inclination angle of the sun with respect to the horizon is the lowest and the solar radiation intensity the strongest.

A.2. Study of solar radiation incidence in the building geometry:

Five simple building geometry/orientations with the same floor area will be analyzed in respect to the heat gains caused by solar radiation. The analysis is starting with a rectangular geometric form with the larger façade section oriented in the most unfavorable direction (E-W) and then moves on to superior solutions finally comparing the results to the oval shape (adopted geometry for the project) which will be orientated in the most optimized direction (avoiding heat gains in the Eastern direction).

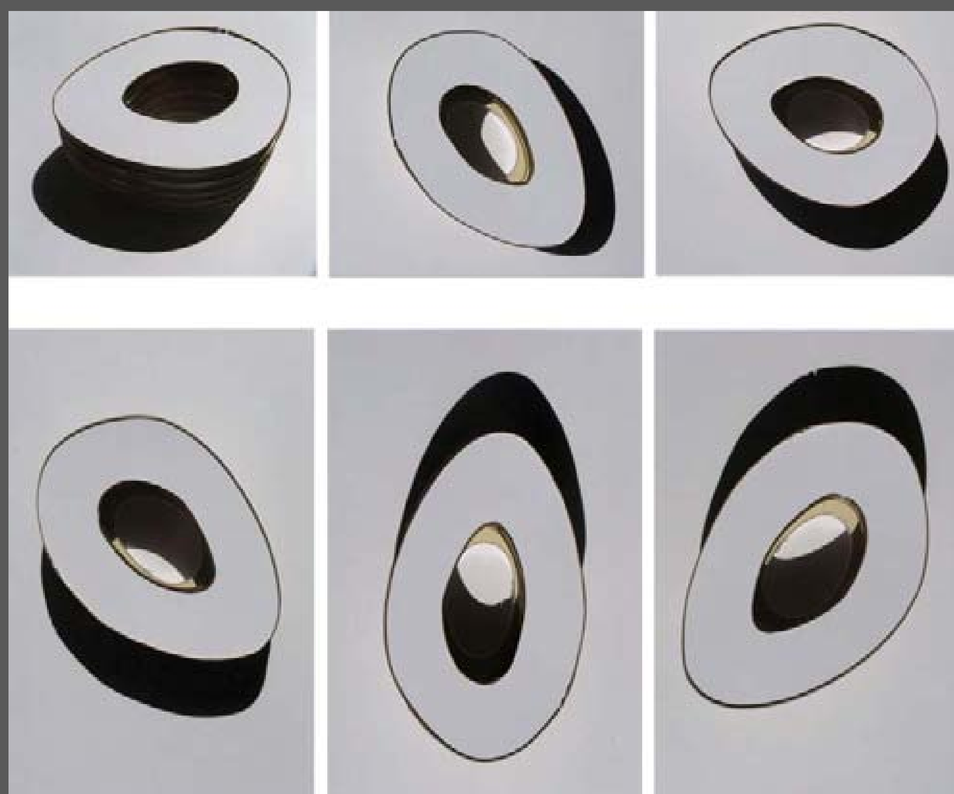
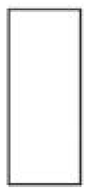
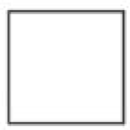
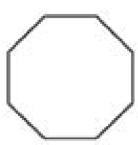
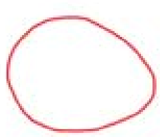
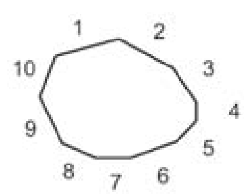


Figure 6.1(c) Shadowing study of the project's shape, respect the volumetry and the courtyard

Comparison of 5 different floor geometries, considering heat gains caused by global solar radiation incidence during a day, on the summer solstice (21st of June).

Data obtain by the computer program SolRad3

Floor plan	Description	Enclosure surface in each orientation	Heat gains from global solar radiation in each orientation surface	Total heat gain on the vertical enclosure surface
	Area : 4000m2 Perimeter : 280m 6 storey building Height : 22m	North facade: 880m East facade: 2200m South facade: 880m West facade: 2200m	N : 2173,9 W/m2 E : 4203,7 W/m2 S : 3010,8 W/m2 W : 4203,9 W/m2	Most unfavorable case Heat gains from solar radiation 100% 2305,91KW
	Area : 4000m2 Perimeter : 253m 6 storey building Height : 22m	North facade: 1394,8m East facade: 1394,8m South facade: 1394,8m West facade: 1394,8m	N : 2173,9 W/m2 E : 4203,7 W/m2 S : 3010,8 W/m2 W : 4203,9 W/m2	Heat gains from solar radiation 82,22% 1895,85KW
	Area : 4000m2 Perimeter : 253m 6 storey building Height : 22m	North facade:2200m East facade: 800m South facade: 2200m West facade: 800m	N : 2173,9 W/m2 E : 4203,7 W/m2 S : 3010,8 W/m2 W : 4203,9 W/m2	Heat gains from solar radiation 81,55% 1880,50KW
	Area : 4000m2 Perimeter : 230,4m 6 storey building Height : 22m	8 Facades Same surface area A : 633,6m2	N : 2173,9 W/m2 N/E and N/W : 3283,7W/m2 E and W : 4203,7 W/m2 E/S and S/W : 3875,6 W/m2 S : 3010,8 W/m2	Heat gains from solar radiation 81,55% 1880,50KW
	 Area : 4000m2 Perimeter : 232m 6 storey building Height : 22m	10 Facades with different orientations and surface area	1 : 2381 W/m2 2 : 2544,8 W/m2 3 : 3312,6 W/m2 4 : 4203,7 W/m2 5 : 3949,5 W/m2 6 : 3296,2 W/m2 7 : 3010,8 W/m2 8 : 3493,5 w/m2 9 : 4212,7 W/M2 10 : 3868,5 W/m2	Heat gains from solar radiation 74,50% 1717,87KW

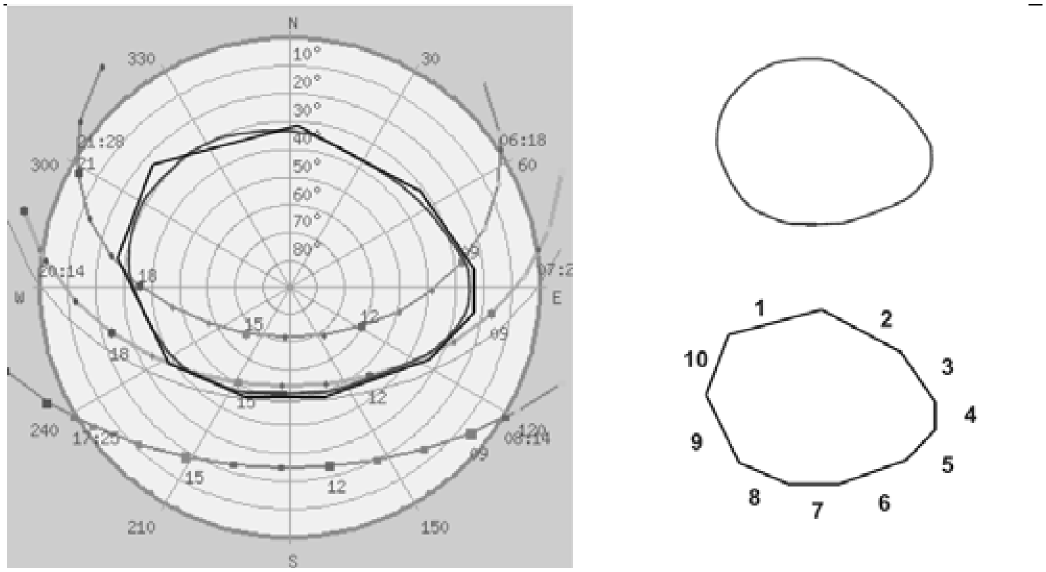


Figure 5.1(d) optimum orientation for the building geometry

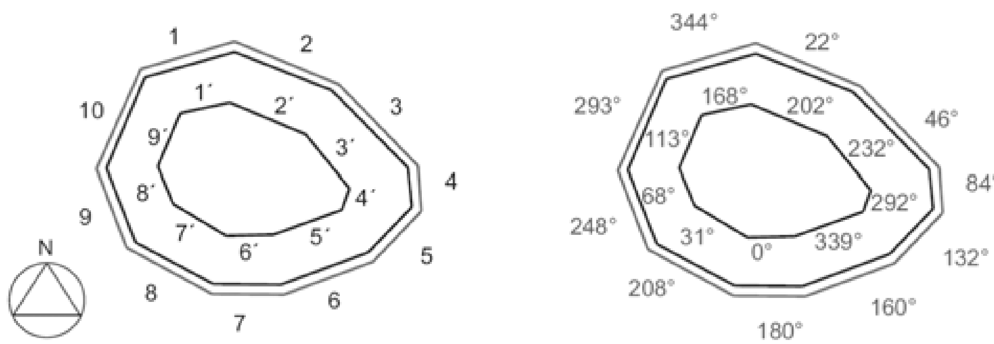


Figure 5.1(e) Description of the building façade orientations

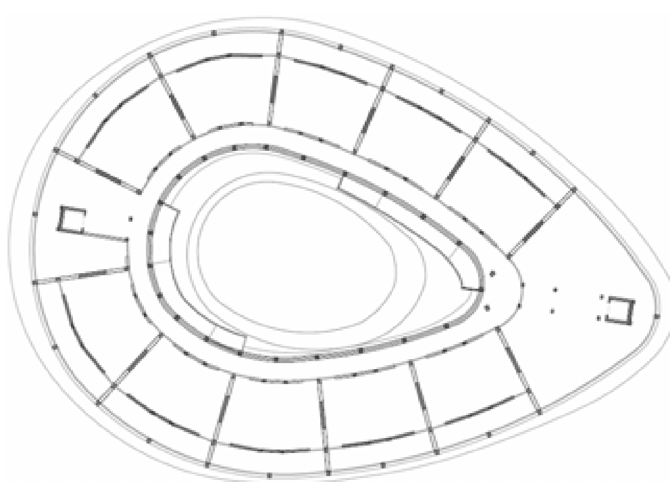


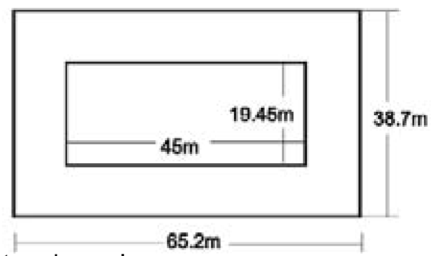
Figure 5.1(f) Hotel project’s general floor plan

Comparison of the total heat gains obtained from direct solar radiation of a rectangular North/South orientated floor plan and the oval shaped floor plan. Data calculated with the computer simulation program SolRad3, on the summer solstice (21st of June) during the day.

In both buildings the façades facing the courtyards also will be considered.

Rectangular floor plan

Global distribution of sun in the surface of every orientation during the day (21st of June):



- Geometry of the building:

6 storey building

Floor Area : 1641m2

Total height : 23m

- Exterior envelope

North facade 2173,9 W/m2 x 1499m2

East facade 4203,7 W/m2 x 890m2

South facade 3010,8 W/m2 x 1499m2

West facade 4203,9 W/m2 x 890m2

- Courtyard envelope

North facade 2173,9 W/m2 x 1035m2

East facade 4203,7 W/m2 x 447m2

South facade 3010,8 W/m2 x 1035m2

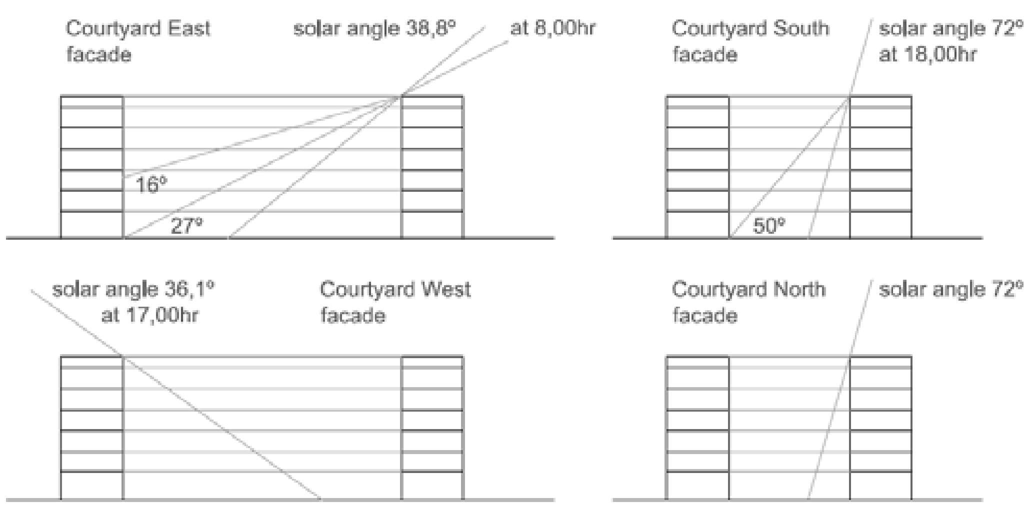
West facade 4203,9 W/m2 x 447m2

- Heat gain due to the solar radiation incidence:

On the outer building envelope 1525,7KW

On the inner building envelope 642.5KW

Total heat gain from solar radiation 2168KW

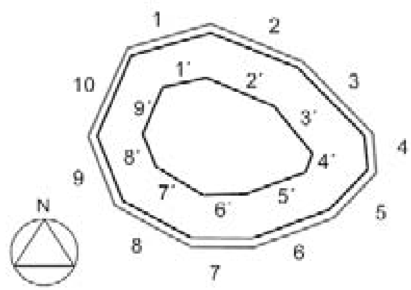


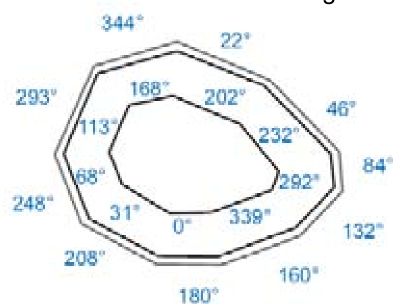
Oval floor plan

Global distribution of sun in the surface of every orientation during the day (21st of June):

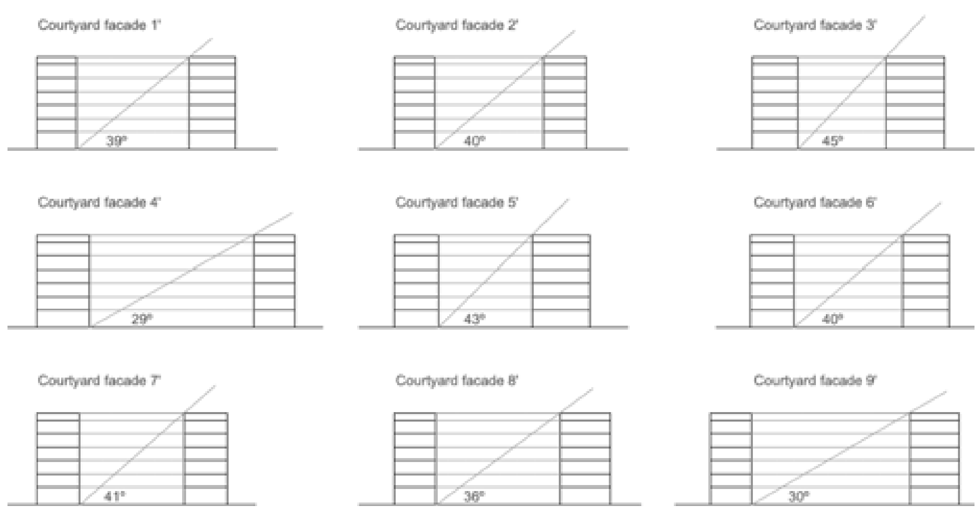
- Geometry of the building:

6 storey building   Floor Area : 1641m2   Total height : 23m





Façade 1 : 2382,2 W/m2	Façade 1' : 2383,3 W/m2	
Façade 2 : 2546,4 W/m2	Façade 2' : 2451,3 W/m2	**Total exterior envelope**
Façade 3 : 3314,4 W/m2	Façade 3' : 2483,5 W/m2	**heat gains : 1343,11 KW**
Façade 4 : 4148,1 W/m2	Façade 4' : 2680,1 W/m2	
Façade 5 : 3934,7 W/m2	Façade 5' : 1203,5 W/m2	**Total courtyard envelope**
Façade 6 : 3274,6 W/m2	Façade 6' : 1107,8 W/m2	**heat gains : 501,96 KW**
Façade 7 : 3010,8 W/m2	Façade 7' : 1269,4 W/m2	
Façade 8 : 3474 W/m2	Façade 8' : 2550,9 W/m2	
Façade 9 : 4202,9 W/m2	Façade 9' : 3055,8 W/m2	**Total heat gains : 1845 KW**
Façade 10 : 3868,2 W/m2		



CONCLUSION : Oval geometry floor plan configuration has **15% less** heat gains caused by solar radiation incidence onto the building envelope.

B. Wind currents study

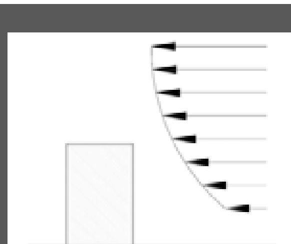
The architectural design can ensure natural air movement through two principles[19]:

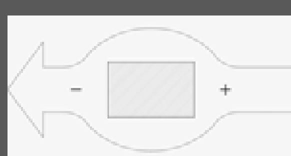
- Air movement by pressure differential
- Air movement by convection

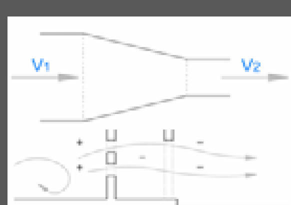
B.1. Air movement by pressure differential:

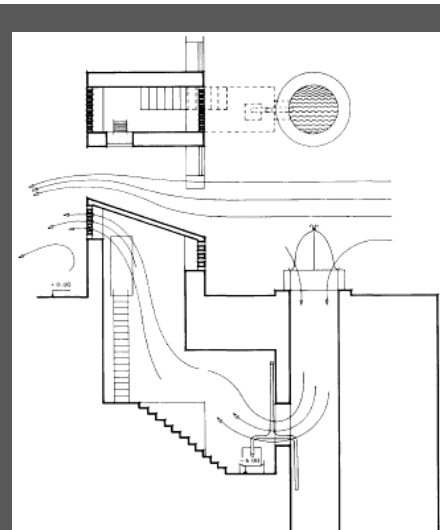
Differences in wind velocity produce a **pressure differential** which results in air flowing from the higher to the lower air pressure zone. This phenomenon is called **Venturi Action**; the pressure of a moving fluid decreases as air volume has to pass, and the speed increases.

In terms of indoor air movement caused by a pressure differential (ΔP) the air flow is steadier in cases that depend more on the suction resulting from low air pressure than on the high air pressure caused by wind force. Experience has shown that air movement is faster and steadier when the area of the openings on the leeward side of a structure is larger than the inlets in the windward side.









Figures 6.1(g)
Explanatory figures show the wind Movement caused by the pressure differential

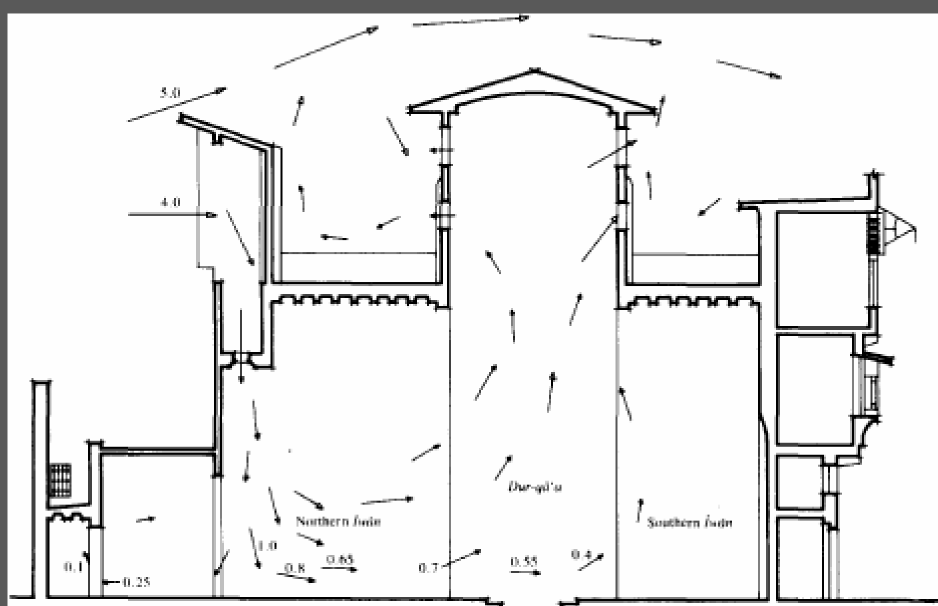
[19] Fathy, Hassan (1986) Natural Energy and Vernacular Architecture: Principles and Examples with Reference to Hot Arid Climates, the University of Chicago Press, Chicago and London.

B.2. Air movement by convection:

The air is warmed, causing convention with warm air rising and being replaced by cooler air. A cool draft is created in the space between the warm area and the cool air intake opening. The rate of air flow caused by convention in buildings is determined by the difference on the level of openings, with greater airflow resulting from the greater difference in the heights of the openings.

The more the air heats up (i.e. absorbs energy), the faster the gas molecules move. The air pressure rises, the air becomes less dense and hence lighter per volumetric unit, and it rises. In an enclosed room, this therefore results in different air temperatures, with a layer of warmer air at the top and cooler air below. Objects create an obstacle to the flow of air, splitting up the current of air as it flows past.

Figures 6.1(h)
Shows the air movement produced by convention
Hassan Fathy, Cairo (1900-89)
Studies to integrate traditional Egyptian architecture with new methodologies



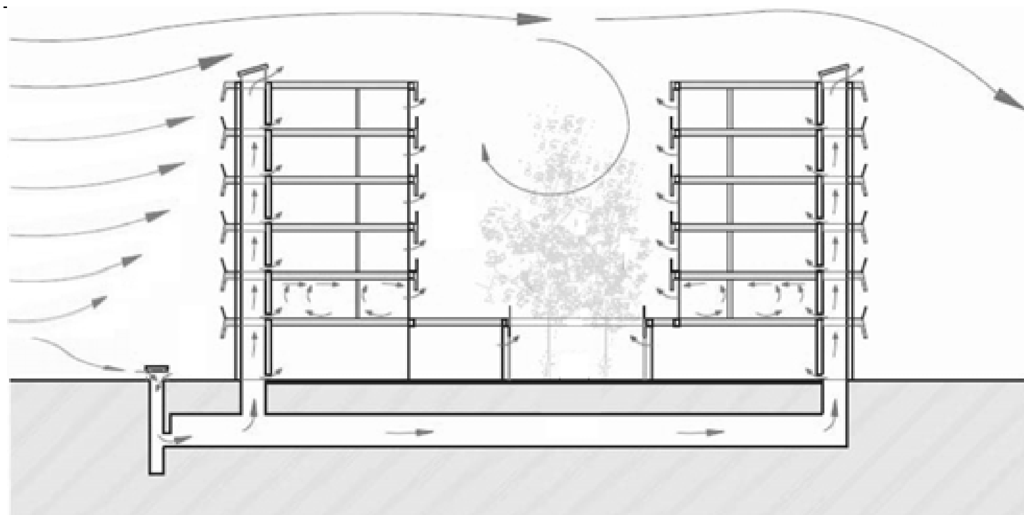
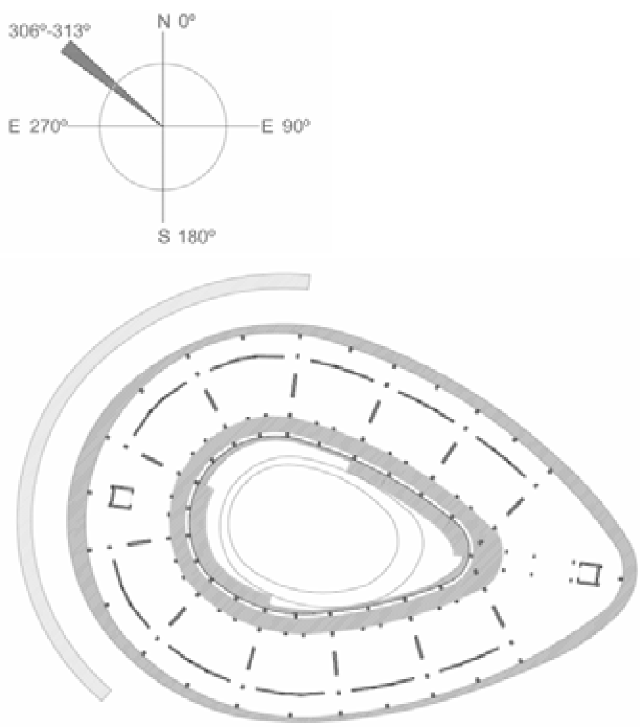


Figure 6.1(i) sketch of wind movements on the Hotel Project Building

Thanks to the implementation of small openings on the windward direction it is possible to generate a subterranean air current that can be distributed into the hotel rooms through courts that open on the top. In that way it creates a chimney effect and facilitates the air circulation and natural ventilation to the building.



