

**EVALUATING THE ENERGY EFFICIENT SOLAR CONTROL
STRATEGIES ON BUILDING FACADES THROUGH A CASE STUDY**

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**Programme : Environmental Control and
Building Technology**

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

**BİNA CEPHELERİNDE ENERJİ ETKİN GÜNEŞ KONTROL
STRATEJİLERİNİN BİR ÖRNEK UYGULAMA İLE
DEĞERLENDİRİLMESİ**

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FOREWORD

‘Energy’ and ‘Architecture’ are closely related subjects. Energy efficiency is becoming more popular as fossil energy sources are reducing in the world. In addition to this, fossil energy is not environmental friendly, it has several negative impacts on nature. Design decisions effect a building’s energy efficiency. Façade design is important as it is the moderator of energy flows and should be taken into careful consideration in building design period. In this thesis research, various energy efficient solar control strategies on building facades are examined.

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Gülçin Yüksel
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ABBREVIATIONS

AC	: Air Conditioning
ac/h	: air changes per hour
AHU	: air handling unit
ASHRAE	: American Society of Heating, Refrigerating and Air-Conditioning Engineers
BIPV	: Building Integrated Photovoltaics
BMS	: Building Management System
clo	: average clothing
CoP	: Coefficient of Performance
CTE	: Spanish New Building Standards
EU	: European Union
G	: Solar Radiation
g-value	: total solar energy transmittance
HVAC	: Heating, ventilating and air conditioning
IEA	: International Energy Agency
IR	: Infrared Radiation
kWp	: kilowatts-peak
low-e	: low emissivity
PC	: Personal Computer
ppm	: parts per million
PV	: Photovoltaics
PVC	: polyvinyl chloride
SARA	: Sustainable Architecture Applied to Replicable Public Access Buildings
THW	: Thermal Hot Water
Te	: External Temperature
Ti	: Internal Temperature
UK	: United Kingdom
UN	: United Nations
U-value	: Heat transfer coefficient
WWR	: Window to Wall Ratio
3D	: three dimensional

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EVALUATING THE ENERGY EFFICIENT SOLAR CONTROL STRATEGIES ON BUILDING FACADES THROUGH A CASE STUDY

SUMMARY

In recent years, buildings' energy use had increased and still have tendency of increasing. This fact increases the fossil based fuel usage and therefore causes emittance of greenhouse gases dominating CO₂. Greenhouse gases, changed global climate and caused an increase in world's average temperature. With global warming cooling demand in buildings became more significant.

The major part of energy used in buildings are used for cooling (especially in commercial buildings). Buildings should be designed to reduce the dependence on mechanical cooling to minimum. Techniques for reducing heat gain varies from site level to building materials. Being designed independent from environmental conditions, results with high building energy uses. Building envelope is significant in energy efficient building design.

In this work, subject of solar control in building facades is dealt as one of the techniques for reducing cooling energy demand in buildings and shading device types are examined which have a wide range at present time. Shading device selection criteria are analysed and advantages and disadvantages of shading device types are indicated.

In the application part of this work, a case study building is examined. This building is a 7 storey Health Care building located in Spain, Barcelona. Fixed shading devices are mounted on one facade of the building. For energy performance assesment of shading devices, one of the computer based energy simulation tools Energy Plus based 'Design Builder' program is used.

First, building is simulated assuming without any façade shading strategy (base case) then with present shading devices, afterwards different shading variations in the façade are examined. Parameters such as device types and physical properties, position as well as control type are modified and maximum energy saving potential that can be obtained is investigated in each case. The results are compared with base case and with each other. To observe the efficiency of present shading devices in two different climates, the building is also simulated in Turkey, Antalya conditions and the results are also compared.

To obtain the optimum solution in this case, design criteria of shading devices at certain conditions are tried to be analysed in this study. In the conclusion part, the results of different façade shading variations are compared with submitting the reasons.

BİNA CEPHELERİNDE ENERJİ ETKİN GÜNEŞ KONTROL STRATEJİLERİNİN BİR ÖRNEK UYGULAMA ÜSTÜNDE DEĞERLENDİRİLMESİ

ÖZET

Son yıllarda binaların enerji kullanımı artış göstermiştir ve artmaya da devam etmektedir. Bu da fosil bazlı yakıt kullanımını artırmakta ve bunun sonucunda CO₂ başta olmak üzere sera gazı salınımına yol açmaktadır. Sera gazları, küresel iklimi değiştirmiş ve dünya ortalama sıcaklığında artışa yol açmıştır. Küresel ısınma ile binalarda soğutma ihtiyacı daha da önem kazanmıştır.

Binalarda kullanılan enerjinin önemli bir kısmı özellikle ticari binalarda soğutma için kullanılmaktadır. Binalar, mekanik soğutmaya olan gereksinmeyi en aza indirecek şekilde tasarlanmalıdır. Bina soğuma yükünü azaltma teknikleri arazi ölçeğinden malzeme ölçeğine kadar gitmektedir. Binanın çevre koşullarından bağımsız olarak tasarlanması binanın enerji kullanımının artmasına yol açmaktadır. Enerji etkin bina tasarımında bina kabuğunun önemi büyüktür.

Bu çalışmada, binalarda soğutma enerjisini azaltmak için alınabilecek önlemlerden biri olan bina cephesinde güneş kontrolü konusu ele alınmış ve günümüzde geniş bir çeşitliliğe sahip olan gölgeleme araç türleri incelenmiştir. Bunun yanısıra güneş kontrol elemanı seçim kriterleri ele alınmış, bu gereçlerin avantajları ve dezavantajları ortaya konulmuştur.