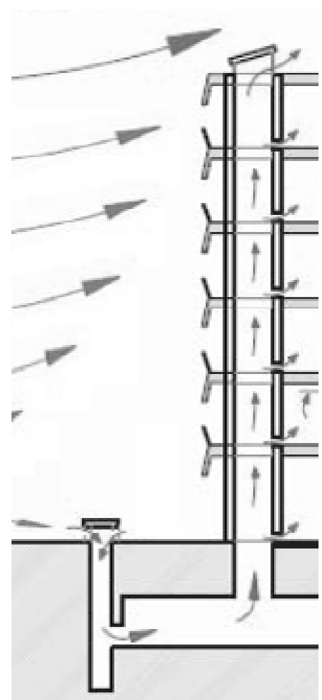


Figure 6.1(j) Floor plan indicating the position of the opening in the direction of the windward, which is the North-West direction, as it is shown in the diagram.

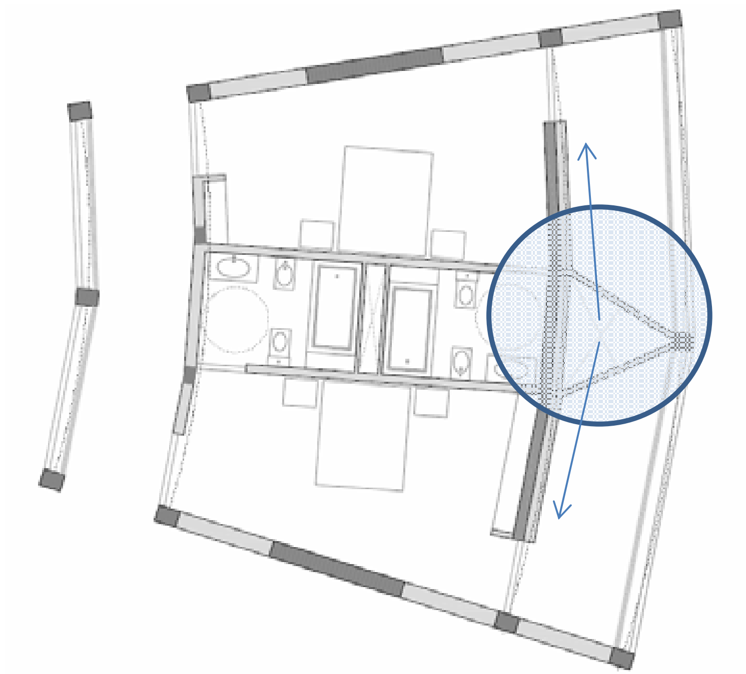


Figure 6.1(k) Hotel room floor plan indicating the ventilation courtyard, which provides fresh air in summer, through the basement.

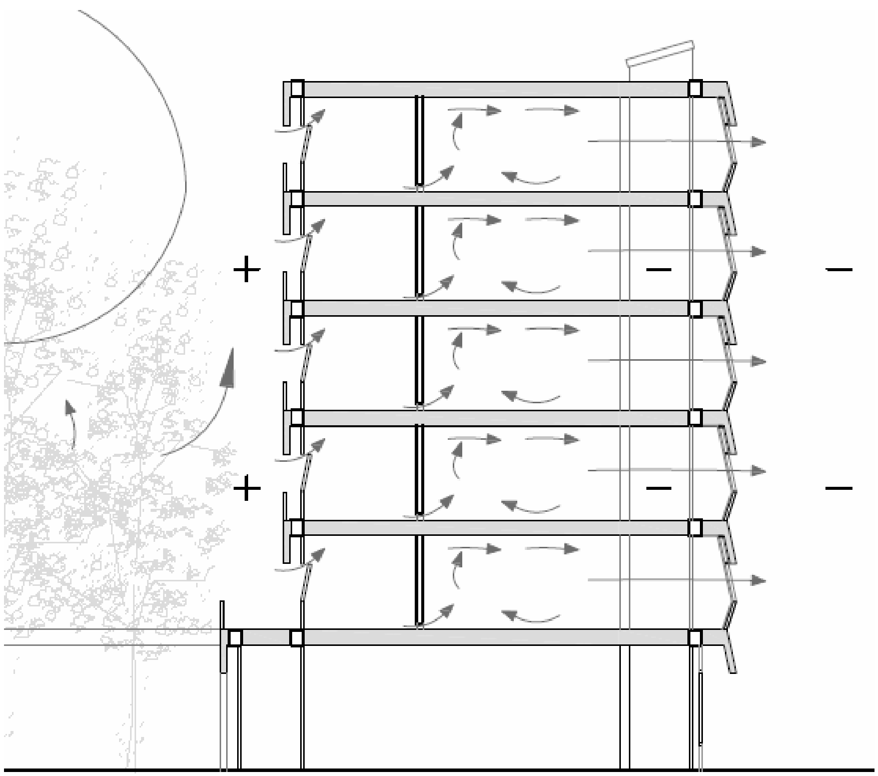


Figure 6.1(l) Diagram of natural ventilation air currents in the hotel rooms

C. Implementation of the courtyard

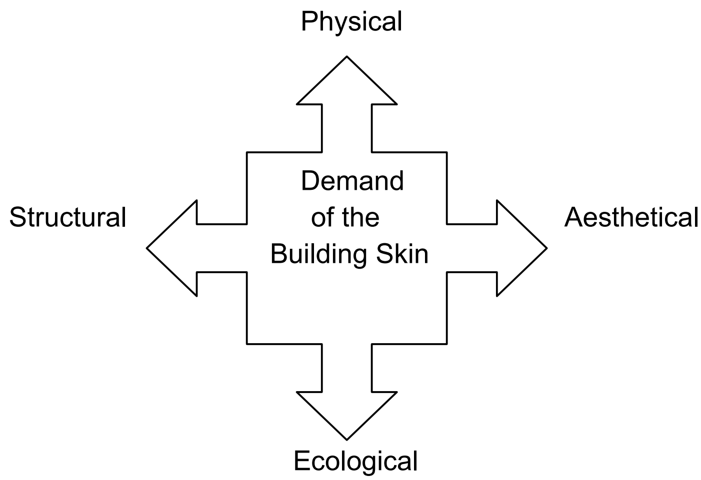
In the Mediterranean region the temperature drops quite a lot after sunset. The air is relatively free of water vapor that would reflect the heat back towards the ground, as occurs in warm-humid regions. To enhance thermal-comfort, this phenomenon has been used in the architectural design of houses by employing the courtyard concept. People learned to close their houses to the outside and open them inwardly onto internal courtyards, which are open to the sky.

As the evening advances, the warn air of the courtyard which has been heated directly by the sun and indirectly by the warm building rises and is gradually replaced by the already cooled night air from above. This cool air accumulates in the courtyard in laminar layers and seeps into the surrounding rooms, cooling them. In the morning, the air of the courtyard, which is shaded by its walls and the surrounding rooms heats up slowly and remains cool until late in the day when the sun shines directly into the courtyard. In this way, the courtyard serves as a reservoir of coolness.

Figures 6.1(m) images of the project model

6.2. The façade study

Façades serve as the separating as well as the linking element between the inside and the outside of a building. Generally speaking, a building envelope has to respond to four key demands: physical demands, aesthetical demands, ecological demands and structural demands (see graphic below).



- The **physical demands** answer to:
Which are the practical purposes of the building skin?

- The **structural demands** answer to:
How is the building skin supported?

- The **aesthetical demands** answer to:
what does the building skin look like?

- The **ecological demands** answer to:
What is the energy consumption of the building skin during construction, use and demolition?

This research project is primarily concerned with the relationship between physical factors and a building's façade. More specifically, it aims at the optimization of the thermal performance of wooden façade-systems under Mediterranean climate conditions. The role of the other factors mentioned here (i.e. structural, ecological and aesthetical demands) as well as the inter-dependencies and potential trade-offs that exist between them are thus not specifically addressed by my research project.

Pertaining to physical factors, façades provide, among other things, the following functionality: Ventilation, heating and cooling, lighting as well as protection from sun, glare, wind, humidity, acoustic (noise) and fire. Façades are thus important to improve a buildings indoor environment (enhanced sun protection and cooling load) and can also significantly affect its operating costs (minimizing lighting, cooling and heating energy use). In terms of the comfort-levels of a buildings indoor environment, façades-systems need to address:

- Thermal requirements

- Visual requirements

- Acoustic requirements

- Hygienic requirements

To study the way the thermal performance of a building can be improved by means of wooden façade-systems, my work must of course consider the constraints of latitude, location (physical surrounding) and solar orientation. It is thus important to examine the climatic conditions of the area in which my building is located. To have a clear geographic reference point for my project, the city of Barcelona has been selected as location of the building-site of my project (a multistory hotel building). However, Barcelona stands here for the example for a city with Mediterranean climate conditions. The façade solutions proposed for my project can thus be applied in other places with similar weather conditions.

Figure 6.2(a) Housing building (2007) Madrid, Foreign Office Architects
Façade composed entirely by Bamboo louvers (secondary façade)

While the weather conditions are resulting from the chosen location of my hotel-project, the geometry of the building and the orientation of its façades are considered to be “variable”. The geometry of the building (its oval shape) and the orientation of its façades will therefore be designed in a way that helps to optimize the thermal performance of my building-project, by addressing factors such as sun radiation quantity, natural lightening and ventilation. The aspired high quality thermal performance of my building-project therefore derives from the combination of its geometry, the employed façade-system as well as the orientation of its façade. The overall design of my project-building (geometry; façade-system and orientation) should produce a positive natural effect that improves the indoor environment of my building-project and reduces its operating costs.

A. Big scale. Façade section study

Once calculated the heat gains caused by the solar radiation in each orientation this research is focused in section solutions for the building façade, in accordance to the sun inclination angle and the intensity of the solar radiation in each of these façade orientation.

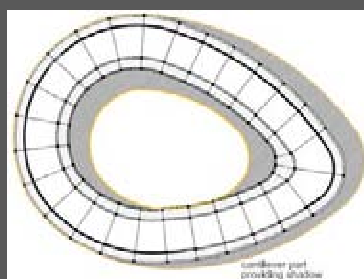
To improve the thermal performance of the facades in each orientation, two solutions are adopted in the project:

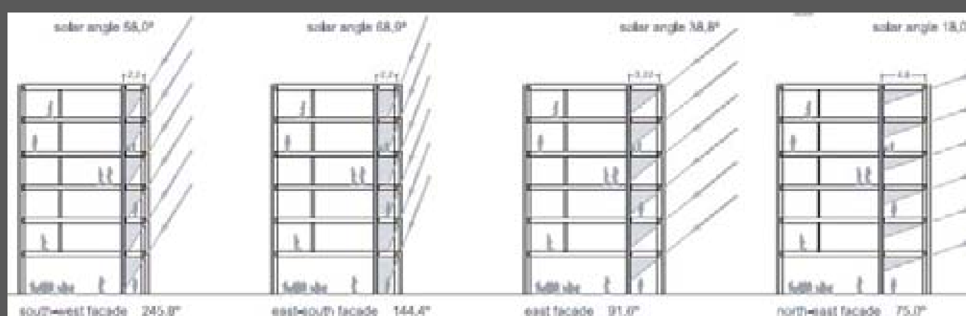
- Adaptation of the traditional Solana (glass façade gallery and timber framing), to the actual architectonic requirements. By using the "double skin" concept it is possible to reduce the energy demand for cooling in summer conditions. The secondary skin (outer skin) serves to protect the building facade from the excessive solar heat gains.

- Sun shading system based on cantilevers that develop in different geometries depending on the façade orientation. In order to respond in an optimum way to the sun protection effectiveness, there are three variations, which are fondant in the same system.

The information data, which are used for the section design results are obtained from the computer program SolRad3. This program provides the data of sun inclination every hour in each façade orientation, its intensity and the angle which the solar radiation affects on the façade.

Analyzing the angle of the solar radiation for every façade section and considering the varying intensity of sun radiation during day time, a façade system is developed that optimizes the sun protection through the cantilever system.



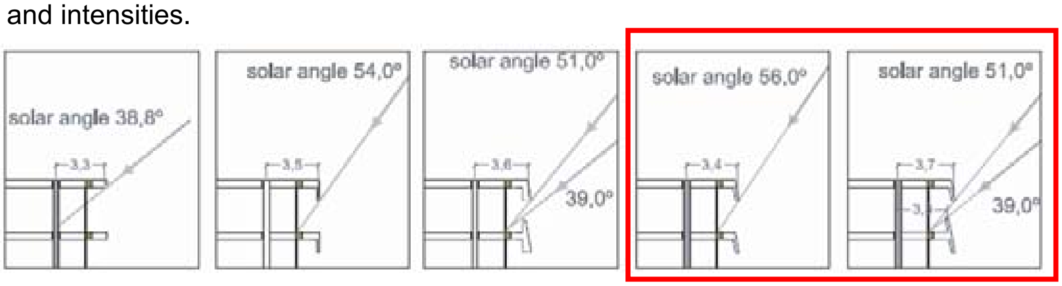


Diagrams of the two façade concepts applied for the project:

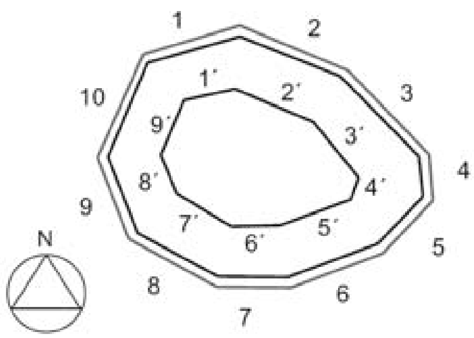
-Double skin façade and cantilever sun shading adapt to each building orientation.

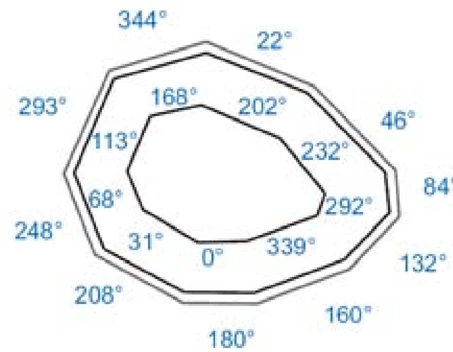
-Depending on the sun inclination the cantilever is larger or shorter.

Step one: design of an optimal cantilever system adaptable to different sun angles and intensities.



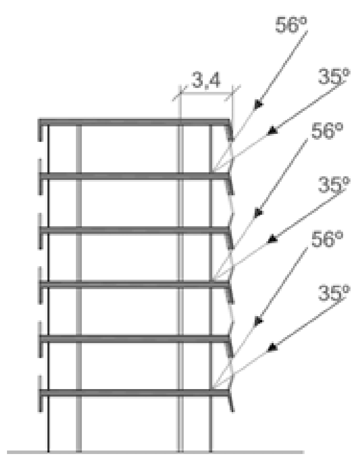
Through the described solutions the range of the solar radiation angle that affects the façade is reduced in comparison to the other solutions shown in this diagram.





Step two: once the system for the cantilever solution has been developed the appropriate cantilever dimensions are indentified for each façade orientation.

Study of the exterior façade



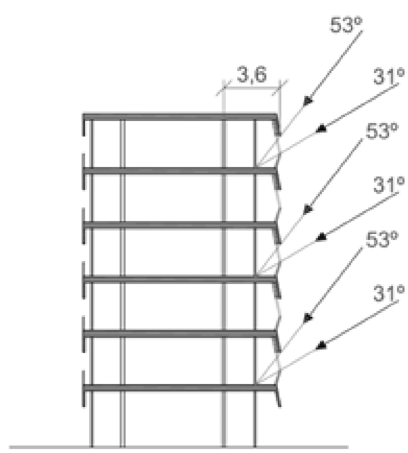
Façade N-W (344º) **1**

Strongest solar radiation:

70º-60º angle (~210W/m2)

55º-45º angle (180-80W/m2)

Uncovered part



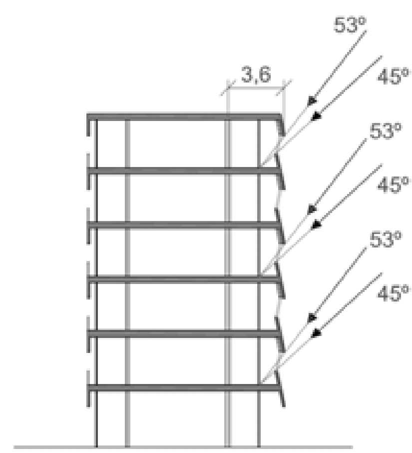
Façade N-E (22º) **2**

Strongest solar radiation:

65º-50º angle (~250W/m2)

50º-42º angle (200-100W/m2)

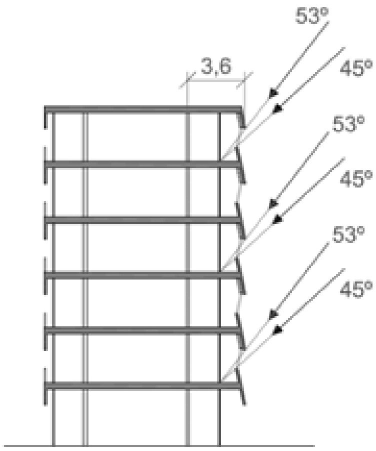
uncovered part



Façade N-E (46º) **3**

Strongest solar radiation:

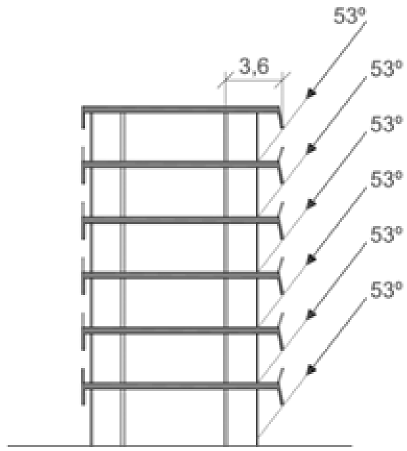
50º-40ºangle(~400W/m2)



Façade N-E (84º) **4**

Strongest solar radiation:

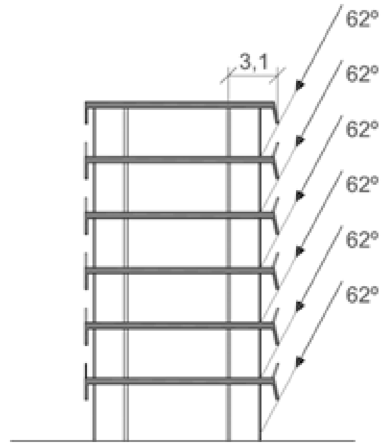
40º-25º angle (~530W/m2)



Façade E-S (132º) **5**

Strongest solar radiation:

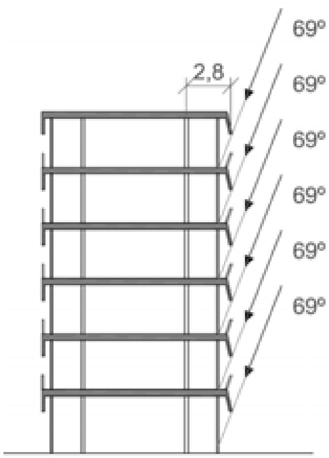
70º-68º angle (~295W/m2)



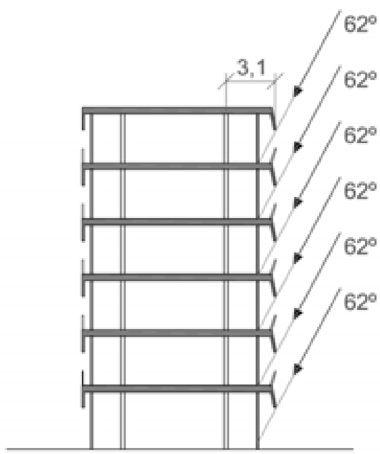
Façade E-S (160º) **6**

Strongest solar radiation:

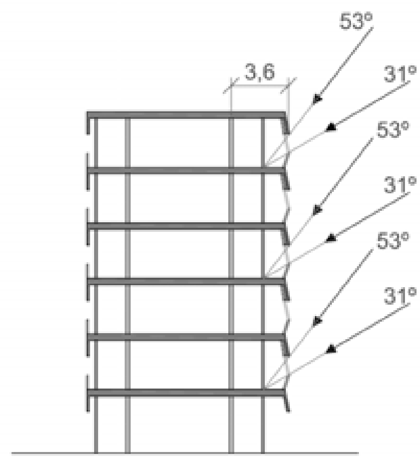
70º-68ºangle(~295W/m2)



Façade S (180º) **7**
Strongest solar radiation:
75º-70º angle (~255W/m2)

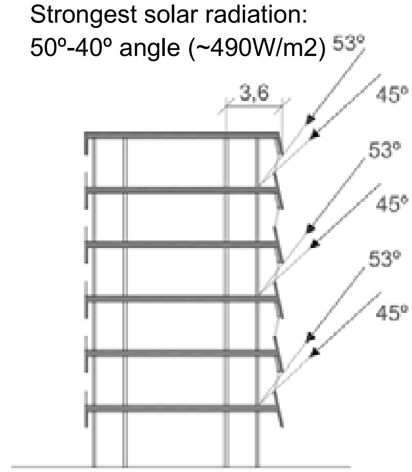


Façade S-W (208º) **8**
Strongest solar radiation:
70º-65º angle (~330W/m2)



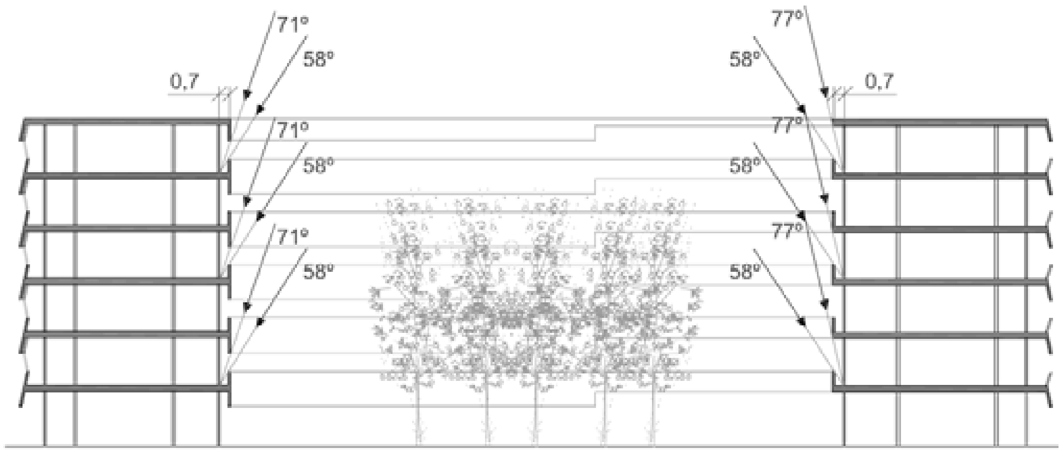
Façade S-W (248º) **9**
Strongest solar radiation:
50º-40º angle (~490W/m2)

Figure 6.2(b) project's model image



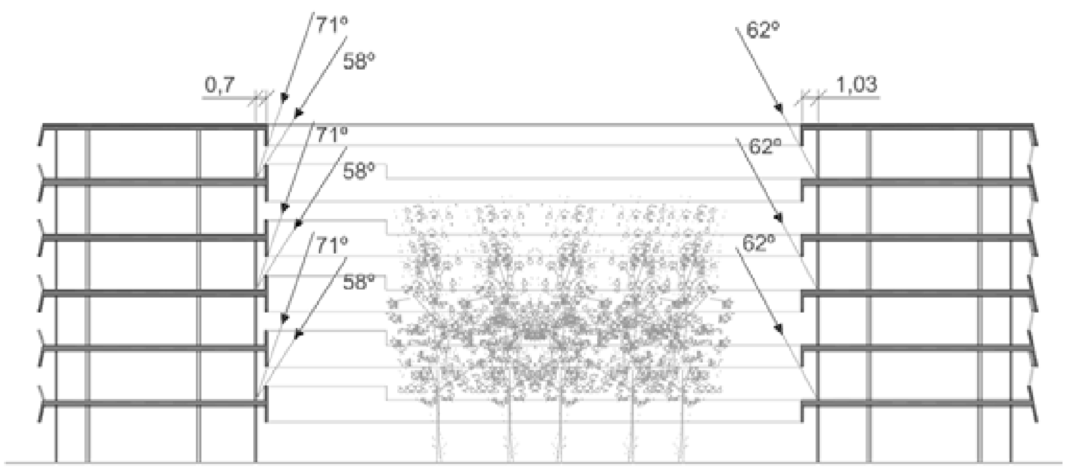
Façade W-N (293º) **10**
45º-35º angle (~490W/m2)

Study of the courtyard façade



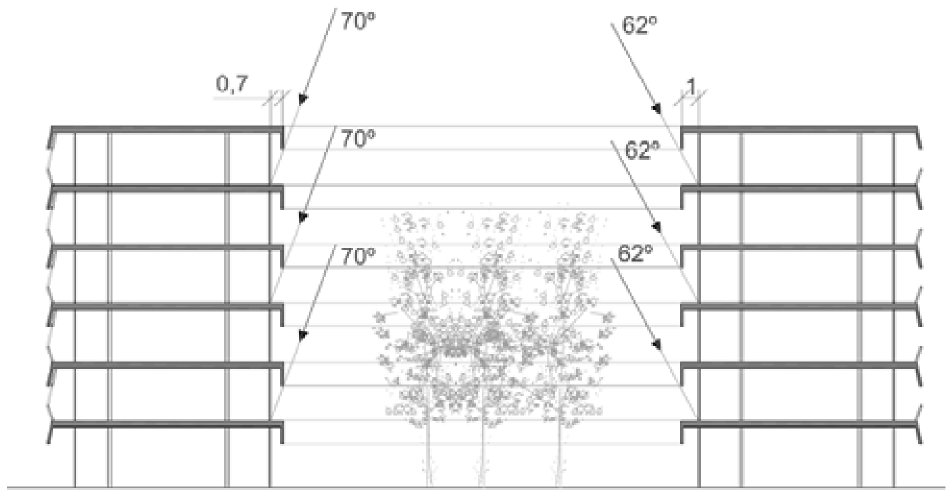
Façade E-S (113º) **9’**
Strongest solar radiation
50º-40º angle (~500W/m2)
Every floor reachable from 9AM-1PM

Façade N-W (292º) **4’**
Strongest solar radiation
40º-30º angle (~520W/m2)
Every floor reachable from 2PM-5PM



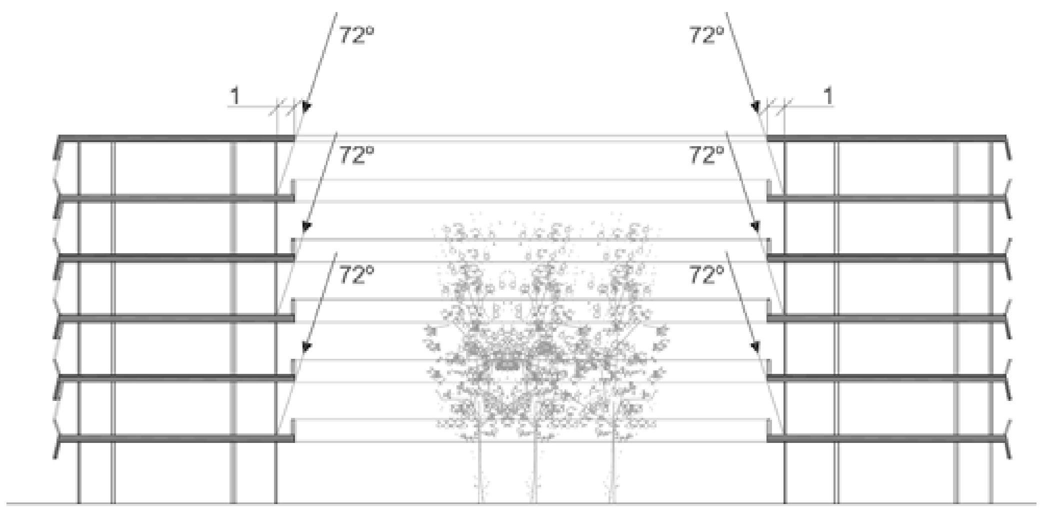
Façade N-E (68º) **8’**
Strongest solar radiation
45º-30º angle (~490W/m2)
Every floor reachable from 9AM-12AM

Façade S-W (232º) **3’**
Strongest solar radiation
60º-50º angle (~440W/m2)
Every floor reachable from 12AM-5PM



Façade S-W (202º) **2’**
Strongest solar radiation
70º-66º angle (~310W/m2)
Every floor reachable from 10AM-12AM

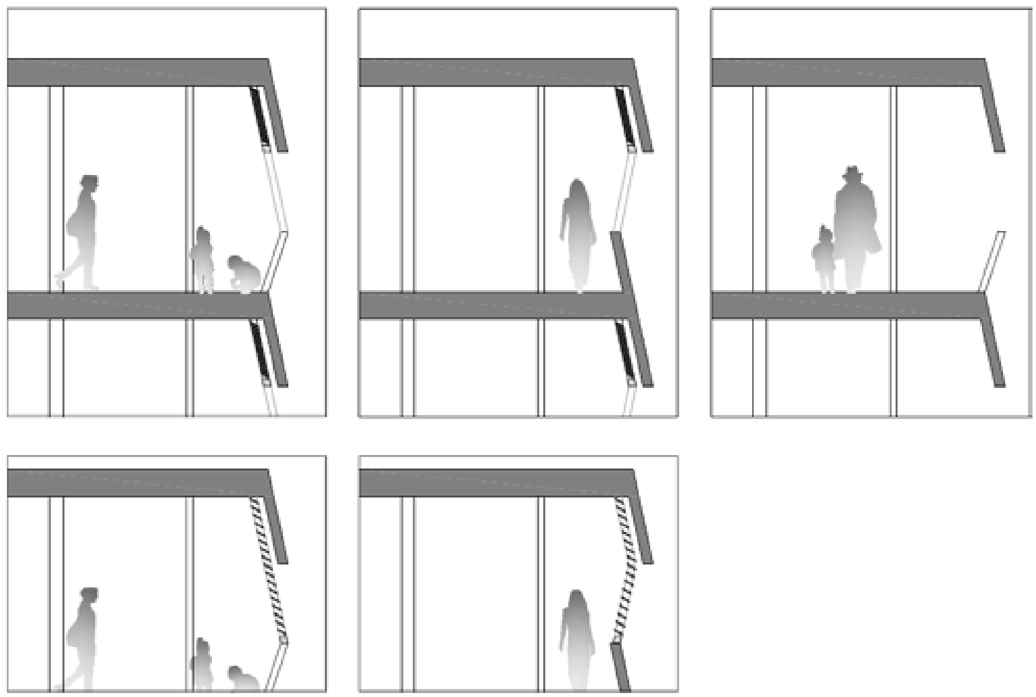
Façade N-W (339º) **5’**
Strongest solar radiation
65º-60º angle (~240W/m2)
Every floor reachable from 4PM-5PM



Façade E-S (168º) **1’**
Strongest solar radiation
73º-70º angle (~275W/m2)
Every floor reachable from 10AM-3PM

Façade N (0º) **6’**
Strongest solar radiation
80º-70º angle (~105W/m2)
Every floor reachable from 4PM-5PM

Step three : After the solar radiation incidence on the façade has been established and the optimal dimensions of the cantilever in different façade sections have been determined, three sun-shading types are developed, which are based on one design system for the envelope.



1 Facades 1, 2 and 9
N, S-W, N-E orientations

2 Facades 3, 4 and 10
N-E, E, N-W orientations

3 Facades 5, 6, 7 and 8
S-E, S, S-W orientations

Step four : Elevations of the building based on the results of the solar façade study:

South Elevation

Figure 6.2(c) Project's model images

West Elevation

North Elevation

Figure 6.2(d) Project's model images

East Elevation

B. Medium scale. Study of the building envelope components

This “medium scale study” further examines the different design alternatives applied at the building envelope:
- Sun shading systems
- Thermal storage capacity of the building (and building envelope)
- Secondary skin facade

B.1. Sun shading system

Windows and glass facades require an efficient sun shading system capable of limiting the heat load for cooling and at the same time their design needs to facilitate the use of natural lighting. It is commonly understood that people feel more comfortable in natural light than in artificial light. For this hotel project, the natural light needs to be sufficient to obtain comfortable visual perception in the individual rooms and should also contribute to a reduction in the energy consumption of the building by avoiding the need for too much artificial lighting.

The measures to protect the façade building against solar radiation have a great impact on the architectural expression of the façade and are thus also important in terms of the overall design.

Figure 6.2(e) 1-Venetian blinds adapted to the contemporaneous architecture
Housing (1992) Barcelona, J.A. Coderch
2-Image of a traditional Mashrabeja

- **Criteria to follow for sun-shading devices**

In order to achieve optimal results, the sun-shading devices should meet the following criteria as much as possible:

- **completely reflecting solar radiation** to the environment (independent from sky conditions)
- **being entirely transparent for diffuse light** from the remainder of the visible sky and for light reflected by surrounding environmental features, such as trees.
- **being entirely transparent to daylight in cases of overcast sky** or during times when the sun is obscured by clouds.

Figure 6.2(f) multiple variations for sun protection devices
Housing buildings (2006) Ceuta/Cadiz, Andalusia, Jose Morales architect

It might goes without saying that these are idealized criteria, which cannot be fully met in the real world. However, the proposed design will ensure a good performance of the façade, which comes quite close in meeting the mentioned criteria. More specifically, the design of the sun shading system will be composed of the following elements:

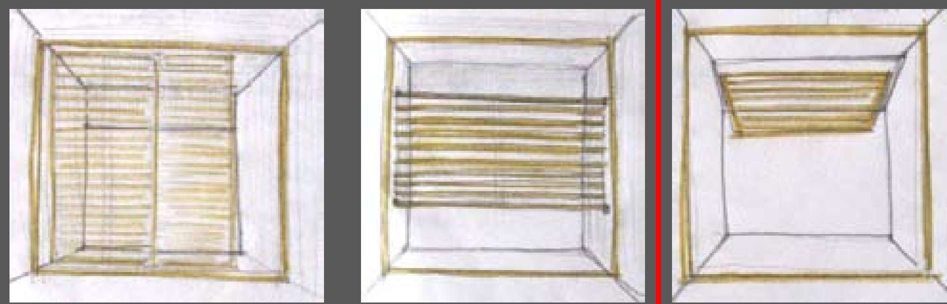
- **External sun-shading system** (offers the most effective protection since solar radiation is intercepted before reaching the facade).
- **Operable sun-shading system** (design combination which adopts the characteristics from traditional Venetian Blinds and Mashrabejas).

According to a study of Dirk U. Hindrichs and Klaus Daniels on solar-shading properties, the most efficient solution is the one that relies on external shading and low-E coated double glazing.[20] In order to measure the effectiveness of different sun-shading systems the Fc values are used. The following table indicates the energy transmittance coefficient of a window with or without solar-shading[21]:

Solar shading systems	Fc values
Without solar shading system	**1.00**
Rotating blades, rear ventilated	**0.25**
Venetian blind with low transparency (below 20%)	**0.25**
Venetian blinds, general	**0.40**
Awnings, general	**0.50**

Table 5.4 Reference values for reduction factors Fc

[20] Hindrichs, Dirk U.; Daniels, Klaus (2007) Plus minus 20º/40º latitude: Sustainable building design in tropical and subtropical regions, Edition Axel Menges, Stuttgart / London.
[21] Ibid



1 2 3

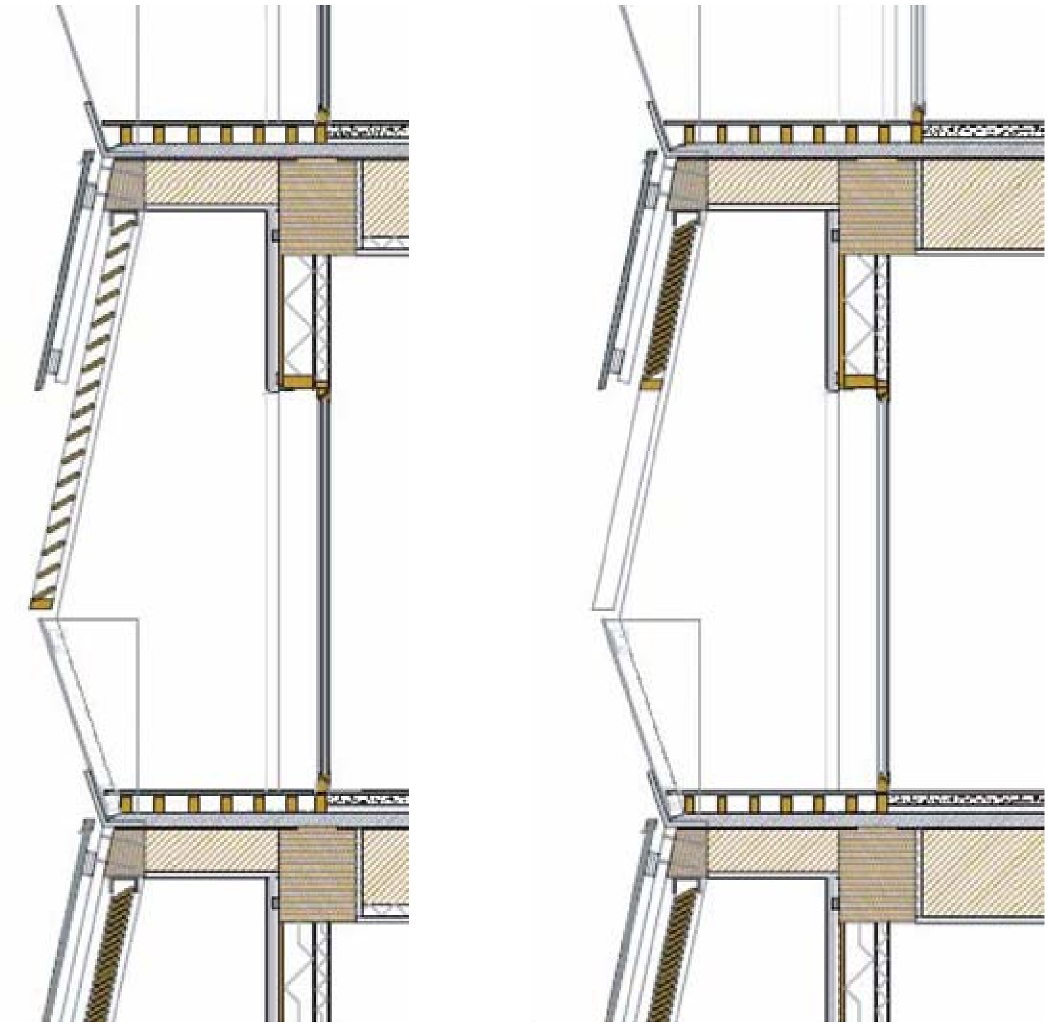
Figures 6.2(g) Early sketches for ideas about different blind types

Figure 1 shows a usual movable blind, very commonly used in Mediterranean Countries.

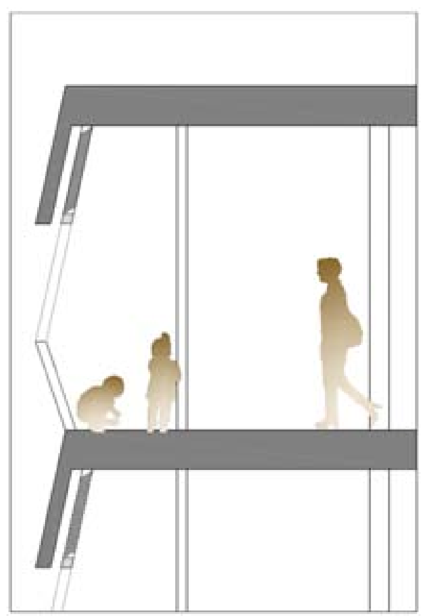
Figure 2 shows a fixed blind placed where the cantilever element can not protect the sun radiation, in a low inclination of the sun.

Figure 3 shows the solution designed for this project, in which the sun-shading system is movable and can be displaced when not needed.

In both previous solutions, the visibility gets reduces because of the blades. In the solution number 3 this disadvantage is corrected through the folding blind system.



Façade section Detail



The façade typology that has been developed in the project consists of:

Sun-shading envelope

20mm vertical Larch strips, 30mm battens and 30mm counter-battens, suppoted by laminated timber edge beams, and movable folding wooden blinds.

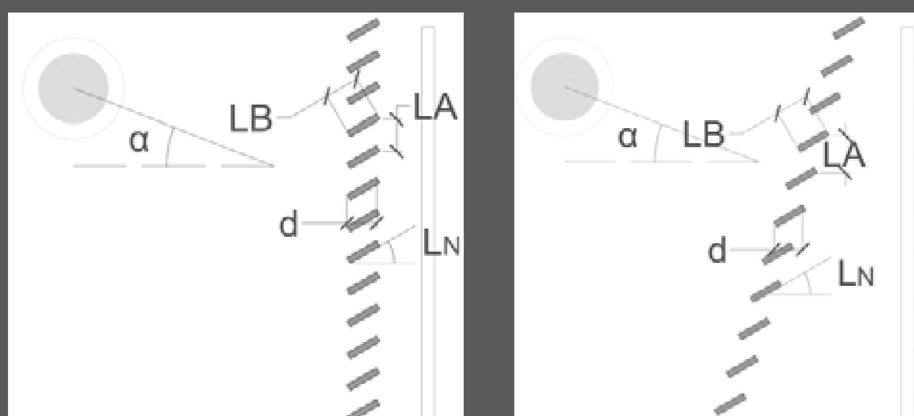
Building envelope

20mm Larch boarding, 30mm battens, windproof layer, 100mm polystyrene thermal insulation between 100mm posts, vapour barrier, 45mm battens, 19mm three layer laminated fir boarding.

- Design for sun-shading systems

- Criteria to follow:
  - Effectiveness of solar shading / Energy transmittance coefficient
  - Light regulation / Utilization of natural light
  - Susceptibility to dirt
  - Wind load resistance

- Parameters to take into account:
  - Angle of Blades **(L_N)**
  - Distance between blades **(L_A)**
  - Blade width **(L_B)**
  - Cantilever length **(d)**
  - Window height **(h)**



Figures 6.2(h) show how to calculate the dimensions of the blades[22].

$d = L_B * \cos (L_N)$ example: L_B=12cm

$\tan \alpha = L_A - L_B * \sin (L_N) / L_B * \cos (L_N)$ L_N=30º

α = critical angle L_A=13cm α =34º

When solar incidence angle onto façade **$\alpha_1 < \alpha$** critical angle the solar protection system is not efficient. The solar incidence angle and the intensity which affects the vertical building envelope are also obtained from the computer program SolRad3.

[22] Hindrichs, Dirk U.; Daniels, Klaus (2007) Plus minus 20º/40º latitude: Sustainable building design in tropical and subtropical regions, Edition Axel Menges, Stuttgart/London.

B.2. Thermal storage capacity of the building and the secondary skin facade

Thermal storage in the building can be decisive considering the reduction in cooling loads and the reduction of temperature increases. Heat gain in buildings is evident when the heat load is a result of solar incidence or when room temperatures change.

External surfaces of building envelopes show higher or lower temperatures not only as function of ambient air temperature, intensity of solar radiation, and the radiation physics of the building envelope itself but also dependent its own thermal properties. The transmission of external temperature fluctuations through a building envelope is not only a function of its U-value, but also of the capacity of the wall to store heat.

B.3. Cooling and heating demands in a "reference" room

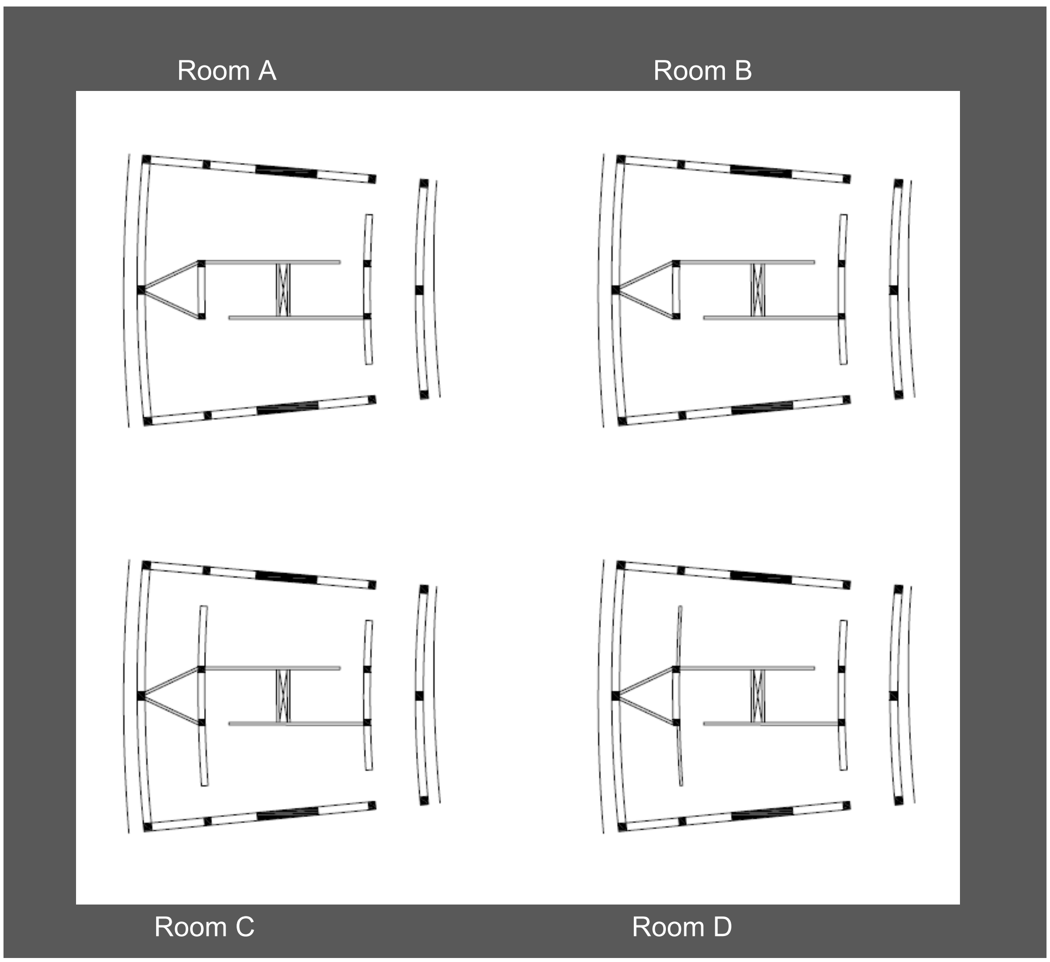
In order to analyze and understand the thermal performance of the Hotel building, this project is centered in studying the case of a “reference” hotel room, in which, it is deepen in the heating and more peruse in the cooling demands that are required during a year. This analysis is carried out with the help of the computer simulation program Lider, provided by the Eduardo Torroja Institute of Construction in Spain.

By this energy demand requirement study it is possible to determine the necessity to use a high thermal storage capacity material as building envelope, or as room partition material ones it has been designed an optimal solar protection for the building skin. And furthermore, to analyze to which extend thermal mass can improve the comfort thermal levels of a room.

When focused mainly in the summer situation, the temperature transmission, from the exterior to the interior space, depends, on the one hand, on the temperature differences between room air and building element surface, and on the other on the air movement on the element surface. The time between the exterior temperature maximum and the maximum on the inside of a space, called thermal lag, is significant when external daily heat loads are delayed and take effect on the inside of a space only after lower external temperatures are present. Large thermal lag is a result of high R-values, inverse of the U-value (R=1/U)[23]. Very light exterior walls show a thermal lag of less that three hours, while heavy walls achieve values of approximately 12 hours.

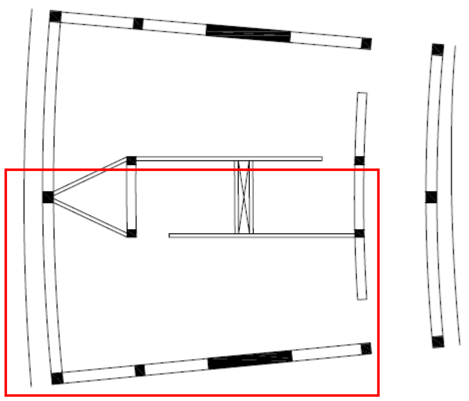
However, as it is demonstrated in the following tests, the results obtained in the computer program Lider, prove that the greatest savings in cooling demand are due to the sun radiation protection measures and to ell insulated assemblies, more than related to the significance of storage capacity of the materials.

The comparison is carried out with two different room geometries, and four different material compositions and building envelope geometries that lead to four room variations, and therefore to four different results.



[23] Hindrichs, Dirk U.; Daniels, Klaus (2007) Plus minus 20º/40º latitude: Sustainable building design in tropical and subtropical regions, Edition Axel Menges, Stuttgart/London.