Çalışmanın uygulama kısmında ise, bir örnek çalışma binası ele alınmıştır. Bu bina İspanya'nın Barcelona şehrinde yer alan 7 katlı bir sağlık yapısıdır. Binanın bir cephesinde sabit güneş kontrol elemanları kullanılmıştır. Gölgeleme gereçlerinin enerji performans değerlendirmesi için bilgisayar tabanlı enerji simulasyon programlarından biri olan Energy Plus tabanlı, 'DesignBuilder' programından yararlanılmıştır.

Bina önce gölgeleme olmaksızın sonra mevcut haliyle simule edilmiş ardından cephede değişik gölgeleme alternatifleri incelenmiştir. Bunun için farklı gereç türleri ve fiziksel özellikleri, konumlarının yanısıra kontrol tipleri gibi parametreler değiştirilerek her durumda sağlanabilecek maksimum enerji tasarrufu potansiyeli irdelenmiştir. Bulunan sonuçlar binanın gölgeleme olmaksızın haliyle ve birbirleriyle karşılaştırılmıştır. Aynı bina, mevcut gölgeleme araçlarının yararlılık oranını iki farklı iklimde karşılaştırabilmek için Türkiye'nin Antalya şehri koşullarında da incelenmiş ve bulunan sonuçlar birbiriyle kıyaslanmıştır.

Çalışmada bu bina için en iyi olacak çözüme ulaşmaya çalışılırken aynı zamanda belli koşullara göre gölgeleme araçlarının tasarım kriterleri de analiz edilmeye çalışılmıştır. Sonuç kısmında farklı tipte cephe gölgeleme araçları ile elde edilen sonuçlar sıralanmış, sebepleri irdelenmiştir.

1. INTRODUCTION

1.1 The Environmental Factor

Climate change is now widely accepted as a reality. It results from emissions of 'greenhouse' gases which are helping to trap heat within the atmosphere resulting in a rise in global temperatures. Increase in the level of greenhouse gas emissions is very likely to have caused most of the increases in global average temperatures since the mid-20th century. Carbon dioxide, methane, nitrous oxide and three groups of fluorinated gases (sulfur hexafluoride, HFCs, and PFCs) are the major greenhouse gases and the subject of the Kyoto Protocol, which came into force in 2005 [1,2,3].

This warming is expected to have severe global impacts. The changes relevant to weather are; general increase in temperatures, wetter winters and more intense rainfall, drier summers, higher daily mean winter wind speeds [2].

It is declared in UN Environmental Report that during 21st century world average air temperature is going to increase in between 1.4°C and 5.3°C (United Nations Ministerial Declaration in Geneva in 2001) [4].

The predicted effects of climate change scenario present a number of primary challenges for buildings. Adapting to climate change, building designs should take into account future changes. It should be ensured that designs don't exacerbate the impacts of climate change and remain fit for purpose (with climate-sensitive low energy design) [5,2,6].

Some predicted impacts of climate change that effect building designs are listed as follows;

- Milder winters: Milder winters will cause reduced energy use in winter.
- Rising summer temperatures: Higher summertime temperatures will increase overheating risk in buildings. Due to rising external temperatures the traditional mechanism for cooling buildings through ventilation with external air cannot be relied upon. Careful design required to reduce dependence on

mechanical cooling and to maintain indoor comfort. Even a 1°C increase in ambient temperature would be undesirable for buildings with already large cooling requirements.

- Enhanced urban heat island effect: The increase in night time urban temperature due to the urban heat island effect reduces the ability of buildings within the urban heat island to use night time cooling as a strategy. Increased temperatures, particularly at night for any building within urban conurbations, reduce the ability to dissipate heat at night making night time ‘free cooling’ less practicable in the future [2,7].

1.2 Energy and Buildings

Buildings are one of the most significant energy consumers. Electricity consumption within the EU is estimated to rise by 50% by 2020. Across the IEA countries buildings consume over half of all electricity and one-third of natural gas, and are responsible for more than one-third of all greenhouse gas emissions. A number of gases are emitted as a result of energy use in buildings and through their use as refrigerants in air conditioning systems [8,9,2].

Both heating and electricity consumption depend strongly on the buildings’s use. Commercial buildings have traditionally been extravagant users of energy [9,1]. The distribution of electricity use in commercial buildings is given in Figure 1.1.

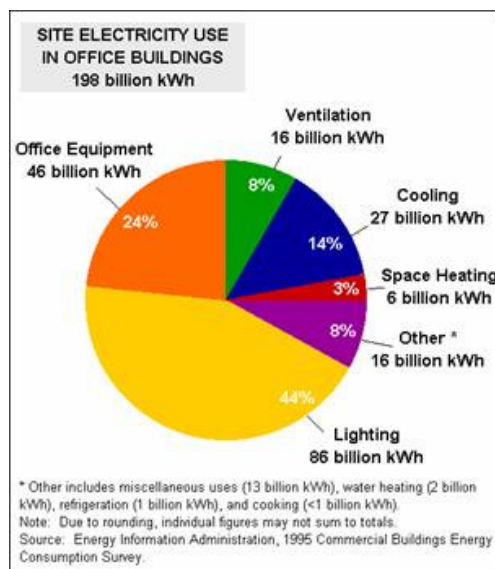


Figure1.1: Distribution of electricity use in commercial buildings [10].

In many cases the major electricity cost is incurred by lighting. Also cooling demands comprise an important ratio in building total energy demands in office buildings because of the high internal gains resulting from lighting and equipments. The operational energy of a commercial building should be kept to a minimum [1].

1.3 Importance of Solar Shading on Energy Efficiency

External building shading components are a passive design strategy that is employed in the design of buildings to control solar heat gain [11].