Room A



Façade Composition:

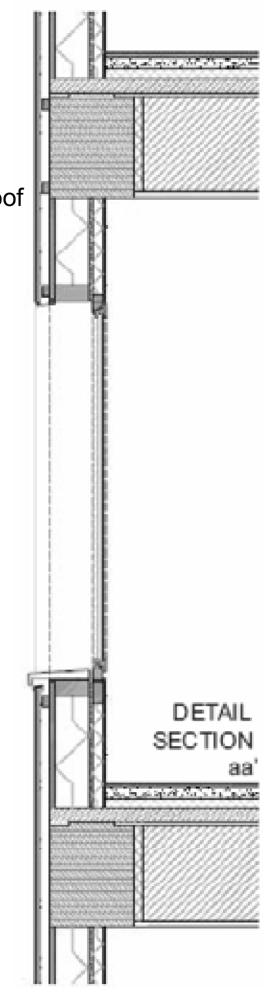
U= 0,40W/m2K

- Larch strips
- Moisture diffusing windproof building paper
- Thermal insulation
- Plasterboard

Interior partitions:

U= 0,45W/m2K

Timber based floor



Room geometry:

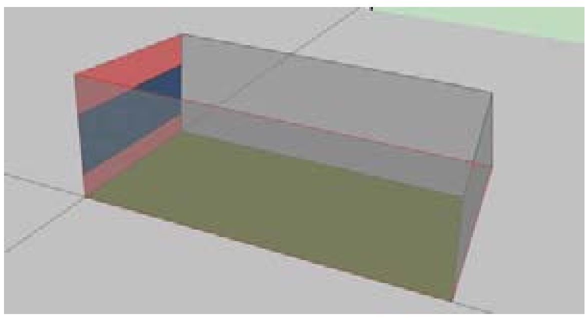
Simple façade

8,5m x 4,5m = 38,25m2

Window dimension:

longitudinal window

1,5m x 4,5 m

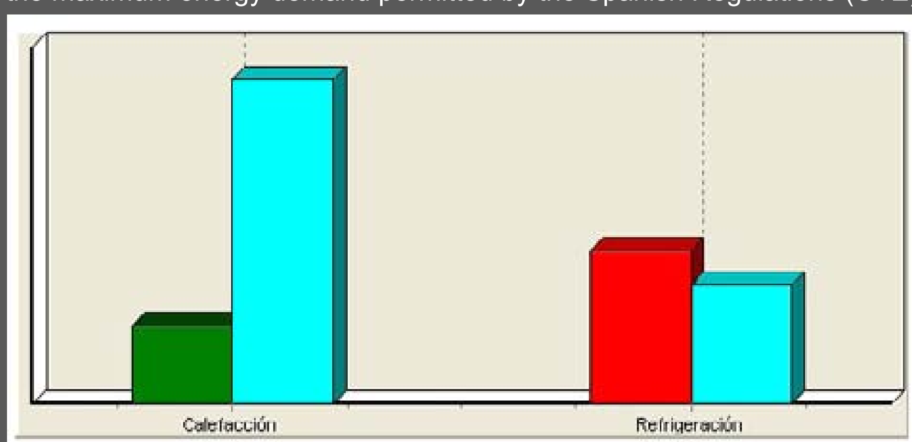


Results obtained from the simulation program:

DOES NOT OBEY

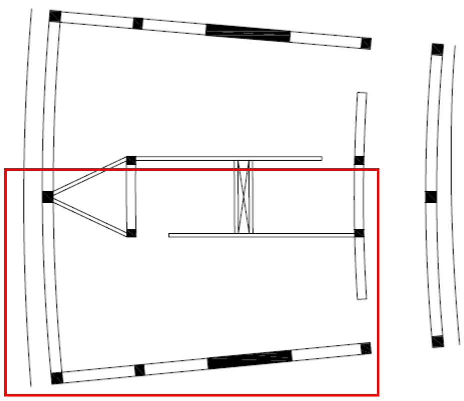
24% respect — 124,9% respect

the maximum energy demand permitted by the Spanish Regulations (CTE)



Annual Heating demand — Annual Cooling demand

Room B



Façade Composition:

- 100mm Prefabricated concrete
- 70mm Thermal insulation
- Vapor barrier
- 250mm Reinforce concrete

Room geometry:

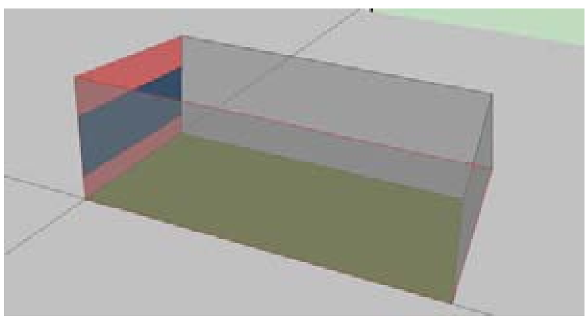
Simple façade

8,5m x 4,5m = 38,25m2

Window dimension:

longitudinal window

1,5m x 4,5 m

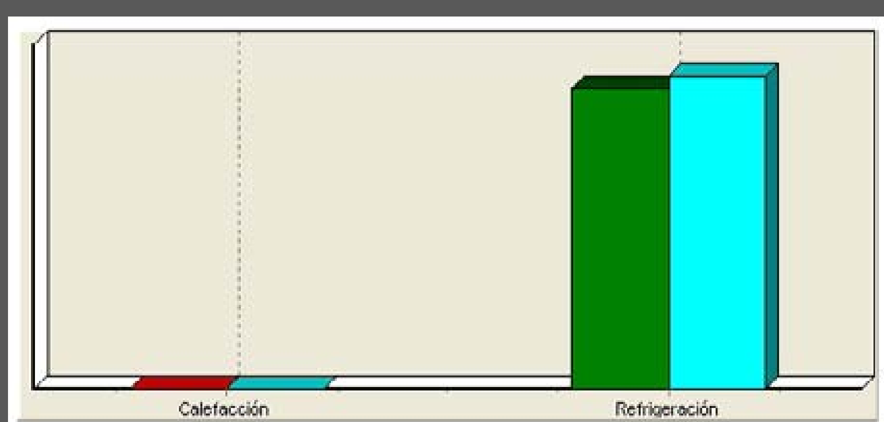


Results obtained from the simulation program:

DOES OBEY

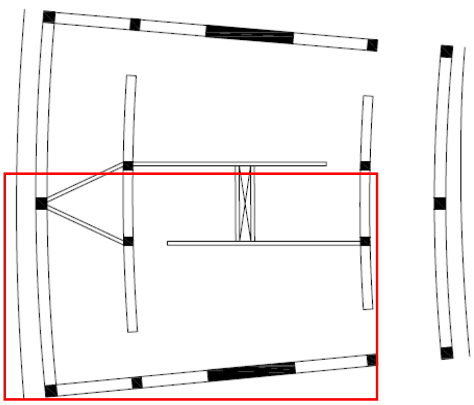
0% respect | 95,9% respect

the maximum energy demand permitted by the Spanish Regulations (CTE)



Annual Heating demand | Annual Cooling demand

Room C



Façade composition

Exterior envelope:

U=0,38W/m2K

- Larch boarding and battens
- Windproof layer
- 70mm thermal insulation
- vapour barrier
- laminated fir boarding on battens

Interior envelope:

U=0,54W/m2K

- 100mm reinforce concrete
- 70mm thermal insulation
- 250mm reinforce concrete

Interior partitions wood base materials

Room geometry:

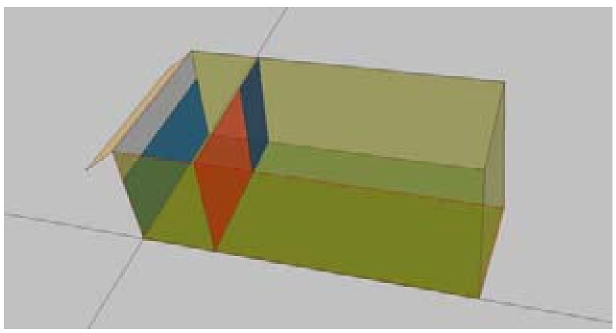
Double skin facade

8,5m x 4,5m = 38,25m2

Window dimension:

Glass fronted window

2,1m x 4,5 m

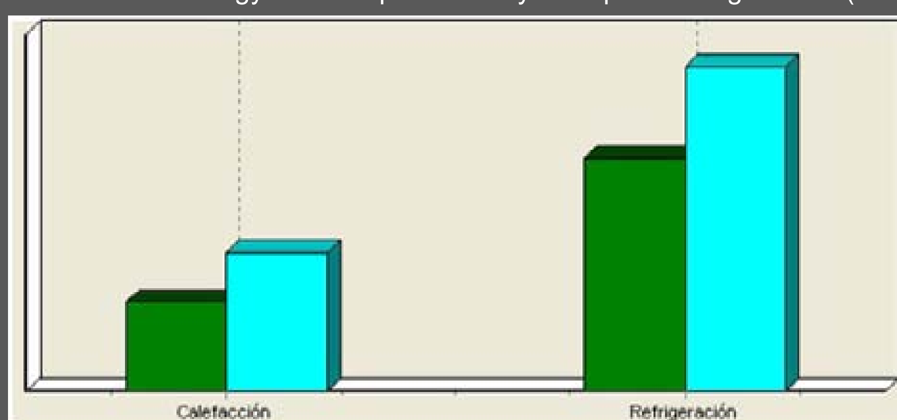


Results obtained from the simulation program:

DOES OBEY

64,4% respect — 71,9% respect

the maximum energy demand permitted by the Spanish Regulations (CTE)



Annual Heating demand — Annual Cooling demand

In this study it is analyzed that the design developed in the project improves considerably the thermal-performance of the testing “reference” room, therefore it is assumed that also helps in reducing the corresponding cooling demands of the project building. The double skin façade, acts as a buffer, in summer conditions, and with the adequate natural ventilation, prevents the overheating and ensures the thermal comfortability.

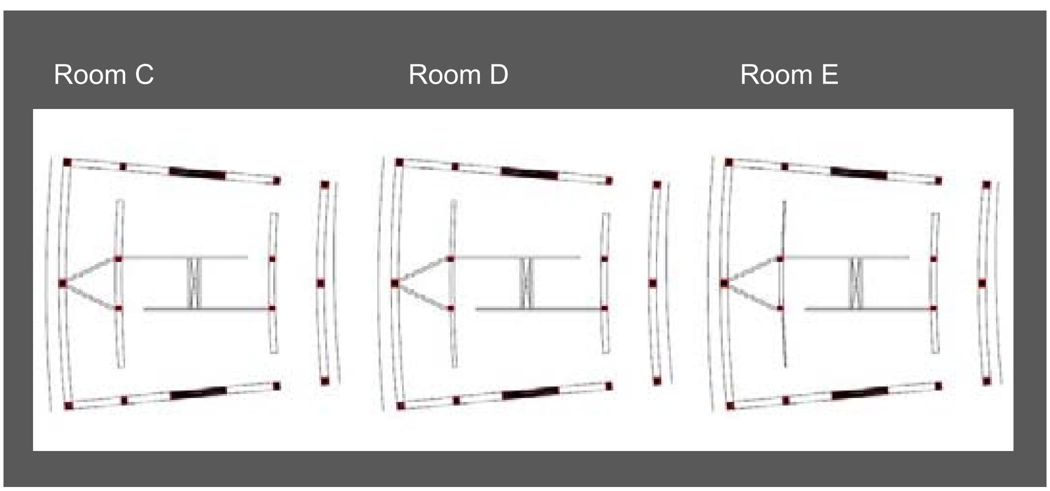
C. Small scale. Study of façade materials and forms

C.1. Cooling and heating demands in a "reference" room

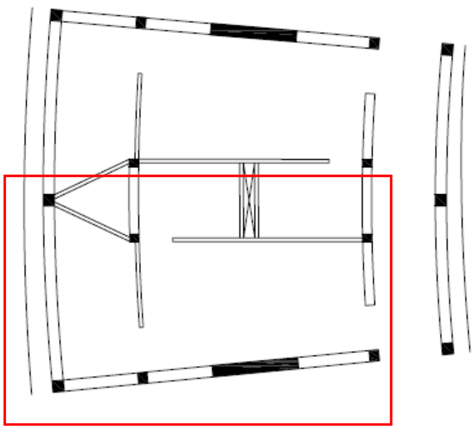
Once it is demonstrated the improvement of the room, in the thermal-performance, by using the double skin façade and the cantilever sun protection system, the following comparative studies analyze the thermal behavior of the different materials used in this room context, with this characterized geometry. That means, by studying the constructional layout. In this sense, regarding the cooling demands of the room, it is determined the relevance of using high storage capacity materials.

The comparison is established between three different constructional layouts of the primary building envelope:

- Concrete + thermal insulation + concrete (case room C, already analyzed)
- Laminated timber wall elements (room D)
- Glass front (room E)



Room D



Façade composition

Exterior envelope:

U=0,38W/m2K

- Larch boarding and battens
- Windproof layer
- 70mm thermal insulation
- vapour barrier
- laminated fir boarding on battens

Interior envelope:

U=0,85W/m2K

- 150mm laminated timber wall element

Room geometry:

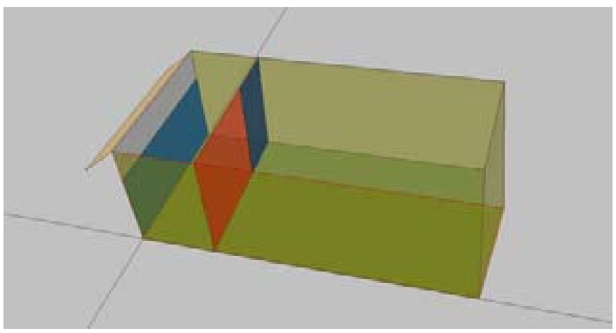
Double skin facade

8,5m x 4,5m = 38,25m2

Window dimension:

Glass fronted window

2,1m x 4,5 m



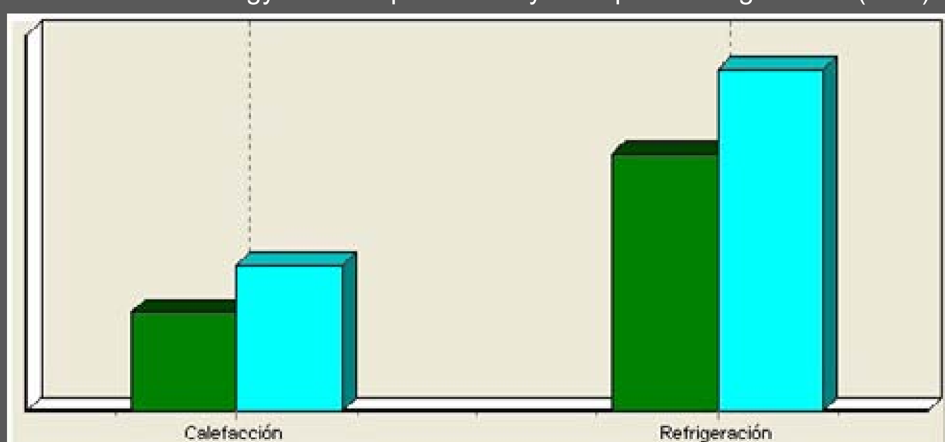
Results obtained from the simulation program:

DOES OBEY

67,7% respect

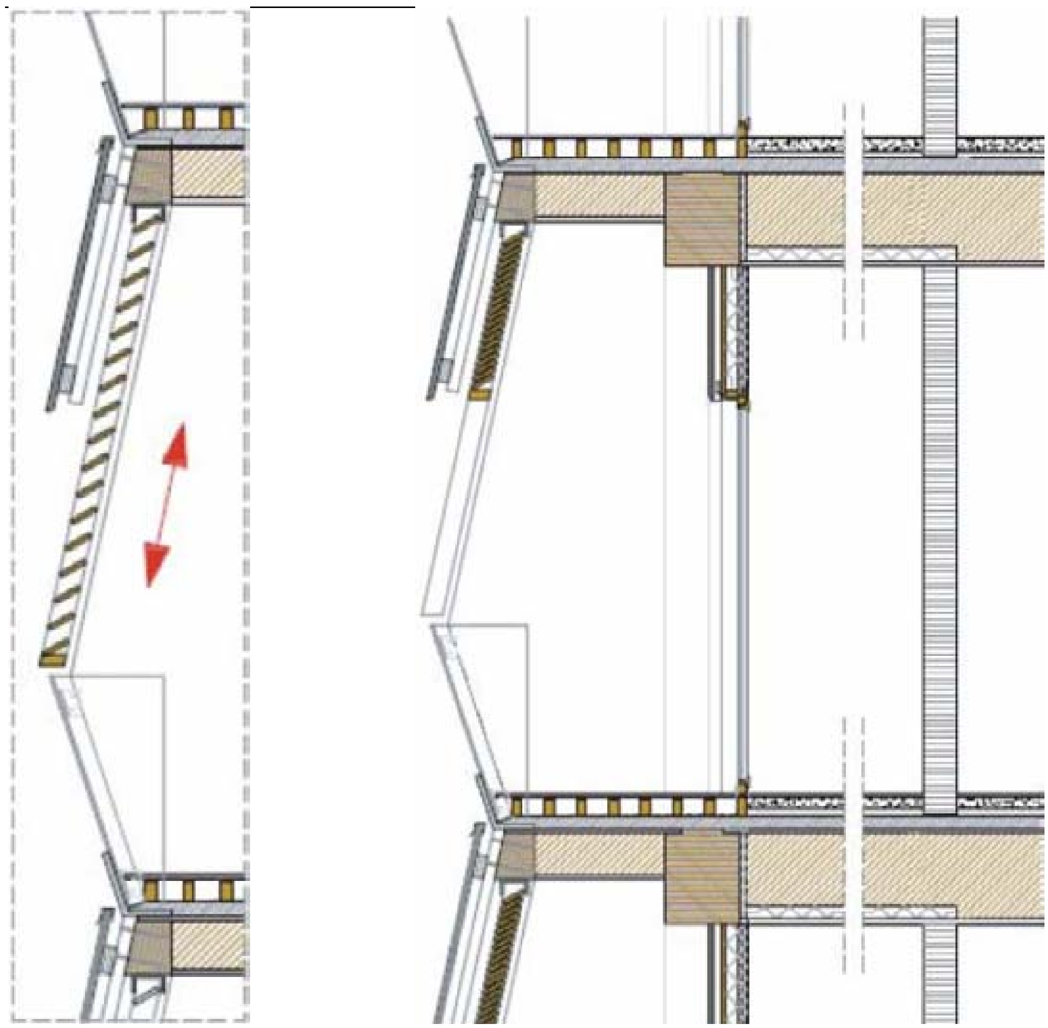
75,1% respect

the maximum energy demand permitted by the Spanish Regulations (CTE)

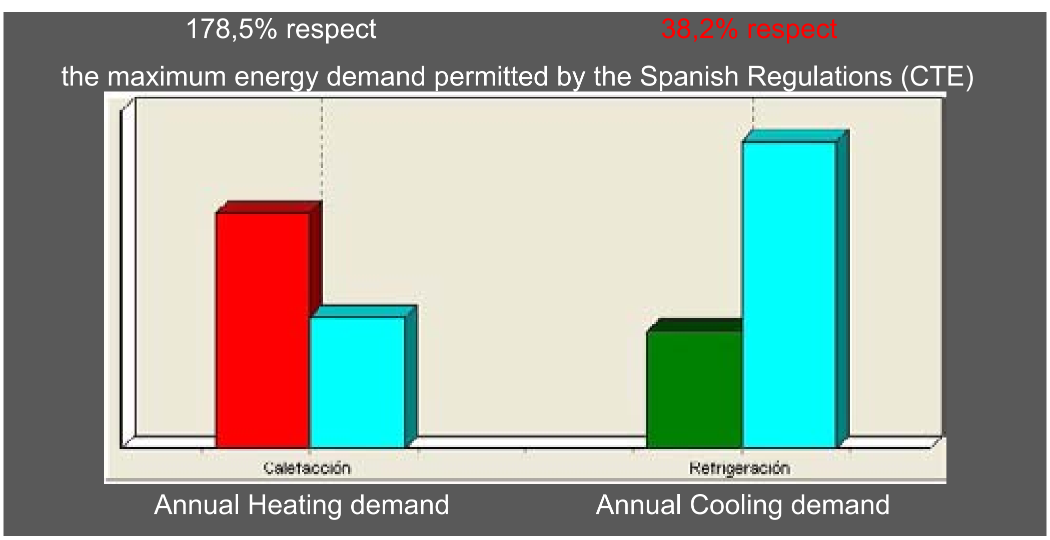


Annual Heating demand

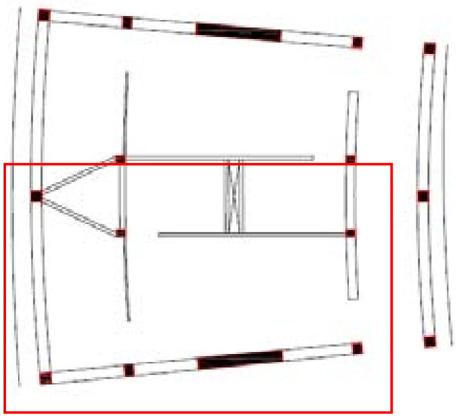
Annual Cooling demand



In the case the sun-shading blind is used, in hot summer conditions the results from the computer simulations are the followings:



Room E



Façade composition

Exterior envelope:

U=0,38W/m2K

- Larch boarding and battens
- Windproof layer
- 70mm thermal insulation
- vapour barrier
- laminated fir boarding on battens

Interior envelope:

U=0,85W/m2K

- 150mm laminated timber wall element
- glass front (3,5x3m2)

Room geometry:

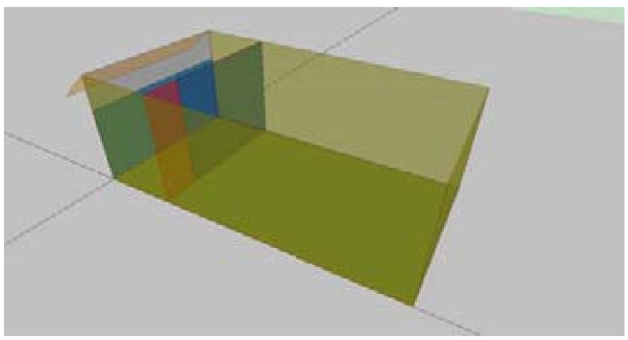
Double skin facade

8,5m x 4,5m = 38,25m2

Window dimension:

Glass fronted window

2,1m x 4,5 m

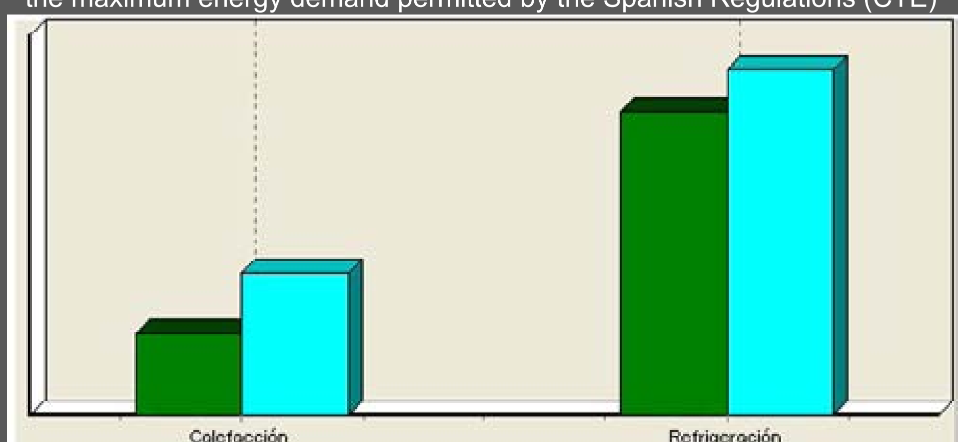


Results obtained from the simulation program:

DOES OBEY

56,6% respect | 87,9% respect

the maximum energy demand permitted by the Spanish Regulations (CTE)

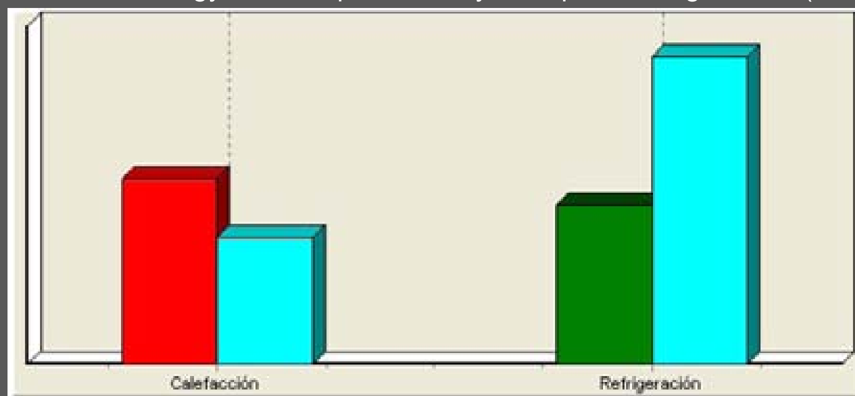


Annual Heating demand | Annual Cooling demand

In the case the sun-shading blind is used, in hot summer conditions the results from the computer simulations are the followings:

145,1% respect 51,9% respect

the maximum energy demand permitted by the Spanish Regulations (CTE)



Annual Heating demand Annual Cooling demand

C.2. Conclusion

It is observed that a significant reduction in the cooling demands of the reference room is achievable with the second (primary) wall, and the cantilever sun shading system. In this sense, the thermal storage materials are not required in order to obtain a better performance. The resulting cooling demand percentages are, in three studied cases, acceptable if it is considered the Spanish code criteria, and optimal results are achieved, for summer conditions, when the specifically designed blinds are used. Therefore, it is possible to project a hotel building, with large glass windows, and without view obstacles (sun-shading blinds), when bio-architectural method are employed.

7. CONLUSION

The central hypothesis posed by this research project was that through the use of bioclimatic architectural techniques the thermal performance of a multi-storey building under Mediterranean climatic conditions can be substantially improved. Based on the findings of this research project, this hypothesis can be verified. The main bioclimatic techniques applied to the wood based hotel building project, namely the geometric design of the building (oval floor plan and internal courtyard) as well as the design of the double layer façade solution (two façade skins and special sun-shading devices) significantly helped to enhance the thermal performance of my building. What is more, it has even been shown that by means of the façade system developed in this research project, the disadvantage wood has in terms of storage mass over alternative construction materials like concrete can be largely offset.

This conclusion provides a brief summary of the central work steps that were employed to “test” my hypothesis. First, the main ideas of this research project had to be specified. It was decided to examine the central hypothesis by developing a concrete building project: a wood based multi-storey hotel building located in Barcelona. Moreover, it was necessary to specify the main challenges posed to the indoor environment of this building project by the Mediterranean climatic conditions. In this respect, the most important challenges clearly stem from the hot temperatures in summer, that reach the highest average of 28 degrees in the month of August. The winter, on the other hand, is mild and the lowest average temperatures of 4.4 degrees that occur in January are not really a significant challenge to the indoor environment of a building. To enhance thermal performance of this wood based hotel building project, it is therefore of great importance to develop solutions to prevent an overheating of the building.

In a next step, the main features of the bioclimatic architectural techniques applied by this research project (basic geometric design of the building and basic design of the façade) had to be developed. Starting with the development of the façade system, this research project conducted a historic analysis of traditional Spanish architecture (review of the literature) in an attempt to learn from the past by identifying interesting design solutions and to adapt them to the purposes of contemporary architecture. In this way, the double layer façade design, as applied in the traditional Spanish wooden galleries, the so-called “Solanas”, has been discovered as an interesting idea with a good potential to inform the design solution of this research project.

Regarding the development of the main ideas for the geometric design of the building, different factors had to be taken into consideration. On the one hand, the geometry and orientation of the building were meant to enhance its thermal performance. Yet, on the other hand it was clear that additional architectural design considerations had to be taken into account, relating, for instance, to the intent and architectural composition of the building project. In so doing, the main features of the geometry of the wood based hotel building project were developed: an oval ground plan as well as the idea of an internal courtyard. To assess the thermal performance of the oval shape of the building, it has been compared to alternative geometric forms. The excellent thermal performance of the oval shape of the building project has been demonstrated well, for instance, by comparing it to a rectangular building geometry with a similar surface and a north-south orientation (that is an orientation that is considered optimal in terms of reducing heat gains). Here the calculations carried out with SolRad3 demonstrate that a rectangular building with a courtyard in the middle (heat gain 2168 KW) would have as much as 12 percent more heat gains than the oval shaped building (heat gain 1907.5 KW). In terms of reducing heat gains, the oval shape developed by this building project thus clearly is superior to a rectangular shape.

Once the general characteristics of the wood based hotel building project were decided, the façade solution needed to be further developed. This was done in three different work steps (big scale, medium scale, small scale). In a first step, the building envelope was divided in different sections according to the orientation of the façade. This was required as the orientation of a façade section results in a different solar radiation intensity and angle. In total, three different design solutions (sun shading devices) for the cantilever shading system of the building were developed, each of which was adapted to the special requirements of its particular location at the building envelope.

To assess the thermal performance of the double layer wood façade system it has been compared to alternative façade system solutions and materials using the Lider computer simulation program administrated by the CSIC (Instituto de la construcción Eduardo Torroja, Pamplona, Spain). The results of these calculations are scaled according to the CTE-DB-HE (Código Técnico de la Edificación-Documentos Básicos-Ahorro Energético, March 2006). Defining a "reference hotel room" of 38 square meters, with a window of 8.1 square meters and a façade surface of 13.5 square meters the cooling demands of a façade solution based on a single façade skin in wood would exceed the maximum level of the cooling demand specified by the Spanish Energy Code[24] (the calculated cooling demand amounted to 132 percent, with 100 percent being the maximum value). A similar single skin façade design solution relying on concrete walls for the façade and the room would did considerably better (cooling demand of 93 percent) due to its higher storage mass, but its cooling demand was still very close to the maximum level as defined by the Spanish Energy Demand Code.

The double layer façade system developed by this research project in combination with the proposed design of the cantilever shading system, on the other hand, resulted in a much better thermal performance. Again relying on calculations based on the Lider computer simulation program, the project's façade design concept in wood would result in a cooling demand of only 44.7 percent. Very importantly, the same façade solution using a concrete wall for the inner façade skin resulted in a very similar cooling demand. When using the double layer façade system developed by this project, the thermal performance of a wood solutions is thus no longer inferior to a solution in concrete.

At a general level, the main findings that can be deducted from the development of this wood based multi-storey hotel project in Barcelona can be summarized as follows: most importantly, it has been shown that functional bioclimatic architectural techniques can significantly enhance the thermal performance of a building under Mediterranean climatic conditions. This finding should be encouraging for architects interested in applying wood based architectural solutions to modern architectural projects in the Mediterranean region. Secondly, it has been shown that the disadvantages wood has as a construction material over alternative materials (like

[24] Código Técnico de la Edificación-Documentos Básicos-Ahorro Energético, March 2006 .

concrete) in terms of storage mass can be counterbalanced by applying functional façade solutions, such as the double layer façade system developed in this research project. Thirdly, it has been shown that it can be a very rewarding experience (particularly when working with a material that has such a rich history in architecture like wood) to learn from the past and to transfer ideas from the traditional architecture to contemporary architectural projects.

At a more specific level, this research project has developed interesting solutions for a wood based multi-storey hotel building that performs well under Mediterranean climate conditions. Many details of this hotel project, both in terms of its geometric design and its façade concept (double layer façade skin, cantilever shading system) offer interesting and innovative ideas that can be of benefit for other architectural projects.

8. BIBLIOGRAPHY

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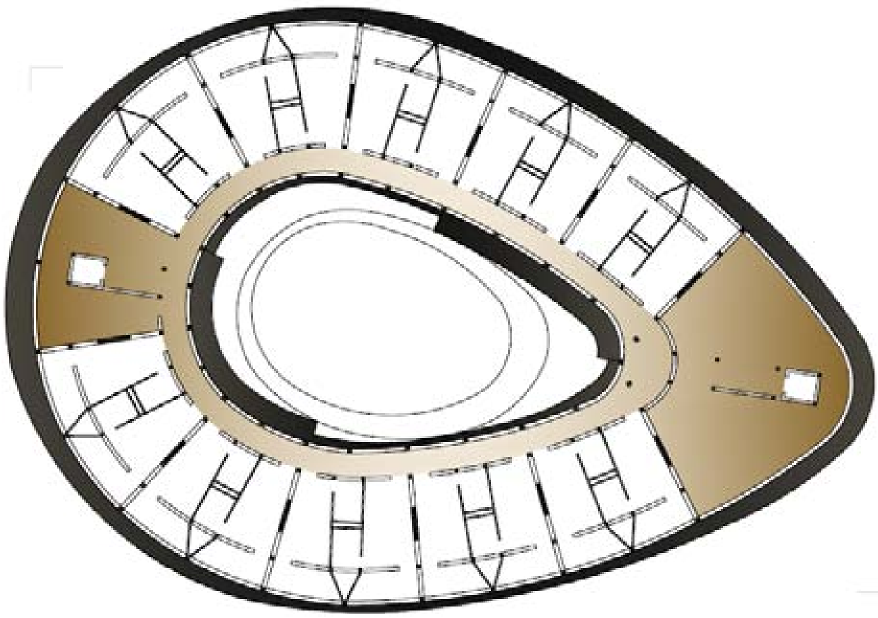
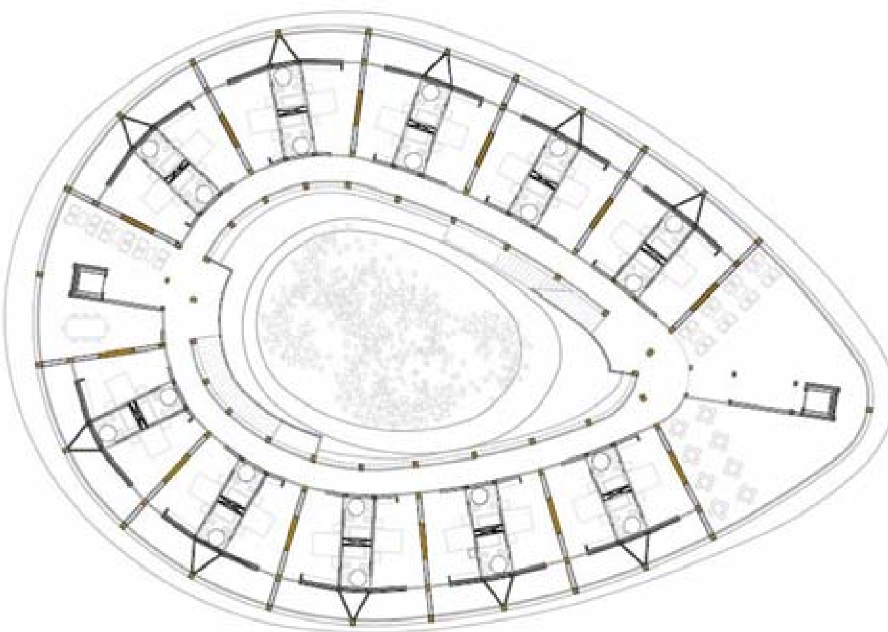
9. APPENDIX

Appendix A Architectural plans

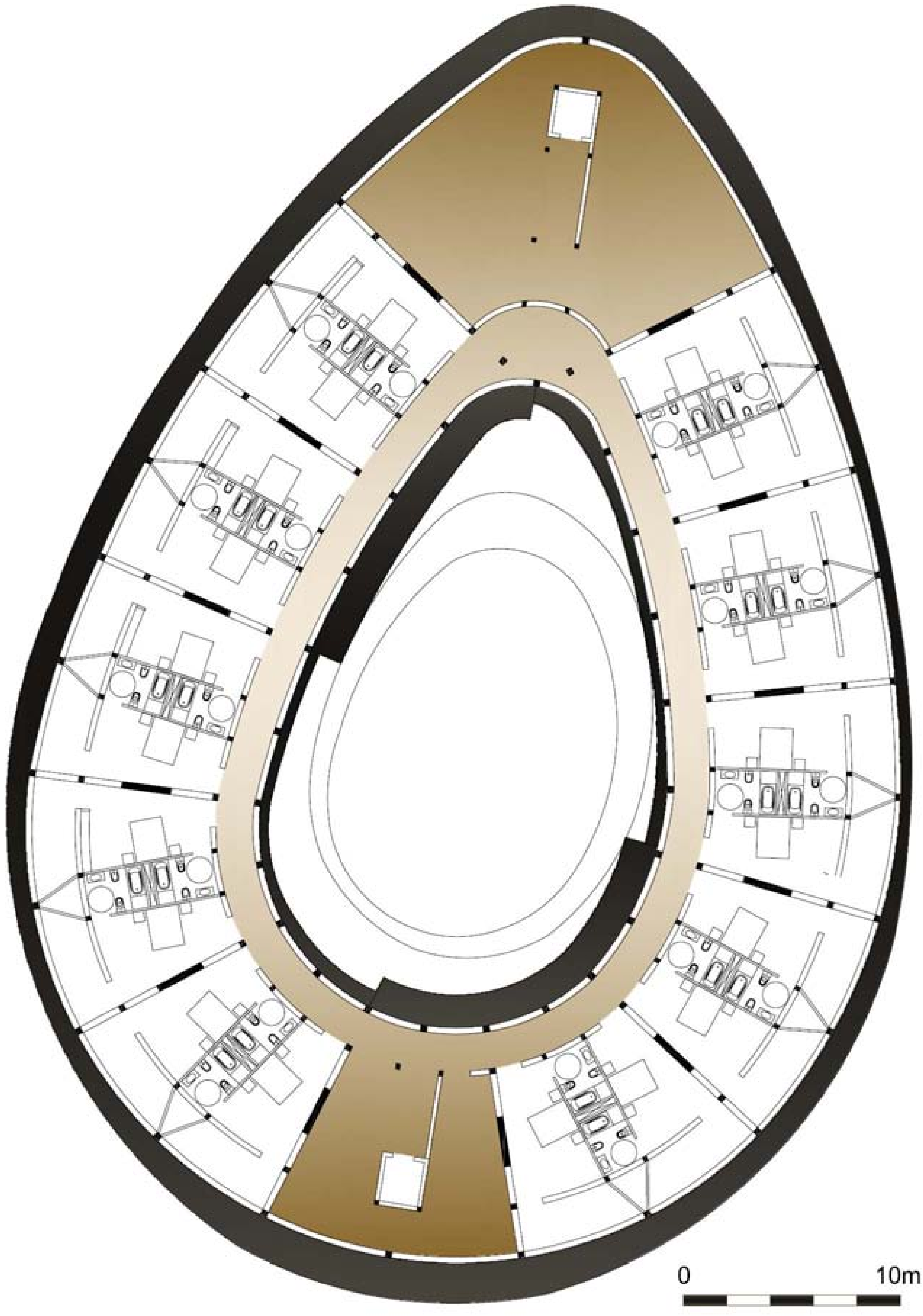
General Floor plan where it is shown the public and circulation spaces in brown and the cantilever space in dark gray.



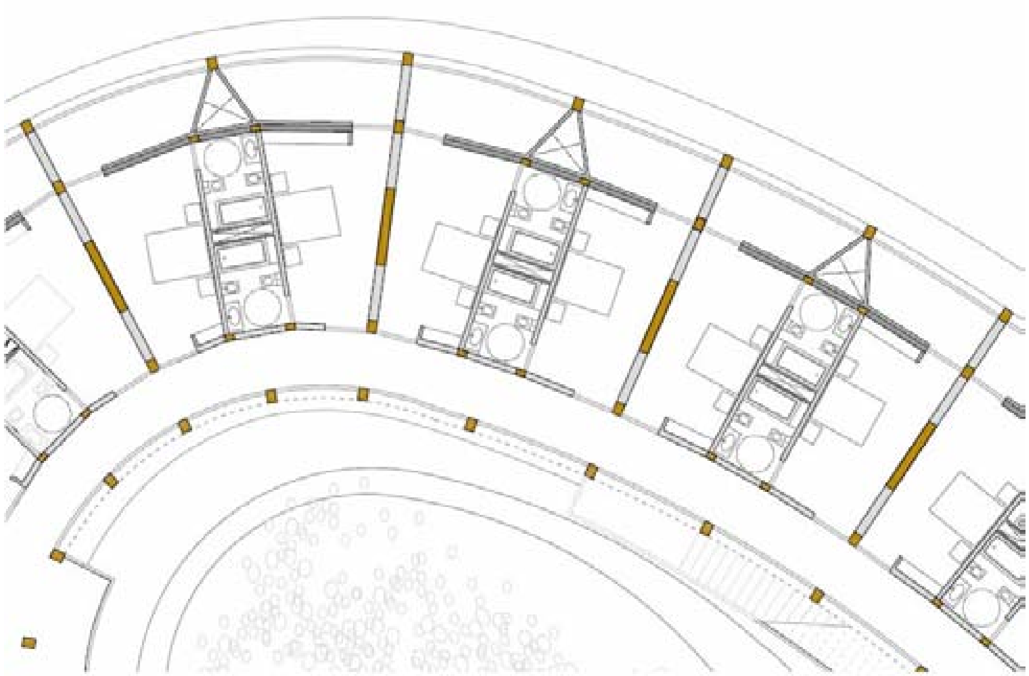
General floor plan furnished



Detailed floor plan



Reference room floor plan



Figures A.1 project's model images

Hotel room detailed floor plan

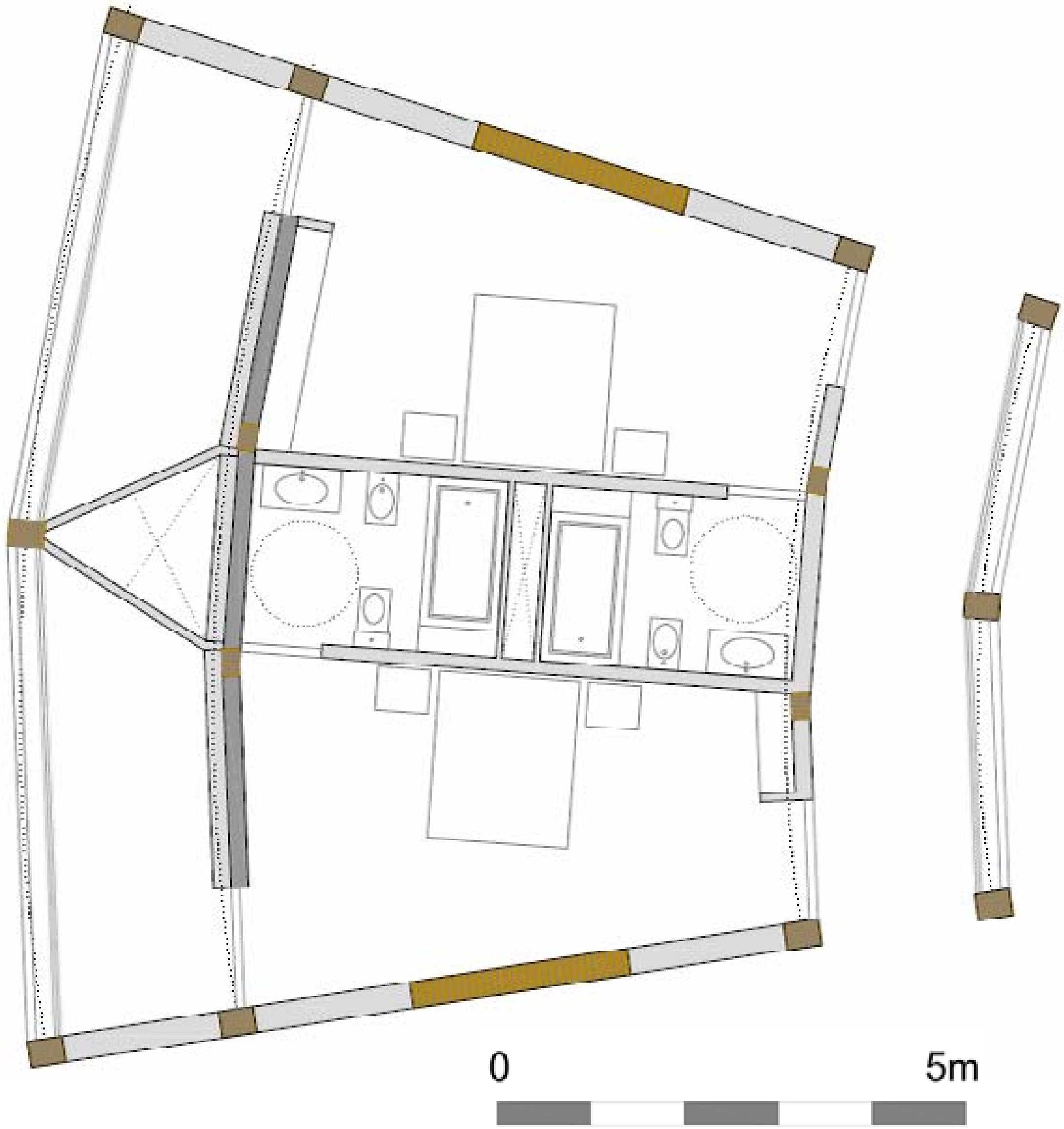


Figure A.2
Project's model images

9.2. Structure plans

Structure floor plan

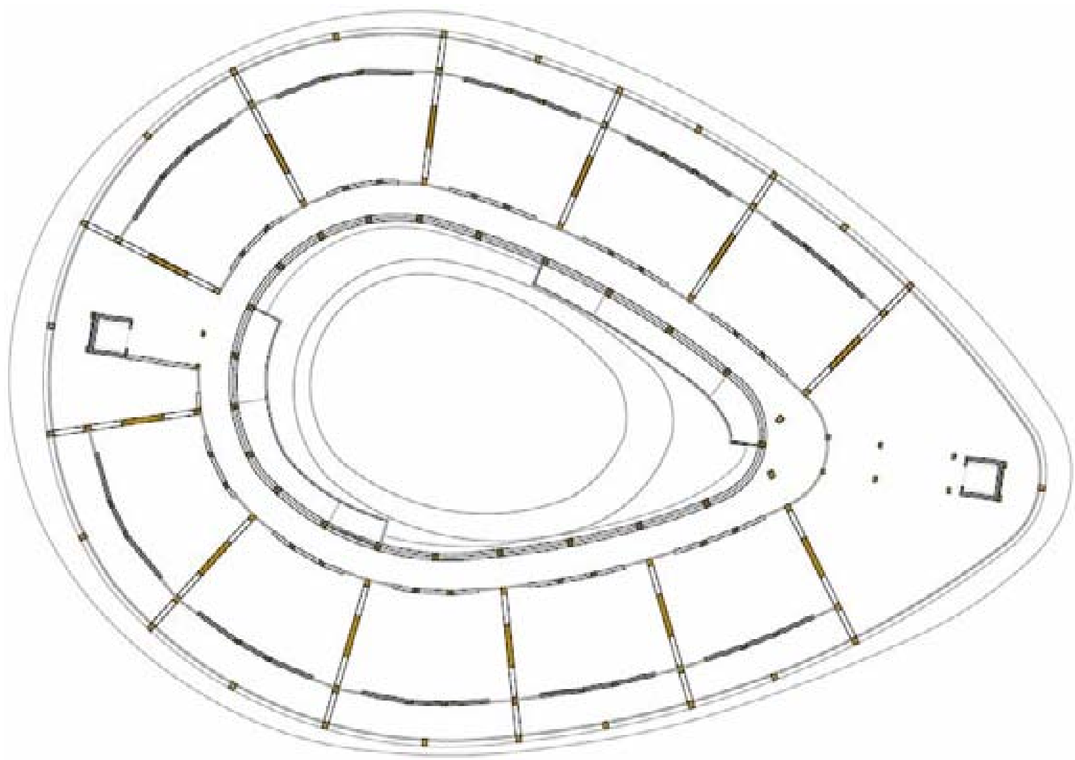
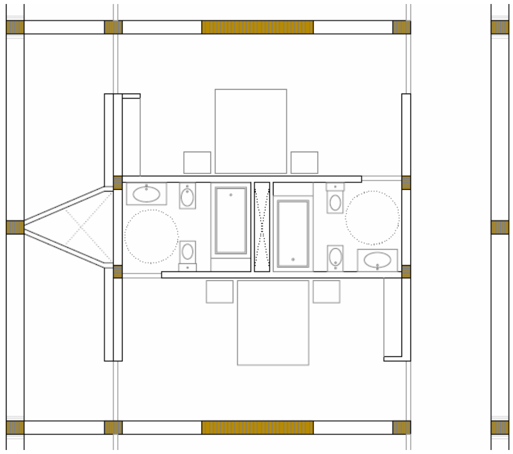
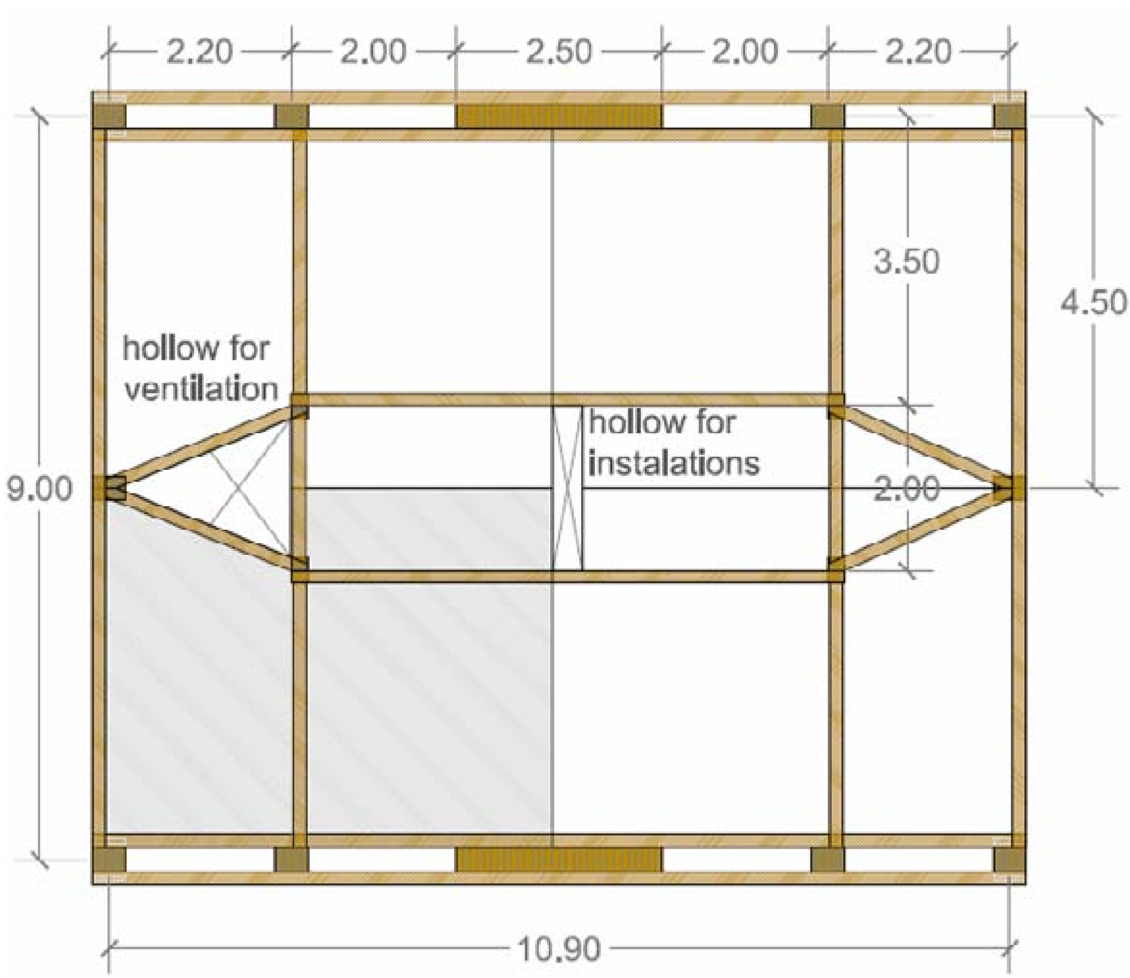