Shading building envelope elements from direct radiation can dramatically lower heat gains during the cooling season. Solar radiation gain through the window can be reduced on the order of 20% with an internal shading device (like a blind), up to 80% with an external device [12].

Shading devices can significantly reduce building heat gains from solar radiation while maintaining opportunities for daylighting, views and natural ventilation. A carefully designed shading can also admit direct solar radiation during times of the year when such energy is desired to passively heat a building [12].

1.4 Objectives of the Work

The purpose of this thesis is to have a look at the influence of façade design aspects on building energy use; especially in commercial buildings in which lighting and cooling loads are extremely high. The argument is strengthened with examination of case study building -Primary Health Care Center- in Barcelona. The thesis study includes six chapters.

The first chapter is the introduction. Beginning with the impacts of climate change, role of buildings on energy consumption and importance of solar shading on building energy use is explained briefly.

In the second chapter, sun, climate and building energy efficiency are examined. Related with climatic factors, energy efficiency of buildings and cooling demands in Europe are analysed. Passive design techniques are highlighted to minimise the dependence on mechanical cooling. Façade design as being one of these factors, is the main subject of the next chapter.

Third chapter is mainly concerned with solar control and shading devices. The classification and properties of shading devices are explained in this part.

Fourth and the fifth chapters are the main part of the thesis. In the fourth chapter, the case study building is described. Environmental conditions, building physical properties, thermal characteristics of building components, building technical specifications, and internal gains are determined for the seven-storey Health Care building in Barcelona, Spain. In the fifth chapter, building is analysed with 'EnergyPlus' building energy simulation programme for comparing several shading design options of case study building. The target is to achieve good thermal and lighting comfort conditions with less energy. Numerical simulations were performed to find appropriate façade shading approach. The results of several shading devices are given with comparisons.

Last chapter includes conclusions of this work.

2. DEFINING THE PROBLEM

2.1 Introduction

In this chapter, climatic regions, building energy efficiency and cooling demands in Europe are analysed. Problems with air conditioning systems are investigated and passive cooling techniques are highlighted as a cheap and clean alternative to mechanical cooling.

2.2 The Sun and the Climate

The Sun's radiation energy is the major energy source which influences the physical formations in earth and the atmosphere system. It drives the Earth's climate and weather. The basic energy source for the Sun is nuclear fusion through a series of steps within the core. This process converts hydrogen into helium and all energy produced by fusion escapes into space as sunlight or kinetic energy of particles [14,13].

The main elements influencing the climate at any location are;

1. solar radiation (its intensity, direction and duration of sunshine hours)
2. air temperature
3. humidity and precipitation
4. wind (speed and direction)
5. clearness of the sky [15].

2.2.1 Solar radiation

Energy from the Sun reaches the earth entirely through radiation. 'Incident solar radiation' (Insolation) refers to the amount of energy received on a given surface area in a given time [12,16].

Solar radiation consists of infrared, visible, and ultra-violet radiation components [12].

The solar radiation that passes directly through to the earth's surface is called 'Direct Solar Radiation' [17].

2.2.1.1 Atmospheric effects

As solar radiation passes through the earth's atmosphere, some of it is absorbed and scattered (25%) by molecules or suspensions in the atmosphere. The diffuse component may also contain reflections of the ground and other elements of the local built environment. Some of the radiation is reflected straight back out into space (usually around 20% but much more with increased cloud cover) whilst the rest arrives somewhere on the Earth's surface [17,18].

The effects of the atmosphere on solar radiation can be seen in Figure 2.1.

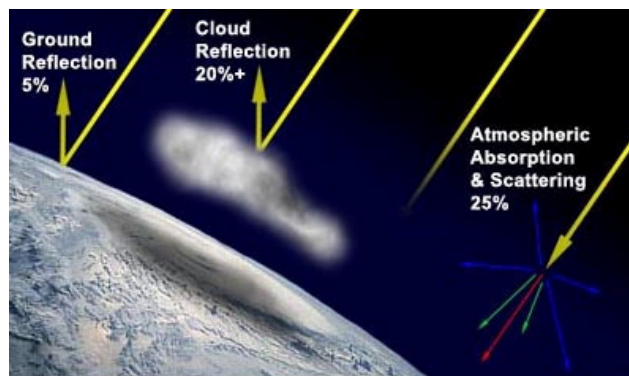


Figure 2.1: The effects of the atmosphere on solar radiation [17].

The radiation reaching the Earth's surface after having been scattered from the direct solar beam is called 'Diffuse Solar Radiation'. About two-thirds of the total light removed from the direct solar beam by scattering in the atmosphere ultimately reaches the earth as diffuse sky radiation. It is the scattered component that makes the sky look bright and provides the ambient diffuse daylighting used in buildings [19,17].

2.2.1.2 Intensity of solar radiation

A season is a division of the year, marked by the changes in weather. The Earth's orbit around the Sun is elliptical, meaning that it is closest to the Sun in late Summer and farthest away in late Winter. However, this has only a slight effect on the intensity of solar radiation. Of more importance is the Earth's revolution around its

tilted axis of 23.45° . Both mean that the path of the Sun through the sky changes significantly throughout the year [20,17].

Of even greater significance is the effect of cloud cover. Whilst a cloudy sky can actually increase the amount of diffuse solar radiation, a heavy rain cloud can reduce the direct component to almost zero. As there is generally an increase in cloud activity during the colder or wetter months, these factors combine to produce a significant seasonal variation in available solar radiation [17].

The addition of the direct component of sunlight and the diffuse component of daylight falling together on a horizontal surface make up ‘Global Horizontal Solar Radiation’ [17].

Insolation is an important consideration when designing a building for a particular climate. It is one of the most important climate variables for human comfort and building energy efficiency [16]. The average insolation of Europe can be seen in the following Figure 2.2.