Figure A.3 Project's model image

Structural floor plan of the Reference rectangular room floor plan





Isometric of the structure of the reference room

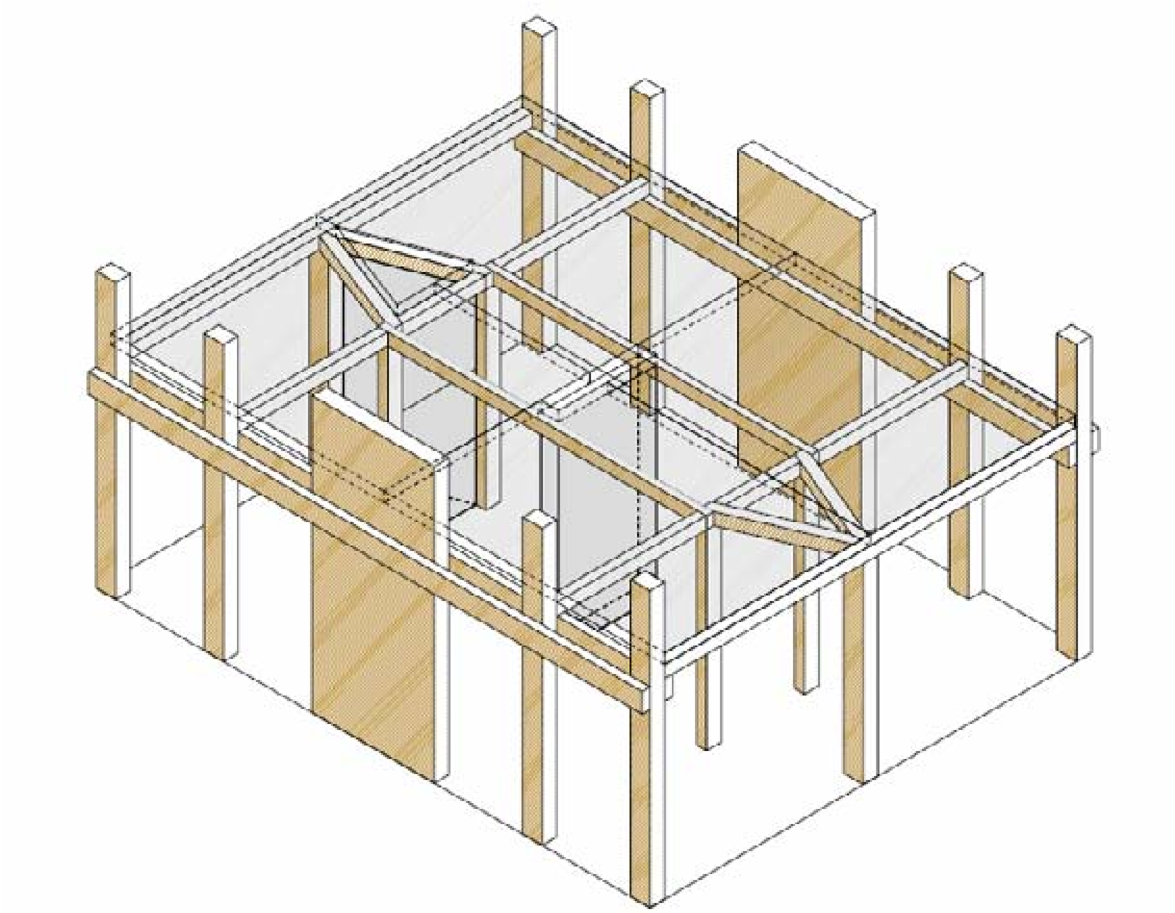
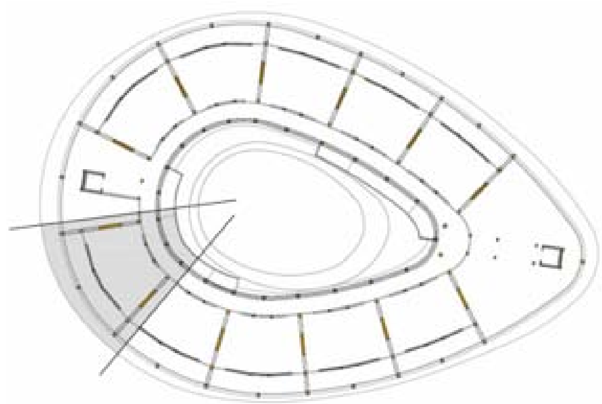


Figure A.4 Project's model images

Structural floor plan of the Hotel room floor plan



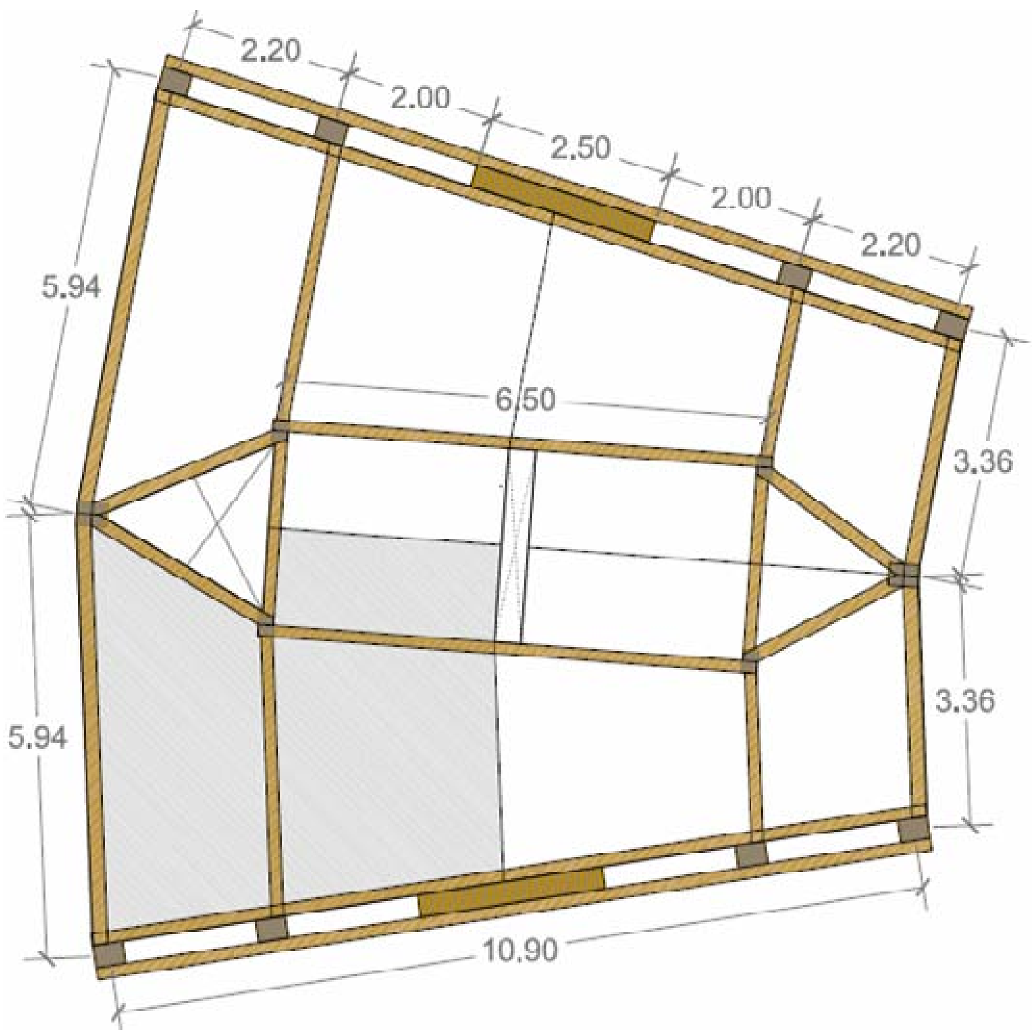
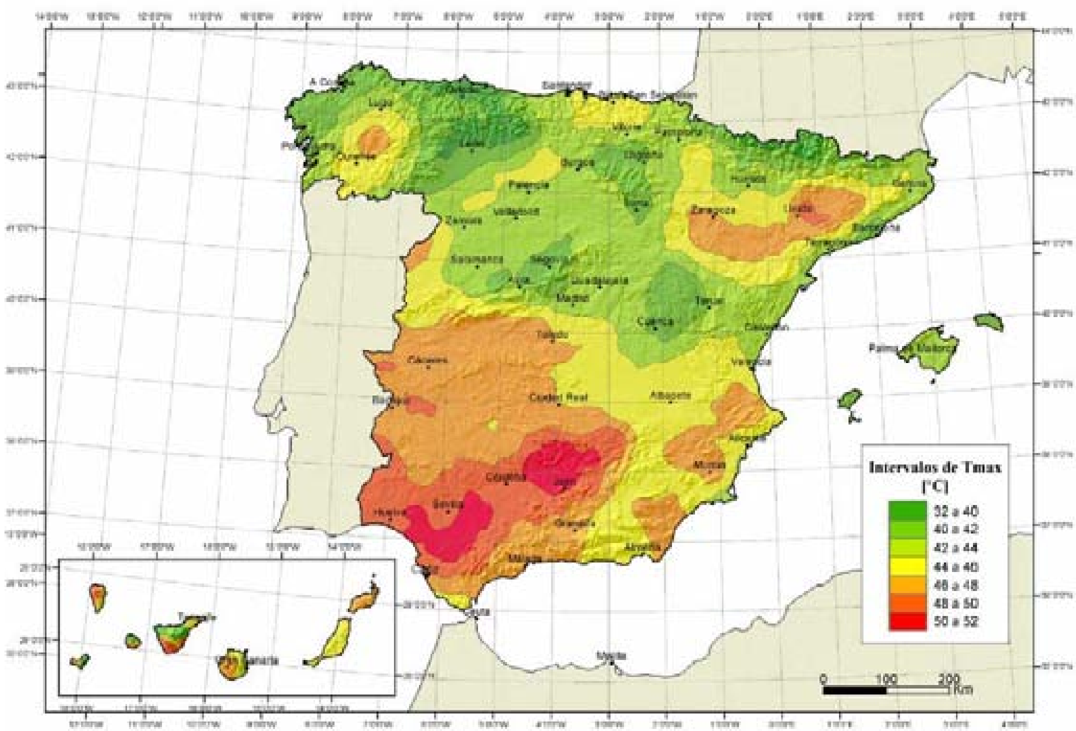


Figure B.1 The characteristic value of the maximum air temperature. Isotherms of the maximum air temperatures during the year. (CTE-DB-SE-AE march 2006)



Barcelona has maximum temperature intervals of 40-42ºC

Table B.1 Minimum exterior air temperature in relation to the altitude of the site and the winter climatic zone, shown in the Figure A.3

Altitud (m)	**Zona de clima invernal**, (según figura E.2)						
	1	**2**	**3**	**4**	**5**	**6**	**7**
0	-7	-11	-11	-6	-5	-6	6
200	-10	-13	-12	-8	-8	-8	5
400	-12	-15	-14	-10	-11	-9	3
600	-15	-16	-15	-12	-14	-11	2
800	-18	-18	-17	-14	-17	-13	0
1.000	-20	-20	-19	-16	-20	-14	-2
1.200	-23	-21	-20	-18	-23	-16	-3
1.400	-26	-23	-22	-20	-26	-17	-5
1.600	-28	-25	-23	-22	-29	-19	-7
1.800	-31	-26	-25	-24	-32	-21	-8
2.000	-33	-28	-27	-26	-35	-22	-10

Based on the Figure A.3, and considering Barcelona in Altitude 20m above sea level, the minimum exterior air temperature is -11ºC

Figure B.2 Winter climatic Zones, based in winter temperatures and precipitations

Barcelona is located in Zone2

Data obtained from the Nasa Langley Research Center Atmospheric Science Data Center. (http://eosweb.larc.nasa.gov/sse/):

Table B.2

Monthly Averaged Air Temperature At 10 m Above The Surface Of The Earth (°C)

Lat 41 Lon 1	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
22-year Average	6.54	7.56	10.2	12.5	16.7	21.1	23.6	23.2	20.1	16.2	10.8	7.74	14.7

Table B.3

Average Daily Temperature Range (°C)

Lat 41 Lon 1	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
22-year Average	7.27	8.18	9.49	9.26	9.44	9.32	9.27 *	8.66	8.10	7.17	6.70	6.70

*** Warmest month**

Table B.4

Monthly Averaged Cooling Degree Days Above 18 °C

Lat 41 Lon 1	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Sum
22-year Average	0	0	0	0	22	104	185	175	77	14	0	0	577

Table B.5

Monthly Averaged Heating Degree Days Below 18 °C

Lat 41 Lon 1	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Sum
22-year Average	339	282	231	158	55	6	0	0	7	62	208	304	1652

Table B.6 Monthly average temperatures and relative humidity

Localidad		Ene	Feb	Mar	Abr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dic
Albacete	T_{med}	5,0	6,3	8,5	10,9	15,3	20,0	24,0	23,7	20,0	14,1	8,5	5,3
	HR_{med}	78	70	62	60	54	50	44	50	58	70	77	79
Alicante	T_{med}	11,6	12,4	13,8	15,7	18,6	22,2	25,0	25,5	23,2	19,1	15,0	12,1
	HR_{med}	67	65	63	65	65	65	64	68	69	70	69	68
Almeria	T_{med}	12,4	13,0	14,4	16,1	18,7	22,3	25,5	26,0	24,1	20,1	16,2	13,3
	HR_{med}	70	68	66	65	67	65	64	66	66	69	70	69
Avila	T_{med}	3,1	4,0	5,6	7,6	11,5	16,0	19,9	19,4	16,5	11,2	6,0	3,4
	HR_{med}	75	70	62	61	55	50	39	40	50	65	73	77
Badajoz	T_{med}	8,7	10,1	12,0	14,2	17,9	22,3	25,3	25,0	22,6	17,4	12,1	9,0
	HR_{med}	80	76	69	66	60	55	50	50	57	68	77	82
Barcelona	T_{med}	8,8	9,5	11,1	12,8	16,0	19,7	22,9	23,0	21,0	17,1	12,5	9,6
	HR_{med}	73	70	70	70	72	70	69	72	74	74	74	71
Bilbao	T_{med}	8,9	9,6	10,4	11,8	14,6	17,4	19,7	19,8	18,8	16,0	11,8	9,5
	HR_{med}	73	70	70	72	71	72	73	75	74	74	74	74
Burgos	T_{med}	2,6	3,9	5,7	7,6	11,2	15,0	18,4	18,3	15,8	11,1	5,8	3,2
	HR_{med}	86	80	73	72	69	67	61	62	67	76	83	86
Caceres	T_{med}	7,8	9,3	11,7	13,0	16,6	22,3	26,1	25,4	23,6	17,4	12,0	8,8
	HR_{med}	55	53	60	63	65	76	76	76	78	74	65	57
Cádiz	T_{med}	12,8	13,5	14,7	16,2	18,7	21,5	24,0	24,5	23,5	20,1	16,1	13,3
	HR_{med}	77	75	70	71	71	70	69	69	70	73	76	77
Castellón	T_{med}	10,1	11,1	12,7	14,2	17,2	21,3	24,1	24,5	22,3	18,3	13,5	11,2
	HR_{med}	68	66	64	66	67	66	66	69	71	71	73	69
Ceuta	T_{med}	11,5	11,6	12,6	13,9	16,3	18,8	21,7	22,2	20,2	17,7	14,1	12,1
	HR_{med}	87	87	88	87	87	87	87	87	89	89	88	88
Ciudad Real	T_{med}	5,7	7,2	9,6	11,9	16,0	20,8	25,0	24,7	21,0	14,8	9,1	5,9
	HR_{med}	80	74	66	65	59	54	47	48	57	68	78	82

Table B.7

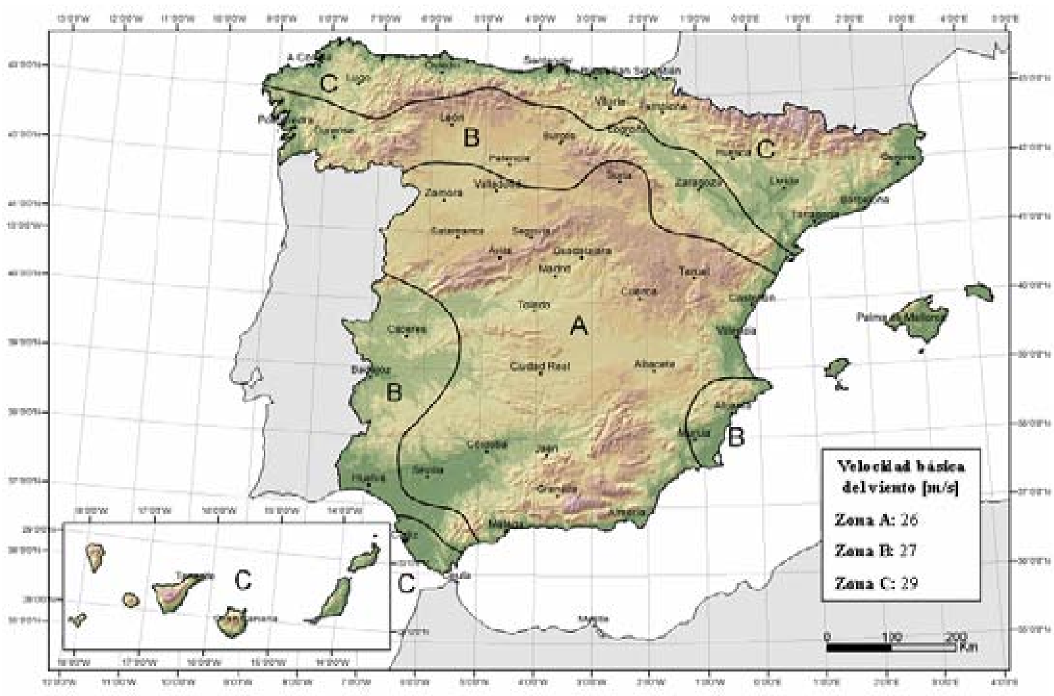
Monthly Averaged Precipitation (mm/day)

Lat 41 Lon 1	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
22-year Average	1.73	1.37	1.37	2.04	2.25	1.50	0.98	1.41	2.25	2.48	2.29	1.90	1.80

Figure B.3 Pluviometric Zones based in the average of the year pluviometric rate

Barcelona is considered as Zone III

Figure B.4 Basic Value of the wind speed in Spain (CTE-DB-SE-AE march 2006)



Barcelona situated in Zone C, Basic wind speed of 29m/s

Data obtained from the Nasa Langley Research Center Atmospheric Science Data Center. (http://eosweb.larc.nasa.gov/sse/):

Table B.8

Monthly Averaged Wind Speed At 10 m Above The Surface Of The Earth For Terrain Similar To Airports (m/s)

Lat 41 Lon 1	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
10-year Average	4.01	4.12	3.99	3.79	3.09	2.91	3.10	3.05	2.96	3.37	3.85	4.01	3.51

Table B.9

Monthly Averaged Wind Direction At 50 m Above The Surface Of The Earth (degrees)

Lat 41 Lon 1	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
10-year Average	306	308	313	312	313	312	313	312	309	307	307	308

Explanatory sketch of the predominant wind direction in Barcelona

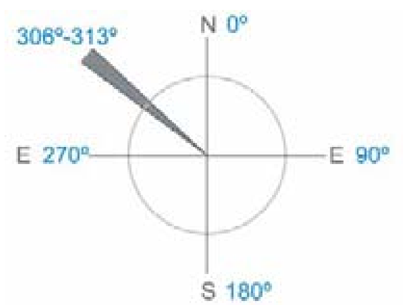


Table B.10

Monthly Averaged Wind Speed At 50 m Above The Surface Of The Earth (m/s)

Lat 41 Lon 1	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
10-year Average	5.08	5.21	5.05	4.80	3.91	3.68	3.93	3.86	3.75	4.26	4.87	5.09	4.45

Minimum And Maximum Difference From Monthly Averaged Wind Speed At 50 m (%)

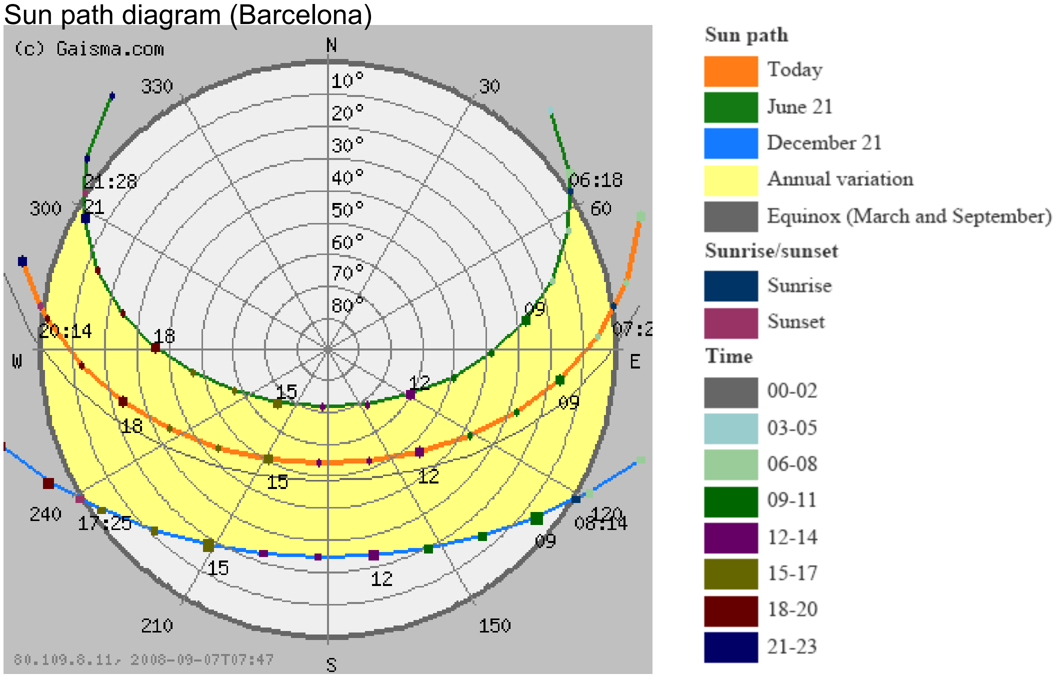
Lat 41 Lon 1	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
Minimum	-20	-11	-15	-11	-13	-11	-14	-9	-12	-16	-9	-19	-13
Maximum	18	14	13	14	19	10	13	8	13	9	10	15	13

Figure B.5 Data obtained from Gaisma.com internet web page.

(http://www.gaisma.com/en/location/barcelona.html) data based on:

- NASA Langley Research Center Atmospheric Science Data Center
- New, M., Lister, D., Hulme, M. and Makin, I., 2002: A high-resolution data set of surface climate over global land areas. Climate Research 21.

Sun path diagram (Barcelona)



Sunrise, sunset dawn and dusk times, graph (Barcelona)

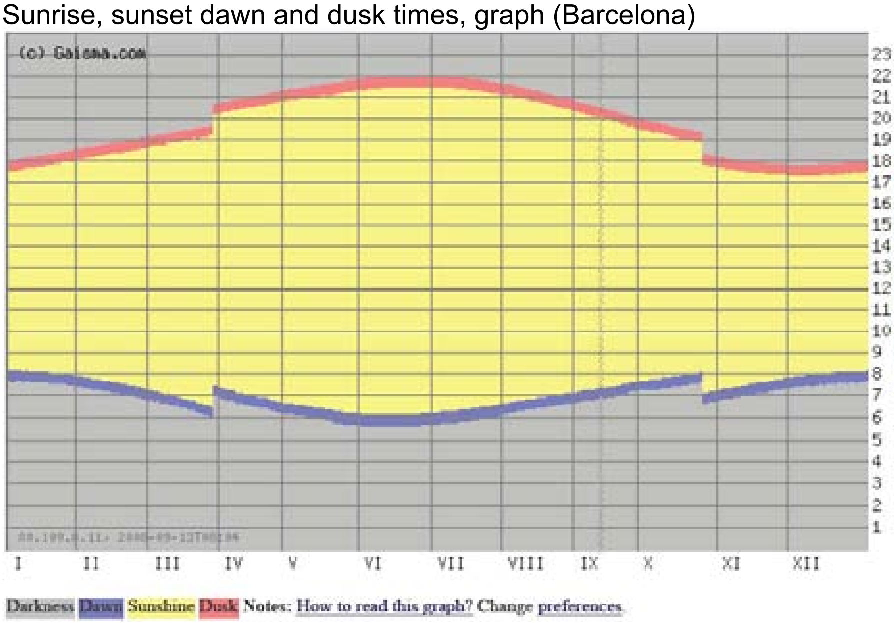


Figure B.6 Geographic Data of Barcelona

Latitude: +41.4 (41°24'00"N)

Longitude: +2.17 (2°10'12"E)

Time zone: UTC+1 hours

Local time: 10:04:36

Country: Spain

Continent: Europe

Sub-region: Southern Europe

Distance: ~1300 km (from your IP)

Altitude: ~20 m

Table B.11 Solar Azimuth and Height during Equinoxes, Summer Solstice and Winter Solstice. Data obtained from the computer program SolRad3.

Sonnengang

Standort: barcelona

Geogr. Länge: 2° 17' O
Geogr. Breite: 41° 40' N
Seehöhe: 20 m
Meridian der Zeitzone: 15° 0' O

Datum:	**21. März** Tag- u. Nachtgleiche		**21. Juni** Sommersonnenwende		**21. Dezember** Wintersonnenwende	
Sonnenaufgang:	**6h 55'**		**5h 18'**		**8h 16'**	
Sonnenuntergang:	**19h 1'**		**20h 27'**		**17h 22'**	
Tageslänge:	12h 6'		15h 9'		9h 6'	
mögliche Sonnenstd.:	**12h 6'**		**15h 9'**		**9h 6'**	
Sonnendeklination:	-0° 0'		23° 27'		-23° 27'	
Uhr	**Azimut**	**Höhe**	**Azimut**	**Höhe**	**Azimut**	**Höhe**
1 h	- - -	- - -	- - -	- - -	- - -	- - -
2 h	- - -	- - -	- - -	- - -	- - -	- - -
3 h	- - -	- - -	- - -	- - -	- - -	- - -
4 h	- - -	- - -	- - -	- - -	- - -	- - -
5 h	- - -	- - -	- - -	- - -	- - -	- - -
6 h	- - -	- - -	64,0°	6,4°	- - -	- - -
7 h	90,3°	0,7°	73,2°	16,8°	- - -	- - -
8 h	100,4°	11,5°	82,2°	27,7°	- - -	- - -
9 h	111,3°	22,3°	91,9°	38,8°	129,1°	6,3°
10 h	124,0°	32,2°	103,3°	49,9°	140,6°	14,1°
11 h	139,5°	40,5°	119,1°	60,4°	153,5°	20,2°
12 h	158,6°	46,3°	145,0°	68,8°	167,8°	24,0°
13 h	180,6°	48,3°	185,6°	71,7°	182,8°	24,9°
14 h	202,5°	46,1°	223,0°	67,0°	197,7°	22,9°
15 h	221,4°	40,1°	245,6°	57,8°	211,5°	18,2°
16 h	236,8°	31,6°	259,9°	47,1°	223,9°	11,4°
17 h	249,3°	21,7°	270,7°	36,0°	234,8°	3,0°
18 h	260,2°	10,9°	280,1°	24,9°	- - -	- - -
19 h	270,3°	0,2°	289,1°	14,1°	- - -	- - -
20 h	- - -	- - -	298,4°	3,9°	- - -	- - -
21 h	- - -	- - -	- - -	- - -	- - -	- - -
22 h	- - -	- - -	- - -	- - -	- - -	- - -
23 h	- - -	- - -	- - -	- - -	- - -	- - -
24 h	- - -	- - -	- - -	- - -	- - -	- - -

Oval shape Data of the solar radiation for the **Façade 1**

Strahlungsflüsse

Feststehendes Flächenelement

Standort: barcelona

Geogr. Länge: 2° 17' O
Geogr. Breite: 41° 40' N
Seehöhe: 20 m
Meridian der Zeitzone: 15° 0' O

Lage der Flächennormale: 1
Azimut: 344° 0'
Neigung: 0° 0'

Trübungsfaktor nach Linke: 4,5
Diffusstrahlungsfaktor nach Reitz: 0,333

Reflexionszahl der Umgebung (Albedo): 0,2
Anteilfaktor für Himmelsstrahlung: 0,5

Auswertungdatum: **21. Juni (Sommersonnenwende)**
Sonnendeklination: 23° 27'
Sonnenaufgang: **5h 18'** Sonnenuntergang: **20h 27'**
Tageslänge: 15h 9'

	Sonnenstand		Horizont	Einfalls	Strahlungsflüsse [W/m²]				
Uhr	Azimut	Höhe	höhe	winkel	Direkt	Himmel	Reflex	Diffus	Global
1 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
2 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
3 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
4 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
5 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
6 h	64,0°	6,4°	0,0°	80,1°	24,6	22,0	6,0	28,0	52,6
7 h	73,2°	16,8°	0,0°	89,2°	5,2	45,0	20,1	65,1	70,3
8 h	82,2°	27,7°	0,0°	97,3°	- - -	58,6	38,0	96,6	96,6
9 h	91,9°	38,8°	0,0°	103,8°	- - -	66,8	56,2	123,0	123,0
10 h	103,3°	49,9°	0,0°	108,4°	- - -	71,8	72,5	144,2	144,2
11 h	119,1°	60,4°	0,0°	110,5°	- - -	74,8	85,0	159,8	159,8
12 h	145,0°	68,8°	0,0°	110,0°	- - -	76,4	92,7	169,1	169,1
13 h	185,6°	71,7°	0,0°	107,0°	- - -	76,8	94,9	171,6	171,6
14 h	223,0°	67,0°	0,0°	101,6°	- - -	76,1	91,3	167,3	167,3
15 h	245,6°	57,8°	0,0°	94,5°	- - -	74,2	82,2	156,4	156,4
16 h	259,9°	47,1°	0,0°	86,0°	52,0	70,7	68,6	139,3	191,3
17 h	270,7°	36,0°	0,0°	76,5°	153,1	65,0	51,7	116,7	269,8
18 h	280,1°	24,9°	0,0°	66,5°	209,8	55,8	33,3	89,0	298,9
19 h	289,1°	14,1°	0,0°	56,1°	182,6	40,3	16,0	56,3	238,8
20 h	298,4°	3,9°	0,0°	45,7°	60,1	14,1	3,4	17,6	77,6
21 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
22 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
23 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
24 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
Strahlungssummen [Wh/m²]:					683,4	886,2	811,3	1697,5	2381,0
Tagesmittelwerte [W/m²]:					28,5	36,9	33,8	70,7	99,2

Oval shape Data of the solar radiation for the **Façade 2**

Strahlungsflüsse

Feststehendes Flächenelement

Standort: barcelona

Geogr. Länge: 2° 17' O
Geogr. Breite: 41° 40' N
Seehöhe: 20 m
Meridian der Zeitzone: 15° 0' O

Lage der Flächennormale: 2
Azimut: 22° 0'
Neigung: 0° 0'

Trübungsfaktor nach Linke: 4,5
Diffusstrahlungsfaktor nach Reitz: 0,333

Reflexionszahl der Umgebung (Albedo): 0,2
Anteilfaktor für Himmelsstrahlung: 0,5

Auswertungdatum: **21. Juni (Sommersonnenwende)**
Sonnendeklination: 23° 27'
Sonnenaufgang: **5h 18'** Sonnenuntergang: **20h 27'**
Tageslänge: 15h 9'

	Sonnenstand		Horizont	Einfalls	Strahlungsflüsse [W/m²]				
Uhr	Azimut	Höhe	höhe	winkel	Direkt	Himmel	Reflex	Diffus	Global
1 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
2 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
3 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
4 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
5 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
6 h	64,0°	6,4°	0,0°	42,4°	105,5	22,0	6,0	28,0	133,4
7 h	73,2°	16,8°	0,0°	53,1°	230,9	45,0	20,1	65,1	296,1
8 h	82,2°	27,7°	0,0°	63,9°	248,4	58,6	38,0	96,6	345,0
9 h	91,9°	38,8°	0,0°	74,4°	183,4	66,8	56,2	123,0	306,3
10 h	103,3°	49,9°	0,0°	84,4°	73,9	71,8	72,5	144,2	218,2
11 h	119,1°	60,4°	0,0°	93,5°	- - -	74,8	85,0	159,8	159,8
12 h	145,0°	68,8°	0,0°	101,4°	- - -	76,4	92,7	169,1	169,1
13 h	185,6°	71,7°	0,0°	107,5°	- - -	76,8	94,9	171,6	171,6
14 h	223,0°	67,0°	0,0°	111,4°	- - -	76,1	91,3	167,3	167,3
15 h	245,6°	57,8°	0,0°	112,7°	- - -	74,2	82,2	156,4	156,4
16 h	259,9°	47,1°	0,0°	111,2°	- - -	70,7	68,6	139,3	139,3
17 h	270,7°	36,0°	0,0°	107,1°	- - -	65,0	51,7	116,7	116,7
18 h	280,1°	24,9°	0,0°	100,8°	- - -	55,8	33,3	89,0	89,0
19 h	289,1°	14,1°	0,0°	92,8°	- - -	40,3	16,0	56,3	56,3
20 h	298,4°	3,9°	0,0°	83,6°	9,6	14,1	3,4	17,6	27,1
21 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
22 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
23 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
24 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
Strahlungssummen [Wh/m²]:					847,2	886,2	811,3	1697,5	2544,8
Tagesmittelwerte [W/m²]:					35,3	36,9	33,8	70,7	106,0

Oval shape Data of the solar radiation for the **Façade 3**

Strahlungsflüsse

Feststehendes Flächenelement

Standort: barcelona

Geogr. Länge: 2° 17' O
Geogr. Breite: 41° 40' N
Seehöhe: 20 m
Meridian der Zeitzone: 15° 0' O

Lage der Flächennormale: 3
Azimut: 46° 0'
Neigung: 0° 0'

Trübungsfaktor nach Linke: 4,5
Diffusstrahlungsfaktor nach Reitz: 0,333

Reflexionszahl der Umgebung (Albedo): 0,2
Anteilfaktor für Himmelsstrahlung: 0,5

Auswertungdatum: **21. Juni (Sommersonnenwende)**
Sonnendeklination: 23° 27'
Sonnenaufgang: **5h 18'** Sonnenuntergang: **20h 27'**
Tageslänge: 15h 9'

Uhr	Sonnenstand Azimut	Sonnenstand Höhe	Horizont höhe	Einfalls winkel	Strahlungsflüsse [W/m²] Direkt	Himmel	Reflex	Diffus	Global
1 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
2 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
3 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
4 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
5 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
6 h	64,0°	6,4°	0,0°	19,1°	135,0	22,0	6,0	28,0	163,0
7 h	73,2°	16,8°	0,0°	31,6°	327,8	45,0	20,1	65,1	392,9
8 h	82,2°	27,7°	0,0°	44,4°	403,6	58,6	38,0	96,6	500,2
9 h	91,9°	38,8°	0,0°	57,1°	370,8	66,8	56,2	123,0	493,7
10 h	103,3°	49,9°	0,0°	69,6°	264,1	71,8	72,5	144,2	408,4
11 h	119,1°	60,4°	0,0°	81,8°	115,6	74,8	85,0	159,8	275,4
12 h	145,0°	68,8°	0,0°	93,3°	- - -	76,4	92,7	169,1	169,1
13 h	185,6°	71,7°	0,0°	103,8°	- - -	76,8	94,9	171,6	171,6
14 h	223,0°	67,0°	0,0°	113,0°	- - -	76,1	91,3	167,3	167,3
15 h	245,6°	57,8°	0,0°	120,1°	- - -	74,2	82,2	156,4	156,4
16 h	259,9°	47,1°	0,0°	124,4°	- - -	70,7	68,6	139,3	139,3
17 h	270,7°	36,0°	0,0°	125,1°	- - -	65,0	51,7	116,7	116,7
18 h	280,1°	24,9°	0,0°	122,1°	- - -	55,8	33,3	89,0	89,0
19 h	289,1°	14,1°	0,0°	116,0°	- - -	40,3	16,0	56,3	56,3
20 h	298,4°	3,9°	0,0°	107,6°	- - -	14,1	3,4	17,6	17,6
21 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
22 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
23 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
24 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
Strahlungssummen [Wh/m²]:					1615,1	886,2	811,3	1697,5	3312,6
Tagesmittelwerte [W/m²]:					67,3	36,9	33,8	70,7	138,0

Oval shape Data of the solar radiation for the **Façade 4**

Strahlungsflüsse

Feststehendes Flächenelement

Standort: barcelona

Geogr. Länge: 2° 17' O
Geogr. Breite: 41° 40' N
Seehöhe: 20 m
Meridian der Zeitzone: 15° 0' O

Lage der Flächennormale: 4
Azimut: 84° 0'
Neigung: 0° 0'

Trübungsfaktor nach Linke: 4,5
Diffusstrahlungsfaktor nach Reitz: 0,333

Reflexionszahl der Umgebung (Albedo): 0,2
Anteilfaktor für Himmelsstrahlung: 0,5

Auswertungdatum: **21. Juni (Sommersonnenwende)**
Sonnendeklination: 23° 27'
Sonnenaufgang: **5h 18'** Sonnenuntergang: **20h 27'**
Tageslänge: 15h 9'

	Sonnenstand		Horizont	Einfalls	Strahlungsflüsse [W/m²]				
Uhr	Azimut	Höhe	höhe	winkel	Direkt	Himmel	Reflex	Diffus	Global
1 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
2 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
3 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
4 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
5 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
6 h	64,0°	6,4°	0,0°	20,9°	133,4	22,0	6,0	28,0	161,4
7 h	73,2°	16,8°	0,0°	19,9°	362,0	45,0	20,1	65,1	427,2
8 h	82,2°	27,7°	0,0°	27,7°	500,1	58,6	38,0	96,6	596,7
9 h	91,9°	38,8°	0,0°	39,5°	527,3	66,8	56,2	123,0	650,3
10 h	103,3°	49,9°	0,0°	52,6°	461,4	71,8	72,5	144,2	605,7
11 h	119,1°	60,4°	0,0°	66,2°	325,9	74,8	85,0	159,8	485,7
12 h	145,0°	68,8°	0,0°	79,9°	145,8	76,4	92,7	169,1	314,9
13 h	185,6°	71,7°	0,0°	93,6°	- - -	76,8	94,9	171,6	171,6
14 h	223,0°	67,0°	0,0°	107,2°	- - -	76,1	91,3	167,3	167,3
15 h	245,6°	57,8°	0,0°	120,3°	- - -	74,2	82,2	156,4	156,4
16 h	259,9°	47,1°	0,0°	132,7°	- - -	70,7	68,6	139,3	139,3
17 h	270,7°	36,0°	0,0°	143,5°	- - -	65,0	51,7	116,7	116,7
18 h	280,1°	24,9°	0,0°	150,7°	- - -	55,8	33,3	89,0	89,0
19 h	289,1°	14,1°	0,0°	151,5°	- - -	40,3	16,0	56,3	56,3
20 h	298,4°	3,9°	0,0°	145,4°	- - -	14,1	3,4	17,6	17,6
21 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
22 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
23 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
24 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
Strahlungssummen [Wh/m²]:					2454,4	886,2	811,3	1697,5	4151,9
Tagesmittelwerte [W/m²]:					102,3	36,9	33,8	70,7	173,0

Oval shape Data of the solar radiation for the **Façade 5**

Strahlungsflüsse

Feststehendes Flächenelement

Standort: barcelona

Geogr. Länge: 2° 17' O
Geogr. Breite: 41° 40' N
Seehöhe: 20 m
Meridian der Zeitzone: 15° 0' O

Lage der Flächennormale: 5
Azimut: 132° 0'
Neigung: 0° 0'

Trübungsfaktor nach Linke: 4,5
Diffusstrahlungsfaktor nach Reitz: 0,333

Reflexionszahl der Umgebung (Albedo): 0,2
Anteilfaktor für Himmelsstrahlung: 0,5

Auswertungdatum: **21. Juni (Sommersonnenwende)**
Sonnendeklination: 23° 27'
Sonnenaufgang: **5h 18'** Sonnenuntergang: **20h 27'**
Tageslänge: 15h 9'

	Sonnenstand		Horizont	Einfalls	Strahlungsflüsse [W/m²]				
Uhr	Azimut	Höhe	höhe	winkel	Direkt	Himmel	Reflex	Diffus	Global
1 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
2 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
3 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
4 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
5 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
6 h	64,0°	6,4°	0,0°	68,1°	53,2	22,0	6,0	28,0	81,2
7 h	73,2°	16,8°	0,0°	60,3°	190,9	45,0	20,1	65,1	256,0
8 h	82,2°	27,7°	0,0°	55,1°	323,1	58,6	38,0	96,6	419,7
9 h	91,9°	38,8°	0,0°	53,5°	406,9	66,8	56,2	123,0	529,9
10 h	103,3°	49,9°	0,0°	55,6°	428,9	71,8	72,5	144,2	573,1
11 h	119,1°	60,4°	0,0°	61,2°	388,5	74,8	85,0	159,8	548,3
12 h	145,0°	68,8°	0,0°	69,3°	293,2	76,4	92,7	169,1	462,3
13 h	185,6°	71,7°	0,0°	79,3°	155,9	76,8	94,9	171,6	327,5
14 h	223,0°	67,0°	0,0°	90,4°	- - -	76,1	91,3	167,3	167,3
15 h	245,6°	57,8°	0,0°	102,3°	- - -	74,2	82,2	156,4	156,4
16 h	259,9°	47,1°	0,0°	114,7°	- - -	70,7	68,6	139,3	139,3
17 h	270,7°	36,0°	0,0°	127,5°	- - -	65,0	51,7	116,7	116,7
18 h	280,1°	24,9°	0,0°	140,4°	- - -	55,8	33,3	89,0	89,0
19 h	289,1°	14,1°	0,0°	153,3°	- - -	40,3	16,0	56,3	56,3
20 h	298,4°	3,9°	0,0°	165,9°	- - -	14,1	3,4	17,6	17,6
21 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
22 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
23 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
24 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
Strahlungssummen [Wh/m²]:					2252,0	886,2	811,3	1697,5	3949,5
Tagesmittelwerte [W/m²]:					93,8	36,9	33,8	70,7	164,6

Oval shape Data of the solar radiation for the **Façade 6**

Strahlungsflüsse

Feststehendes Flächenelement

Standort: barcelona

Geogr. Länge: 2° 17' O
Geogr. Breite: 41° 40' N
Seehöhe: 20 m
Meridian der Zeitzone: 15° 0' O

Lage der Flächennormale: 6
Azimut: 160° 0'
Neigung: 0° 0'

Trübungsfaktor nach Linke: 4,5
Diffusstrahlungsfaktor nach Reitz: 0,333

Reflexionszahl der Umgebung (Albedo): 0,2
Anteilfaktor für Himmelsstrahlung: 0,5

Auswertungdatum: **21. Juni (Sommersonnenwende)**
Sonnendeklination: 23° 27'
Sonnenaufgang: **5h 18'** Sonnenuntergang: **20h 27'**
Tageslänge: 15h 9'

	Sonnenstand		Horizont	Einfalls	Strahlungsflüsse [W/m²]				
Uhr	Azimut	Höhe	höhe	winkel	Direkt	Himmel	Reflex	Diffus	Global
1 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
2 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
3 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
4 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
5 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
6 h	64,0°	6,4°	0,0°	95,9°	- - -	22,0	6,0	28,0	28,0
7 h	73,2°	16,8°	0,0°	86,9°	20,6	45,0	20,1	65,1	85,7
8 h	82,2°	27,7°	0,0°	79,2°	106,0	58,6	38,0	96,6	202,5
9 h	91,9°	38,8°	0,0°	73,1°	198,1	66,8	56,2	123,0	321,1
10 h	103,3°	49,9°	0,0°	69,3°	268,4	71,8	72,5	144,2	412,7
11 h	119,1°	60,4°	0,0°	68,0°	301,4	74,8	85,0	159,8	461,2
12 h	145,0°	68,8°	0,0°	69,5°	290,7	76,4	92,7	169,1	459,7
13 h	185,6°	71,7°	0,0°	73,6°	236,9	76,8	94,9	171,6	408,5
14 h	223,0°	67,0°	0,0°	79,8°	146,8	76,1	91,3	167,3	314,1
15 h	245,6°	57,8°	0,0°	87,6°	32,9	74,2	82,2	156,4	189,3
16 h	259,9°	47,1°	0,0°	96,7°	- - -	70,7	68,6	139,3	139,3
17 h	270,7°	36,0°	0,0°	106,6°	- - -	65,0	51,7	116,7	116,7
18 h	280,1°	24,9°	0,0°	117,1°	- - -	55,8	33,3	89,0	89,0
19 h	289,1°	14,1°	0,0°	127,7°	- - -	40,3	16,0	56,3	56,3
20 h	298,4°	3,9°	0,0°	138,3°	- - -	14,1	3,4	17,6	17,6
21 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
22 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
23 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
24 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
Strahlungssummen [Wh/m²]:					1598,7	886,2	811,3	1697,5	3296,2
Tagesmittelwerte [W/m²]:					66,6	36,9	33,8	70,7	137,3

Oval shape Data of the solar radiation for the **Façade 7**

Strahlungsflüsse

Feststehendes Flächenelement

Standort: barcelona

Geogr. Länge: 2° 17' O
Geogr. Breite: 41° 40' N
Seehöhe: 20 m
Meridian der Zeitzone: 15° 0' O

Lage der Flächennormale: 7
Azimut: 180° 0'
Neigung: 0° 0'

Trübungsfaktor nach Linke: 4,5
Diffusstrahlungsfaktor nach Reitz: 0,333

Reflexionszahl der Umgebung (Albedo): 0,2
Anteilfaktor für Himmelsstrahlung: 0,5

Auswertungdatum: **21. Juni (Sommersonnenwende)**
Sonnendeklination: 23° 27'
Sonnenaufgang: **5h 18'** Sonnenuntergang: **20h 27'**
Tageslänge: 15h 9'

	Sonnenstand		Horizont	Einfalls	Strahlungsflüsse [W/m²]				
Uhr	Azimut	Höhe	höhe	winkel	Direkt	Himmel	Reflex	Diffus	Global
1 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
2 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
3 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
4 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
5 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
6 h	64,0°	6,4°	0,0°	115,8°	- - -	22,0	6,0	28,0	28,0
7 h	73,2°	16,8°	0,0°	106,1°	- - -	45,0	20,1	65,1	65,1
8 h	82,2°	27,7°	0,0°	96,9°	- - -	58,6	38,0	96,6	96,6
9 h	91,9°	38,8°	0,0°	88,6°	17,2	66,8	56,2	123,0	140,2
10 h	103,3°	49,9°	0,0°	81,5°	112,5	71,8	72,5	144,2	256,7
11 h	119,1°	60,4°	0,0°	76,1°	194,1	74,8	85,0	159,8	353,9
12 h	145,0°	68,8°	0,0°	72,7°	246,5	76,4	92,7	169,1	415,6
13 h	185,6°	71,7°	0,0°	71,8°	261,4	76,8	94,9	171,6	433,0
14 h	223,0°	67,0°	0,0°	73,4°	236,5	76,1	91,3	167,3	403,8
15 h	245,6°	57,8°	0,0°	77,3°	175,5	74,2	82,2	156,4	332,0
16 h	259,9°	47,1°	0,0°	83,1°	88,7	70,7	68,6	139,3	228,0
17 h	270,7°	36,0°	0,0°	90,6°	- - -	65,0	51,7	116,7	116,7
18 h	280,1°	24,9°	0,0°	99,2°	- - -	55,8	33,3	89,0	89,0
19 h	289,1°	14,1°	0,0°	108,5°	- - -	40,3	16,0	56,3	56,3
20 h	298,4°	3,9°	0,0°	118,3°	- - -	14,1	3,4	17,6	17,6
21 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
22 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
23 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
24 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
Strahlungssummen [Wh/m²]:					1337,9	886,2	811,3	1697,5	3035,5
Tagesmittelwerte [W/m²]:					55,7	36,9	33,8	70,7	126,5

Oval shape Data of the solar radiation for the **Façade 8**

Strahlungsflüsse

Feststehendes Flächenelement

Standort: barcelona

Geogr. Länge: 2° 17' O
Geogr. Breite: 41° 40' N
Seehöhe: 20 m
Meridian der Zeitzone: 15° 0' O

Lage der Flächennormale: 8
Azimut: 208° 0'
Neigung: 0° 0'

Trübungsfaktor nach Linke: 4,5
Diffusstrahlungsfaktor nach Reitz: 0,333

Reflexionszahl der Umgebung (Albedo): 0,2
Anteilfaktor für Himmelsstrahlung: 0,5

Auswertungdatum: **21. Juni (Sommersonnenwende)**
Sonnendeklination: 23° 27'
Sonnenaufgang: **5h 18'** Sonnenuntergang: **20h 27'**
Tageslänge: 15h 9'