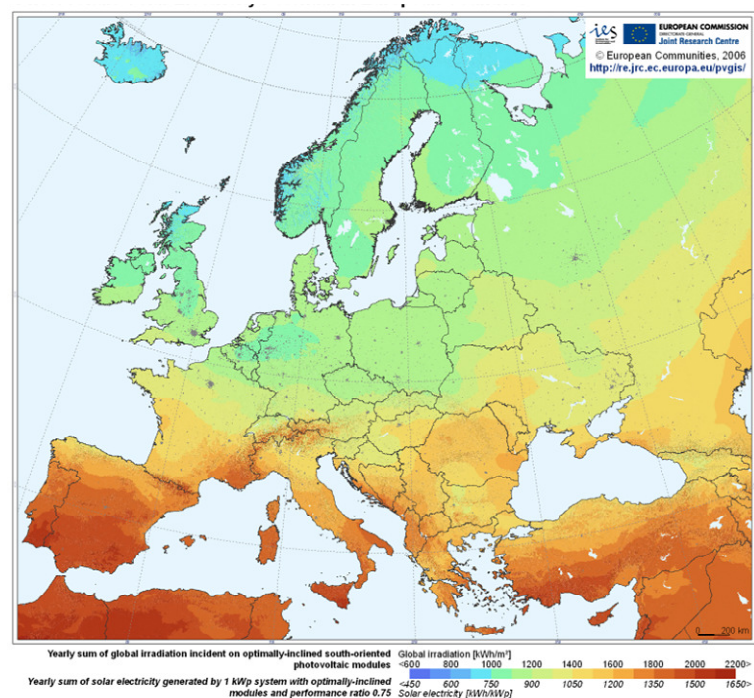


Figure 2.2: Average insolation in Europe [16].

2.2.2 Climatic regions of Europe

Climate has a major effect on the performance of the building and its energy consumption. The two most important climatic considerations are air temperature

and humidity. Based on the temperature range and the amount of relative humidity the climates can be classified as in Table 2.1 [21,15].

Table 2.1: Classification of climates [15].

Mean Temperature				Mean Vapour Pressure			
Hot	Warm	Temperate	Cool	Humid		Dry	
Over 30°C	Between 20°C–30°C	Between 10°C–20°C	Below 10°C	Over 20mb	Below 20mb	Below 20mb	Below 20mb

Temperature regime of any large area is determined by the amount of solar radiation which falls upon that area from one season to another. Regions which are exposed full face to the sun for a large part of the year are hot; those which receive sunshine only at low angles and for small portions of the year are cold [15].

The European climate zones have been described as follows:

1. North European Coastal: Cold winters with low solar radiation and short days; mild summers.
2. Mid European Coastal: Cool winters with low solar radiation; mild summers. Wind can be added to this classification for its importance for natural ventilation. This climate zone is characterized by a strong wind regime.
3. Continental: Cold winters with high radiation and longer days; hot summers. The continental type of climate dominates a giant share of Europe. Winters coldest in the northeast and summers hottest in the southeast.
4. Southern and Mediterranean: Mild and wet winters with high radiation and long days; hot and dry summers, clear skies for much of the year [22,23].

The European climate zones are showed at Figure 2.3.



Figure 2.3: European climate zones [22].

2.3 Environmental Design

Environmental design is not new; vernacular buildings have evolved over time in one location to suit the local climate, culture and economy. There is much to learn from the vernacular when designing the passive low-energy types of buildings. The design of vernacular, or traditional buildings is sensitive to climate, using a number of techniques to suit the building to the climate [22,24].

Energy conservation and passive cooling are the most efficient and cheap alternatives to conventional energy sources. Energy efficiency is the lowest-cost energy measure among projected capital and operating costs of all energy service options [25].

Insulation and energy efficiency are given higher priority in building regulations for countries like Germany and in Scandinavia [24].

2.3.1 Building energy efficiency

Buildings account today for about 40% of the final energy consumption of European Union, with a large energy saving potential of 22% in the short term (up to 2010) [9]. Distribution of end energy consumption within a total value of 10^{12} Mwh per year is given in Figure 2.4.

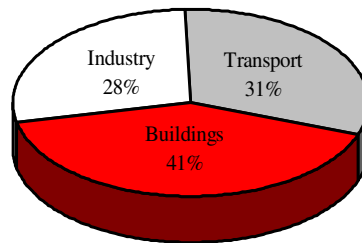


Figure 2.4: Distribution of end energy consumption in Europe [9].

Under the Kyoto protocol, the European Union with 15 members has committed itself to reducing the emission of greenhouse gases by 8% in 2012 compared to the level in 1990, and buildings have to play a major role in achieving this goal. The European Directive for Energy Performance of Buildings adopted in 2002 (to be implemented in 2005) is an attempt to unify the diverse national regulations, to define minimum common standards on buildings' energy performance and to provide certification and inspection rules for heating and cooling plants. While there are already extensive standards on limiting heating energy consumption (EN832 and

prEN13790), cooling requirements and daylighting of buildings are not yet set by any European standard [9].

Low-energy design requires heat gains minimised. This means the use of solar shade, lighting controls (maximum use of daylight-which may conflict with solar shade) and good management of internal gains [6].

2.3.2 Cooling load analysis

Cooling energy is often required in commercial buildings, because overheating problems may occur even in cold or temperate countries. The world-wide lowest cooling consumption is in UK. It is related with the solar radiation amount of a certain location. In southern Europe the annual irradiance on a horizontal surface can reach up to 1770 kWh/m^2 . (Almeria /Spain at 37° northern latitude) [9].