	Sonnenstand		Horizont	Einfalls	Strahlungsflüsse [W/m²]				
Uhr	Azimut	Höhe	höhe	winkel	Direkt	Himmel	Reflex	Diffus	Global
1 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
2 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
3 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
4 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
5 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
6 h	64,0°	6,4°	0,0°	143,5°	- - -	22,0	6,0	28,0	28,0
7 h	73,2°	16,8°	0,0°	132,4°	- - -	45,0	20,1	65,1	65,1
8 h	82,2°	27,7°	0,0°	121,2°	- - -	58,6	38,0	96,6	96,6
9 h	91,9°	38,8°	0,0°	110,1°	- - -	66,8	56,2	123,0	123,0
10 h	103,3°	49,9°	0,0°	99,4°	- - -	71,8	72,5	144,2	144,2
11 h	119,1°	60,4°	0,0°	89,4°	7,9	74,8	85,0	159,8	167,8
12 h	145,0°	68,8°	0,0°	80,5°	136,7	76,4	92,7	169,1	305,7
13 h	185,6°	71,7°	0,0°	73,1°	242,9	76,8	94,9	171,6	414,5
14 h	223,0°	67,0°	0,0°	67,8°	312,3	76,1	91,3	167,3	479,7
15 h	245,6°	57,8°	0,0°	65,0°	336,3	74,2	82,2	156,4	492,7
16 h	259,9°	47,1°	0,0°	65,2°	312,0	70,7	68,6	139,3	451,4
17 h	270,7°	36,0°	0,0°	68,2°	244,0	65,0	51,7	116,7	360,7
18 h	280,1°	24,9°	0,0°	73,8°	146,6	55,8	33,3	89,0	235,6
19 h	289,1°	14,1°	0,0°	81,4°	49,1	40,3	16,0	56,3	105,3
20 h	298,4°	3,9°	0,0°	90,4°	- - -	14,1	3,4	17,6	17,6
21 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
22 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
23 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
24 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
Strahlungssummen [Wh/m²]:					1796,0	886,2	811,3	1697,5	3493,5
Tagesmittelwerte [W/m²]:					74,8	36,9	33,8	70,7	145,6

Oval shape Data of the solar radiation for the **Façade 9**

Strahlungsflüsse

Feststehendes Flächenelement

Standort: barcelona

Geogr. Länge: 2° 17' O
Geogr. Breite: 41° 40' N
Seehöhe: 20 m
Meridian der Zeitzone: 15° 0' O

Lage der Flächennormale: 9
Azimut: 248° 0'
Neigung: 0° 0'

Trübungsfaktor nach Linke: 4,5
Diffusstrahlungsfaktor nach Reitz: 0,333

Reflexionszahl der Umgebung (Albedo): 0,2
Anteilfaktor für Himmelsstrahlung: 0,5

Auswertungdatum: **21. Juni (Sommersonnenwende)**
Sonnendeklination: 23° 27'
Sonnenaufgang: **5h 18'** Sonnenuntergang: **20h 27'**
Tageslänge: 15h 9'

	Sonnenstand		Horizont	Einfalls	Strahlungsflüsse [W/m²]				
Uhr	Azimut	Höhe	höhe	winkel	Direkt	Himmel	Reflex	Diffus	Global
1 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
2 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
3 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
4 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
5 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
6 h	64,0°	6,4°	0,0°	172,5°	- - -	22,0	6,0	28,0	28,0
7 h	73,2°	16,8°	0,0°	162,5°	- - -	45,0	20,1	65,1	65,1
8 h	82,2°	27,7°	0,0°	149,1°	- - -	58,6	38,0	96,6	96,6
9 h	91,9°	38,8°	0,0°	135,4°	- - -	66,8	56,2	123,0	123,0
10 h	103,3°	49,9°	0,0°	121,7°	- - -	71,8	72,5	144,2	144,2
11 h	119,1°	60,4°	0,0°	108,1°	- - -	74,8	85,0	159,8	159,8
12 h	145,0°	68,8°	0,0°	94,7°	- - -	76,4	92,7	169,1	169,1
13 h	185,6°	71,7°	0,0°	81,6°	121,7	76,8	94,9	171,6	293,3
14 h	223,0°	67,0°	0,0°	69,2°	293,0	76,1	91,3	167,3	460,4
15 h	245,6°	57,8°	0,0°	57,9°	423,8	74,2	82,2	156,4	580,2
16 h	259,9°	47,1°	0,0°	48,3°	494,8	70,7	68,6	139,3	634,1
17 h	270,7°	36,0°	0,0°	41,7°	491,1	65,0	51,7	116,7	607,8
18 h	280,1°	24,9°	0,0°	39,8°	404,1	55,8	33,3	89,0	493,1
19 h	289,1°	14,1°	0,0°	43,0°	239,2	40,3	16,0	56,3	295,4
20 h	298,4°	3,9°	0,0°	50,5°	54,7	14,1	3,4	17,6	72,3
21 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
22 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
23 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
24 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
Strahlungssummen [Wh/m²]:					2515,1	886,2	811,3	1697,5	4212,7
Tagesmittelwerte [W/m²]:					104,8	36,9	33,8	70,7	175,5

Oval shape Data of the solar radiation for the **Façade 10**

Strahlungsflüsse

Feststehendes Flächenelement

Standort: barcelona

Geogr. Länge: 2° 17' O
Geogr. Breite: 41° 40' N
Seehöhe: 20 m
Meridian der Zeitzone: 15° 0' O

Lage der Flächennormale: 10
Azimut: 293° 0'
Neigung: 0° 0'

Trübungsfaktor nach Linke: 4,5
Diffusstrahlungsfaktor nach Reitz: 0,333

Reflexionszahl der Umgebung (Albedo): 0,2
Anteilfaktor für Himmelsstrahlung: 0,5

Auswertungdatum: **21. Juni (Sommersonnenwende)**
Sonnendeklination: 23° 27'
Sonnenaufgang: **5h 18'** Sonnenuntergang: **20h 27'**
Tageslänge: 15h 9'

	Sonnenstand		Horizont	Einfalls	Strahlungsflüsse [W/m²]				
Uhr	Azimut	Höhe	höhe	winkel	Direkt	Himmel	Reflex	Diffus	Global
1 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
2 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
3 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
4 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
5 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
6 h	64,0°	6,4°	0,0°	130,7°	- - -	22,0	6,0	28,0	28,0
7 h	73,2°	16,8°	0,0°	137,4°	- - -	45,0	20,1	65,1	65,1
8 h	82,2°	27,7°	0,0°	139,5°	- - -	58,6	38,0	96,6	96,6
9 h	91,9°	38,8°	0,0°	136,6°	- - -	66,8	56,2	123,0	123,0
10 h	103,3°	49,9°	0,0°	129,4°	- - -	71,8	72,5	144,2	144,2
11 h	119,1°	60,4°	0,0°	119,4°	- - -	74,8	85,0	159,8	159,8
12 h	145,0°	68,8°	0,0°	107,9°	- - -	76,4	92,7	169,1	169,1
13 h	185,6°	71,7°	0,0°	95,4°	- - -	76,8	94,9	171,6	171,6
14 h	223,0°	67,0°	0,0°	82,3°	110,6	76,1	91,3	167,3	277,9
15 h	245,6°	57,8°	0,0°	68,9°	286,9	74,2	82,2	156,4	443,3
16 h	259,9°	47,1°	0,0°	55,3°	423,6	70,7	68,6	139,3	562,9
17 h	270,7°	36,0°	0,0°	41,5°	492,6	65,0	51,7	116,7	609,3
18 h	280,1°	24,9°	0,0°	27,8°	465,0	55,8	33,3	89,0	554,0
19 h	289,1°	14,1°	0,0°	14,6°	316,7	40,3	16,0	56,3	373,0
20 h	298,4°	3,9°	0,0°	6,7°	85,5	14,1	3,4	17,6	103,0
21 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
22 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
23 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
24 h	- - -	- - -	0,0°	- - -	- - -	- - -	- - -	- - -	- - -
Strahlungssummen [Wh/m²]:					2171,0	886,2	811,3	1697,5	3868,5
Tagesmittelwerte [W/m²]:					90,5	36,9	33,8	70,7	161,2

Provincia	Capital	Altura de referencia (m)	Desnivel entre la localidad y la capital de su provincia (m)				
			≥200 <400	≥400 <600	≥600 <800	≥800 <1000	≥1000
Albacete	D3	677	D2	E1	E1	E1	E1
Alicante	B4	7	C3	C1	D1	D1	E1
Almería	A4	0	B3	B3	C1	C1	D1
Ávila	E1	1054	E1	E1	E1	E1	E1
Badajoz	C4	168	C3	D1	D1	E1	E1
Barcelona	C2	1	C1	D1	D1	E1	E1
Bilbao	C1	214	D1	D1	E1	E1	E1
Burgos	E1	861	E1	E1	E1	E1	E1
Cáceres	C4	385	D3	D1	E1	E1	E1
Cádiz	A3	0	B3	B3	C1	C1	D1
Castellón de la Plana	B3	18	C2	C1	D1	D1	E1
Ceuta	B3	0	B3	C1	C1	D1	D1
Ciudad real	D3	630	D2	E1	E1	E1	E1
Córdoba	B4	113	C3	C2	D1	D1	E1
Coruña (a)	C1	0	C1	D1	D1	E1	E1
Cuenca	D2	975	E1	E1	E1	E1	E1
Donostia-San Sebastián	C1	5	D1	D1	E1	E1	E1
Girona	C2	143	D1	D1	E1	E1	E1
Granada	C3	754	D2	D1	E1	E1	E1
Guadalajara	D3	708	D1	E1	E1	E1	E1
Huelva	B4	50	B3	C1	C1	D1	D1
Huesca	D2	432	E1	E1	E1	E1	E1
Jaén	C4	436	C3	D2	D1	E1	E1
León	E1	346	E1	E1	E1	E1	E1
Lleida	D3	131	D2	E1	E1	E1	E1
Logroño	D2	379	D1	E1	E1	E1	E1
Lugo	D1	412	E1	E1	E1	E1	E1
Madrid	D3	589	D1	E1	E1	E1	E1
Málaga	A3	0	B3	C1	C1	D1	D1
Melilla	A3	130	B3	B3	C1	C1	D1
Murcia	B3	25	C2	C1	D1	D1	E1
Ourense	C2	327	D1	E1	E1	E1	E1
Oviedo	C1	214	D1	D1	E1	E1	E1
Palencia	D1	722	E1	E1	E1	E1	E1
Palma de Mallorca	B3	1	B3	C1	C1	D1	D1
Palmas de gran canaria (las)	A3	114	A3	A3	A3	B3	B3
Pamplona	D1	456	E1	E1	E1	E1	E1
Pontevedra	C1	77	C1	D1	D1	E1	E1
Salamanca	D2	770	E1	E1	E1	E1	E1
Santa cruz de Tenerife	A3	0	A3	A3	A3	B3	B3
Santander	C1	1	C1	D1	D1	E1	E1
Segovia	D2	1013	E1	E1	E1	E1	E1
Sevilla	B4	9	B3	C2	C1	D1	E1
Soria	E1	984	E1	E1	E1	E1	E1
Tarragona	B3	1	C2	C1	D1	D1	E1
Teruel	D2	995	E1	E1	E1	E1	E1
Toledo	C4	445	D3	D2	E1	E1	E1
Valencia	B3	8	C2	C1	D1	D1	E1
Valladolid	D2	704	E1	E1	E1	E1	E1
Vitoria-Gasteiz	D1	512	E1	E1	E1	E1	E1
Zamora	D2	617	E1	E1	E1	E1	E1
Zaragoza	D3	207	D2	E1	E1	E1	E1

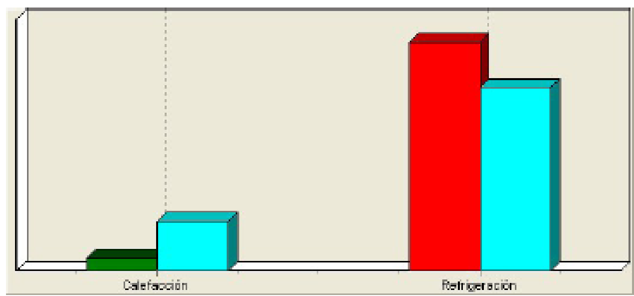
Table D.1 indicates the climatic zone Barcelona is consider, that is C2. This specification is required in the computer program Lider.

Room A Annual Energy demand results for **Heating and Cooling**

2. CONFORMIDAD CON LA REGLAMENTACIÓN

El edificio descrito en este informe NO CUMPLE con la reglamentación establecida por el código técnico de la edificación.

	Calefacción	Refrigeración
% de la demanda de Referencia	24,5	124,8
Proporción realtiva calefacción refrigeración	5,0	95,0



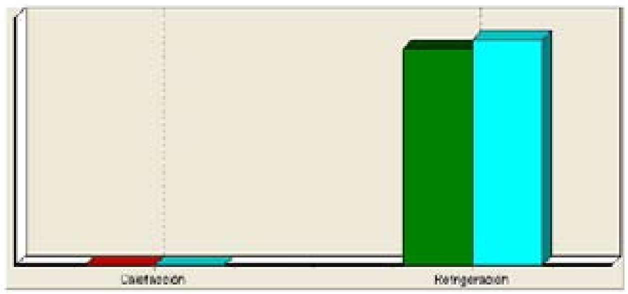
Nombre	U (W/m²K)	Peso (kg/m²)	Material	Espesor (m)
muro exterior	0,40	0,00	Conífera de peso medio 435 < d < 520	0,030
			Cámara de aire ligeramente ventilada vertica	0,000
			EPS Poliestireno Expandido [0.037 W/[mK]]	0,070
			1 pie LM métrico o catalán 40 mm< G < 50 m	0,260
particion interior	0,45	0,00	Placa de yeso laminado [PYL] 750 < d < 900	0,015
			EPS Poliestireno Expandido [0.037 W/[mK]]	0,030
			Conífera de peso medio 435 < d < 520	0,050
			EPS Poliestireno Expandido [0.037 W/[mK]]	0,030
			Placa de yeso laminado [PYL] 750 < d < 900	0,015
forjado interior	0,82	0,00	Conífera de peso medio 435 < d < 520	0,020
			Poliacetato	0,015
			Mortero de cemento o cal para albañilería y	0,040
			Conífera de peso medio 435 < d < 520	0,120

Room B Annual Energy demand results for **Heating and Cooling**

2. CONFORMIDAD CON LA REGLAMENTACIÓN

El edificio descrito en este informe CUMPLE con la reglamentación establecida por el código técnico de la edificación.

	Calefacción	Refrigeración
% de la demanda de Referencia	0,0	95,9
Proporción realtiva calefacción refrigeración	0,0	100,0



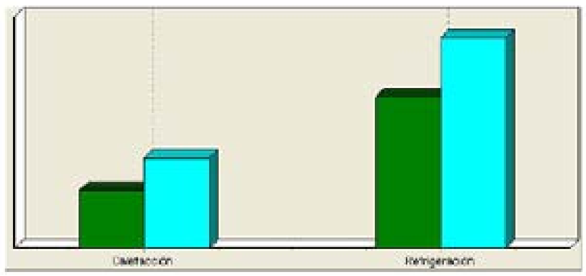
Nombre	U (W/m²K)	Peso (kg/m²)	Material	Espesor (m)
muro hormigon	0,54	0,00	Hormigón armado 2300 < d < 2500	0,100
			EPS Poliestireno Expandido [0.046 W/[mK]]	0,070
			Hormigón armado 2300 < d < 2500	0,250
forjado hormigon	0,65	0,00	Conífera de peso medio 435 < d < 520	0,030
			Poliacetato	0,015
			Mortero de cemento o cal para albañilería y	0,040
			EPS Poliestireno Expandido [0.046 W/[mK]]	0,040
			FR Entrevigado cerámico -Canto 300 mm	0,300
particion hormigon	2,94	0,00	1 pie LM métrico o catalán 40 mm< G < 50 m	0,260

Room C Annual Energy demand results for **Heating and Cooling**

2. CONFORMIDAD CON LA REGLAMENTACIÓN

El edificio descrito en este informe CUMPLE con la reglamentación establecida por el código técnico de la edificación.

	Calefacción	Refrigeración
% de la demanda de Referencia	64,4	71,9
Proporción realtiva calefacción refrigeración	27,8	72,2



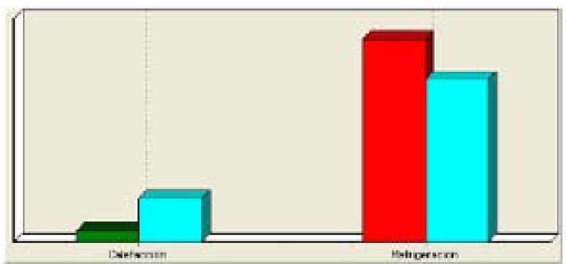
Nombre	U (W/m²K)	Peso (kg/m²)	Material	Espesor (m)
cerramiento exterior	0,38	0,00	Conífera de peso medio 435 < d < 520	0,030
			Cámara de aire ligeramente ventilada vertica	0,000
			EPS Poliestireno Expandido [0.046 W/[mK]]	0,070
			Conífera de peso medio 435 < d < 520	0,100
particion interior	0,45	0,00	Placa de yeso laminado [PYL] 750 < d < 900	0,015
			EPS Poliestireno Expandido [0.037 W/[mK]]	0,030
			Conífera de peso medio 435 < d < 520	0,050
			EPS Poliestireno Expandido [0.037 W/[mK]]	0,030
			Placa de yeso laminado [PYL] 750 < d < 900	0,015
forjado interior	0,82	0,00	Conífera de peso medio 435 < d < 520	0,020
			Poliacetato	0,015
			Mortero de cemento o cal para albañilería y	0,040
			Conífera de peso medio 435 < d < 520	0,120
muro hormigon	0,54	0,00	Hormigón armado 2300 < d < 2500	0,100
			EPS Poliestireno Expandido [0.046 W/[mK]]	0,070
			Hormigón armado 2300 < d < 2500	0,250

Room D Annual Energy demand results for **Heating and Cooling**

2. CONFORMIDAD CON LA REGLAMENTACIÓN

El edificio descrito en este informe NO CUMPLE con la reglamentación establecida por el código técnico de la edificación.

	Calefacción	Refrigeración
% de la demanda de Referencia	24,5	124,0
Proporción realtiva calefacción refrigeración	5,0	95,0



Nombre	U (W/m²K)	Peso (kg/m²)	Material	Espesor (m)
muro exterior	0,40	0,00	Conífera de peso medio 435 < d < 520	0,030
			Cámara de aire ligeramente ventilada vertica	0,000
			EPS Poliestireno Expandido [0.037 W/[mK]]	0,070
			1 pie LM métrico o catalán 40 mm< G < 50 m	0,260
particion interior	0,45	0,00	Placa de yeso laminado [PYL] 750 < d < 900	0,015
			EPS Poliestireno Expandido [0.037 W/[mK]]	0,030
			Conífera de peso medio 435 < d < 520	0,050
			EPS Poliestireno Expandido [0.037 W/[mK]]	0,030
			Placa de yeso laminado [PYL] 750 < d < 900	0,015
forjado interior	0,82	0,00	Conífera de peso medio 435 < d < 520	0,020
			Poliacetato	0,015
			Mortero de cemento o cal para albañilería y	0,040
			Conífera de peso medio 435 < d < 520	0,120

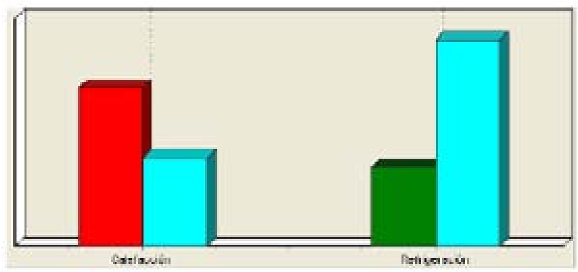
Room D Annual Energy demand results for **Heating and Cooling**

With the use of sun sahding blinds

2. CONFORMIDAD CON LA REGLAMENTACIÓN

El edificio descrito en este informe NO CUMPLE con la reglamentación establecida por el código técnico de la edificación.

	Calefacción	Refrigeración
% de la demanda de Referencia	178,5	38,2
Proporción realtiva calefacción refrigeración	66,7	33,3



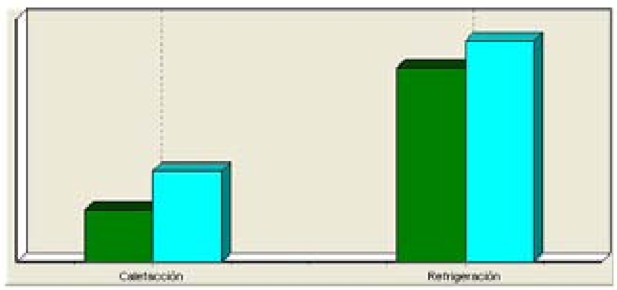
Nombre	U (W/m²K)	Peso (kg/m²)	Material	Espesor (m)
cerramiento exterior	0,38	0,00	Conífera de peso medio 435 < d < 520	0,030
			Cámara de aire ligeramente ventilada vertica	0,000
			EPS Poliestireno Expandido [0.046 W/[mK]]	0,070
			Conífera de peso medio 435 < d < 520	0,100
particion interior	0,45	0,00	Placa de yeso laminado [PYL] 750 < d < 900	0,015
			EPS Poliestireno Expandido [0.037 W/[mK]]	0,030
			Conífera de peso medio 435 < d < 520	0,050
			EPS Poliestireno Expandido [0.037 W/[mK]]	0,030
			Placa de yeso laminado [PYL] 750 < d < 900	0,015
forjado interior	0,82	0,00	Conífera de peso medio 435 < d < 520	0,020
			Poliacetato	0,015
			Mortero de cemento o cal para albañilería y	0,040
			Conífera de peso medio 435 < d < 520	0,120
muro madera	0,85	0,00	Conífera de peso medio 435 < d < 520	0,150

Room E Annual Energy demand results for **Heating and Cooling**

2. CONFORMIDAD CON LA REGLAMENTACIÓN

El edificio descrito en este informe CUMPLE con la reglamentación establecida por el código técnico de la edificación.

	Calefacción	Refrigeración
% de la demanda de Referencia	56,6	87,9
Proporción realtiva calefacción refrigeración	21,0	79,0



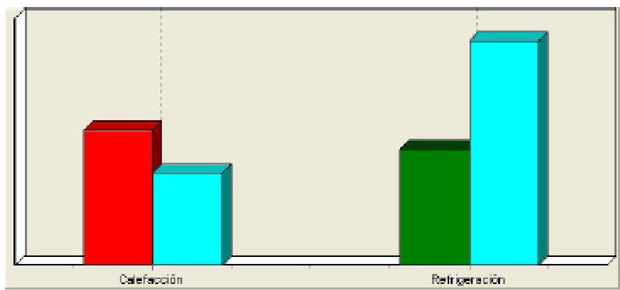
Nombre	U (W/m²K)	Peso (kg/m²)	Material	Espesor (m)
cerramiento exterior	0,38	0,00	Conífera de peso medio 435 < d < 520	0,030
			Cámara de aire ligeramente ventilada vertica	0,000
			EPS Poliestireno Expandido [0.046 W/[mK]]	0,070
			Conífera de peso medio 435 < d < 520	0,100
particion interior	0,45	0,00	Placa de yeso laminado [PYL] 750 < d < 900	0,015
			EPS Poliestireno Expandido [0.037 W/[mK]]	0,030
			Conífera de peso medio 435 < d < 520	0,050
			EPS Poliestireno Expandido [0.037 W/[mK]]	0,030
			Placa de yeso laminado [PYL] 750 < d < 900	0,015
forjado interior	0,82	0,00	Conífera de peso medio 435 < d < 520	0,020
			Poliacetato	0,015
			Mortero de cemento o cal para albañilería y	0,040
			Conífera de peso medio 435 < d < 520	0,120
muro madera	0,85	0,00	Conífera de peso medio 435 < d < 520	0,150

Room E Annual Energy demand results for **Heating and Cooling**

2. CONFORMIDAD CON LA REGLAMENTACIÓN

El edificio descrito en este informe NO CUMPLE con la reglamentación establecida por el código técnico de la edificación.

	Calefacción	Refrigeración
% de la demanda de Referencia	145,1	51,9
Proporción realtiva calefacción refrigeración	53,7	46,3



Nombre	U (W/m²K)	Peso (kg/m²)	Material	Espesor (m)
cerramiento exterior	0,38	0,00	Conífera de peso medio 435 < d < 520	0,030
			Cámara de aire ligeramente ventilada vertica	0,000
			EPS Poliestireno Expandido [0.046 W/[mK]]	0,070
			Conífera de peso medio 435 < d < 520	0,100
particion interior	0,45	0,00	Placa de yeso laminado [PYL] 750 < d < 900	0,015
			EPS Poliestireno Expandido [0.037 W/[mK]]	0,030
			Conífera de peso medio 435 < d < 520	0,050
			EPS Poliestireno Expandido [0.037 W/[mK]]	0,030
			Placa de yeso laminado [PYL] 750 < d < 900	0,015
forjado interior	0,82	0,00	Conífera de peso medio 435 < d < 520	0,020
			Poliacetato	0,015
			Mortero de cemento o cal para albañilería y	0,040
			Conífera de peso medio 435 < d < 520	0,120
muro madera	0,85	0,00	Conífera de peso medio 435 < d < 520	0,150