Cooling energy demand (MWh/a) comparison for new commercial buildings in different locations can be seen in Figure 2.5.

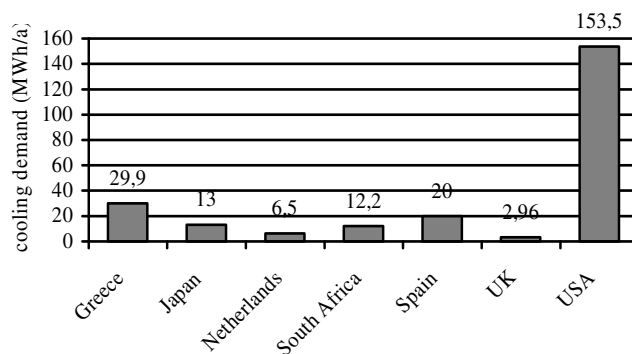


Figure 2.5: Cooling energy demands for new commercial buildings of different countries [9].

Cooling needs are higher in southern European countries (Italy, Spain, Greece and Portugal). However, there is an increasing need for cooling in other countries too (including northern Europe), due to global warming and to the increasing use of working equipment indoors, particularly in office and commercial buildings [26].

The total external and internal loads lead to an average cooling load in administrative buildings of around 50 W/m^2 in Germany. With a cooling load of 50 W/m^2 the loads are typically distributed as shown in Figure 2.6. With 20 W/m^2 , external loads are the biggest portion of cooling loads [9].

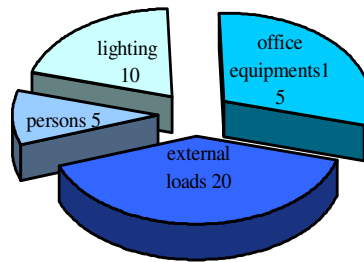


Figure 2.6: A typical breakdown of the cooling load at a total load of 50W/m^2 [9].

2.3.3 Air conditioning in buildings

The use of air conditioning in the building sector is increasing rapidly. Increase in living standards has a very important impact on the use of air conditioning. Between Southern and Northern European countries there is a high potential for further social improvements. Thus, it is expected that in most of the Southern European countries, cooling consumption in the building sector will continue to increase, at least for social and economic reasons. The most rapidly growing EU markets are in Greece, Spain and Italy [25,24].

Intensive use of air conditioning is the result of many processes, in particular:

1. Adoption of a universal style of buildings that does not consider climatic issues and results in increasing energy demands during the summer period.
2. Increase of ambient temperature, particularly in the urban environment, owing to the heat island phenomenon, which exacerbates cooling demand in buildings;
3. Changes in comfort culture, consumer behaviour and expectations;
4. Improving of living standards and increased affluence of consumers; and
5. Increase in building internal loads [25].

2.3.4 Problems with air conditioning

There are considerable problems associated with the use of AC (air conditioning). Apart from the serious increase in the absolute energy consumption of buildings, other drawbacks include:

1. an increase in the peak electricity load;

2. environmental problems associated with ozone depletion and global warming; and
3. indoor air-quality problems [25].

Figure 2.7 presents the CO₂ emissions in selected EU countries due to air conditioning.

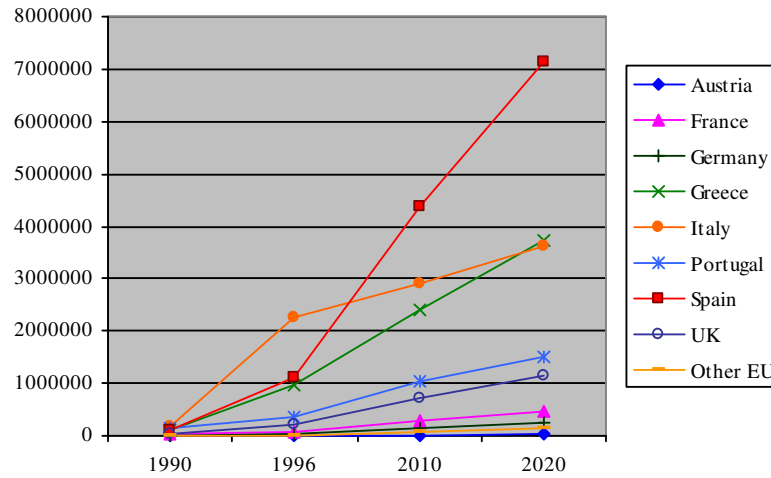


Figure 2.7: CO₂ emissions in selected EU countries due to air conditioning [25].

Countries within Europe are taking enormous strides forward in building their own low-carbon economies. Germany has built the world's leading solar economy, being followed in this field by the massive investment in solar technologies by China. Amongst European governments, Spain has the highest dependency on fossil fuels, using them to meet 84% of its energy needs, and in 2007 it spent some 17 billion euro on oil imports [24].

Beside environmental factors, the cost of cooling is also expensive. Globally rising energy prices that could double and triple in the coming years [24].

2.4 Passive Cooling Design

Passive cooling techniques are natural and low energy use cooling strategies which can serve as alternatives to mechanical cooling or reducing the need to air-conditioning systems. These cooling techniques can be subdivided into 'reducing heat gain' and 'enhancing heat loss'. 'Solar protection', which is the main issue of the thesis is one of methods of the reducing heat gain.

The primary parameters of passive cooling strategies can be defined as; use of local climatic factors, site planning, building form, façade design and building materials [24]. These factors should be managed to reduce energy consumption but maintain comfort.

2.4.1 Impact of local climatic conditions

Local factors should be considered as the first step of the design. Local conditions can differ significantly and have implications for design. Within a climate zone, a wide range of climatic characteristics can be found as a result of, for example, topography, altitude, and urban density. In order to define a local climate more precisely than simply according to the generic typologies, more detailed information is required about the local air temperatures, wind patterns and humidity (or precipitation) [27].

Urban microclimate has differences from rural environments which is called the ‘heat island effect’ as shown in Table 2.2.

Table 2.2: Urban microclimate compared with the rural environs [27].

Climatic factor	Compared with rural environs
Temperature (annual mean)	0.5-3.0°C more
Radiation (total horizontal)	0-20% less
Wind speed (annual mean)	20-30% less
Relative humidity (annual mean)	6% less

The heat island is caused by a range of factors, such as the lack of moisture (fast run-off and little vegetation), the product of heat, the absorption of solar radiation, and lower wind speeds in cities. The aspects of the urban context impacts upon the energy performance of a window. Obstructions will reduce the availability of solar gains (useful or unwanted) and daylight (increasing reliance on electric lighting) [27].

2.4.2 Site planning

The arrangement of buildings on a site should respond to climatic factors such as solar angles and wind. Site data includes factors such as surrounding buildings and open spaces between them, water and vegetation [27].

2.4.3 Building form and orientation

Includes factors such as; plan type (deep or shallow, cellular or open) and façade orientation, having courtyards or atria. Building facades shouldn't be identical. Zoning the building allows high heat gain uses to be served separately from the other parts of the building [27,2].

2.4.4 Façade design

Includes factors such as; glazing ratio and glazing distribution, ventilation openings and shading strategies. Glass buildings with little or no shading cause severe overheating is an even more severe problem in hotter climates [27,24].

Solar gains may be controlled by appropriately sizing and orienting windows, and using shading devices [28].

2.4.5 Building materials

Includes thermal effects (insulation value and thermal mass) of opaque layers of building skin and properties of transparent components by selecting glazing with high light transmission properties but low solar heat gain factor [27,2].

2.5 Conclusion

Climatic conditions and building use effect cooling demand of a building but buildings can be modified and improved in one area to be more efficient in wide range of temperatures. Small changes in the design of the building can have a large impact on its energy use. Range of adaptive opportunities available to ameliorate building's internal climate using passive and active systems. To maintain indoor comfort, the use of mechanical cooling (or heating) should be avoided where possible [24].

The primary parameters of passive cooling strategies (local factors, site planning, building form, façade design and building materials) should be managed to reduce energy consumption and maintain comfort. Aspects of energy efficient façade design is going to be examined in the next chapter.

3. FUNDAMENTALS OF SOLAR CONTROL AND DESIGN OF SOLAR SHADING COMPONENTS

3.1 Introduction

The purpose of a building is to create an artificial environment contained by the building skin. This skin should not be considered as a barrier, but as a moderator of flows. It is three dimensioned, having thickness and therefore has the ability to store energy [29].

The skin has to control a variety of flows. Functions of building façade are:

- Heat: solar radiation, air temperature
- Light: sunlight, glare, artificial
- Air: wind, ventilation
- Water: rain, humidity, condensation
- Sound: desired, undesired
- View: in and out, private or public
- Fire: flames, heat, smoke
- Pollution: gases, particles
- Security: breaking in
- Safety: falling out
- Explosions: from outside, from inside [29].

In extreme or static environments the requirements for the built form are relatively clear. It is more difficult to moderate and control environments which are constantly under change. These changes include:

- Seasonal variation
- daily variation

- variation between facades facing different directions [29].

Keeping these flows in balance often leads to conflicts. Daylight is desirable but glare is not; solar gain is useful in winter but undesirable in summer; ventilation is needed while keeping noise and pollution out implies a closed window; a good window is required while still maintaining security. The art of building facade design is to reconcile all these conflicting factors [29].

In Europe there is a growing preference for the maximisation of the following attributes for office facades:

- Energy efficiency
- Natural lighting
- Natural ventilation
- Good views through clear glass [29].

Natural lighting and good view lead to larger glazed areas, while energy efficiency requires optimum use of the sun, while controlling solar heat gain [29].

The amount of transmitted heat, or solar load, of transparent areas of a building envelope is determined primarily by:

- the size of the glazed areas;
- the orientation of the glazed areas with respect to the sun;
- external obstructions by surrounding buildings, trees, etc.;
- glazing properties;
- the properties of sun-shading devices; and
- how they are operated [25].

3.2 Solar Radiation

The intensity of solar radiation incident on building envelope surfaces varies according to the location, orientation, and tilt. This is an important criteria for designing and selecting solar control systems.

East-facing windows will let in solar radiation early in the morning contributing to warming the space- which may be beneficial. However, a west facing window will

be heating the space in the afternoon when the space will probably already be warm due to occupation and therefore this may contribute quite significantly to overheating [30].

When solar radiation strikes a surface, the radiation may be reflected, absorbed, or transmitted depending upon the nature of the surface [12].

Solar gains are determined by the solar radiation intensity; the total solar energy transmittance of the facade element, and the area of the glazing. The total solar energy transmittance or g-value is the total fraction of the incident solar energy that is transferred through a building component at normal incidence irradiation. It is also known as the solar heat gain coefficient or solar factor. A g-value of 0.2 indicates that 20% of the incident solar energy reaches the room. The g-value depends upon several factors such as the direction of the incident radiation and the wind conditions. If a sun-shading device is combined with a glazing unit, the g-value depends upon both the glazing unit and the sun shading system [12].

3.3 Heat Transfer

The largest portion of radiant heat travels through glazing. So, glazing ratio (the percentage of glazing in a façade) has a significant impact on the building's energy use [12].

The type of material and surface properties of the building objects surrounding the glazing, especially the shading devices, affects the heat transfer across the glass. Window louvres or overhangs made of materials having high thermal mass and capacitance absorb and retain short wave radiation during the day. This stored heat is finally released or re-radiated to the atmosphere and its immediate surroundings later in the day as long wave radiation [11].

The radiant energy emitted from the surfaces depends not only on the temperature but also on the emissivity, absorptance and reflectance of the materials. These are further affected by the properties of the materials, such as surface properties –color, texture etc. [11].

When designing a shading device the ratio of influence can be estimated as follows:

- geometry, shape, orientation: 70%

- material properties: 15%
- surface treatment, colour: 15% [31].

3.4 Solar Control Methods

The first main criterion in façade design is the number of glazing skins incorporated in the design (the single skin facades and multiple skin facades). Second criterion is the positioning of the solar control devices. In case of multiple skin facades, the solar control devices are generally placed between the glazing skins [32].

To achieve a certain level of solar control in a single skin facade, coatings can be applied to the glass, such as IR reflecting coatings and/or coatings to absorb and reflect wavelengths in the visible range. As the properties of various glazing types are fixed, they also restrict solar gain in the colder months and to reduce daylighting levels. For this reason, it is necessary to provide additional adjustable solar control measures in buildings with large surface areas of facade glazing and in buildings where air conditioning requirements are strictly regulated [32].

3.5 Shading Design

Appropriate shading design is dependent upon a number of physical variables, such as the path of the sun, nearby obstructions, time of day, orientation, and latitude. Knowing the applicable sun paths at different times of the year allows the designer to create a shading device that provides shade when it is desirable to do so [12].

Fixed shading devices are generally positioned for the difference between the high summer and low winter sun position for shade in summer and sun in winter [12]. Seasonal effect of a shading device on south façade is schematically described in Figure 3.1.

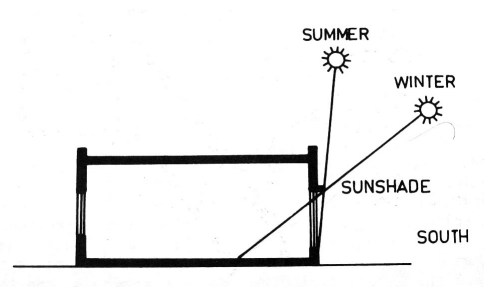


Figure 3.1: Seasonal effect of a shading device [15].

Some shading devices use adjustable movable parts for the time of day or the year to optimize shading effects. Louvers can be moved to admit light or to block it, depending upon the time of day, season or orientation [12].

Shading devices are an essential technique of avoiding unwanted solar gains, but need to respond in design and orientation. Fixed devices are rarely sufficient to control sunshine and movable devices are often required not only for thermal control but also for glare control [27].

In order to provide comfort, solar shading must be integrated with a ventilation strategy. The design of the window to perform the functions of solar shading, glare control, provision of natural light and source of ventilation air needs careful consideration. Shading systems must not interfere with ventilation flow or increase air temperatures locally. An example of this may be a brise soleil, which, although it intercepts unwanted solar radiation, ironically heats up coming air as it flows over the solar warmed device [27].

3.5.1 Design tools

Several tools are available for analyzing the extent and pattern of shade that will be provided by a particular shading device at varying latitudes, orientations and times of the year. A sun path chart (or Sun Angle Calculator) can quickly provide the sun's altitude and azimuth angles for any specific latitude, month, day, and time of day. This manual tool also provides the profile angle, the key angle for determining the extent of shading that a device provides. The percentage of a window shaded on various dates can be determined [12].

3.5.2 Design procedure

The shading device can be determined by the following design steps;

1. Determining the shading requirements: Shading requirements are building - and space- specific and are dependent upon many variables including climate, building envelope design, building/space functions, visual comfort expectations, thermal comfort expectations, and the like. It is impossible to make generic statements about this first critical step in the design process.
2. Determining whether shading will be interior, exterior or integral to glazing; whether movable or fixed: The project budget, façade design intents,

importance of views and daylighting (among other considerations) will help determine which is most appropriate.

3. Developing a trial design for the shading device: Examples of shading devices and their applications can greatly assist in this step.
4. Checking the performance of the proposed shading device- using shading masks, computer simulations, or scale models as most appropriate to the project context and designer's experiences.
5. Modifying the shading device design until the required performance is obtained and the design is considered acceptable with respect to other factors (daylighting, ventilation, aesthetics, etc.) [12].

3.6 Classification of Shading Devices

Olgyay classified shading devices according to their shading coefficient from the least to the most effective in reducing solar radiation:

1. Venetian blinds
2. roller shades
3. insulating curtains
4. external shading screen
5. external metallic blind
6. coating on glazing surface
7. trees
8. external awning
9. external fixed shading device
10. external movable shading device [33].

The energy reduction coefficients of sun protection devices depend particularly on the location of the sun protection: external sun protection can reduce the energy transmission of solar radiation by 80-90%, whereas with sun protection on the inside a reduction at most 55% is possible [9,34].

In other words, exterior shading devices are more effective by 30-35% in reducing solar radiation entering a building than interior devices which can only reflect a small part of the radiation and release heat absorbed back into the building [33].

The efficiency of sun shading systems can be roughly estimated and compared indicating the transmitted radiation impact as in Table 3.1 [31].

Table 3.1: Energy reduction coefficients of internal and external sun protection [34,31].

Sun shading system	Colour	Energy reduction coefficient (-)
external movable louvres		0.15
external Venetian blinds	white/ bright	0.13-0.20
continuous overhang on South side		0.25
external Venetian blinds	dark	0.20-0.30
internal Venetian blinds	white/ bright	0.45-0.55
internal Venetian blinds	dark	0.75
reflection glazings	-	0.20-0.55
regular glass	-	1

Solar control methods have traditionally been used in a wide geographical distribution in the world as in Figure 3.2. The most elemental materials for sun control are mentioned in the following.

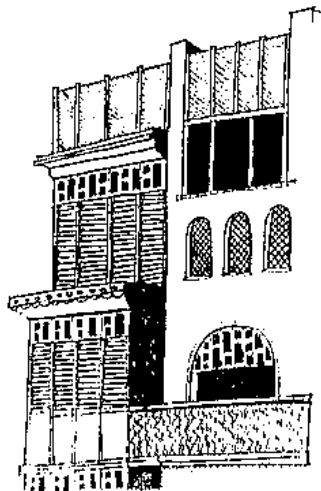


Figure 3.2: Traditional screened windows (mashrabias and rowshans) [31].

External obstructions are useful in warm climates such as Mediterranean and Arab cities. With their tight mazes of streets, buildings are so close that they shade each

other. In other architectural traditions, porticoes and overhangs offer similar protection [35]. Figure 3.3 shows shading of buildings and building elements by cantilevered construction, arcades, loggias and high building parts.

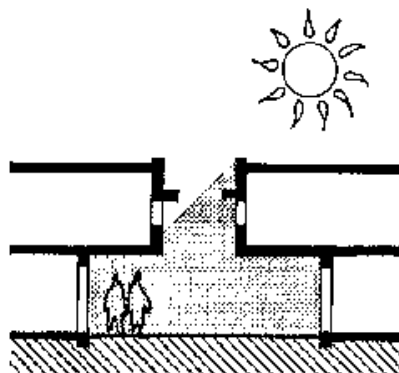


Figure 3.3: Shading of buildings and building elements [31].

Deciduous trees provide access to winter sun but protect against summer sun when it is needed [31]. Figure 3.4 shows the effects of deciduous trees.

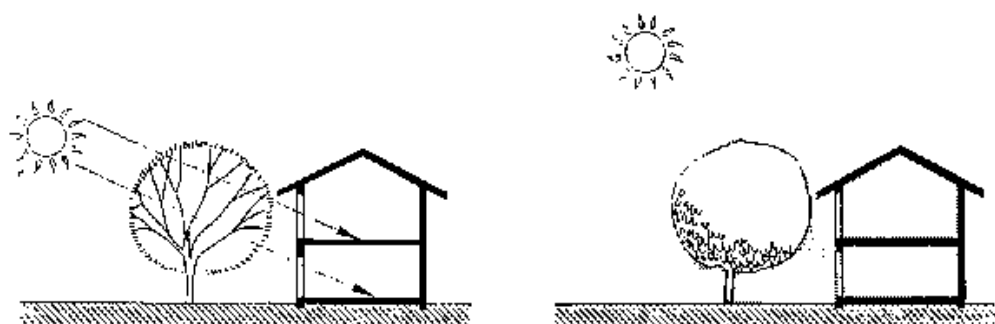


Figure 3.4: Effects of deciduous trees [31].

Plant shading can often be more effective than from a fixed shading device because sun angles do not always correlate to ambient air temperature (and a resulting need for heating and cooling). For example, the sun angles on the spring equinox (March 21) are identical to the sun angles on the fall equinox (September 21). However, in the northern hemisphere, it is typically much warmer in the late September than it is in late March, requiring more shading in September than in March. Deciduous plants respond more to temperature than to solar position. Leaves may not be present in early March, allowing sun to warm a building, while they are still on the trees in September, providing shading [12].

Façade greenery can be provided in two possible approaches as in following Figure 3.5.

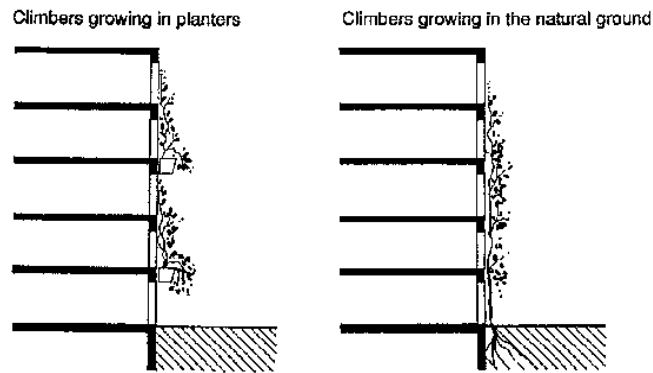


Figure 3.5: Facade greenery approaches [31].

To decrease the amount of solar radiation, the wall element can be inclined and orientated independent of the building structure [36].

Also thick skins use depth in the façade and projections to achieve a shading effect from the sun. Recessed window openings and façade geometry can allow a building to act as its own shading device (structural shading) [36,12].

Le Corbusier's Capitolgroup in Chandigarh, India, is an example of structural shading given in Figure 3.6.



Figure 3.6: Structural shading , Capitolgroup in Chandigarh [37].

The effect of shading, for an air-conditioned commercial building, may be expressed in terms of annual energy expended in cooling, as predicted for a south facing room using a variety of shading methods and dimensions. The comparisons are given in Table 3.2 [2].

Table 3.2 : Effect of shading methods and dimensions upon annual energy consumption for cooling [2].

Shading Method	Depth (mm)	Annual index
No shading		1.0
Window recess	150	0.94
	500	0.82
	1000	0.68
Vertical fins	150	0.97
	500	0.94
	1000	0.88
Horizontal overhang	500	0.87
	1000	0.76
	2000	0.57

3.6.1 Local shading

Local shading components are external elements as a part of the building envelope. Overhangs, fins, egg crates, awnings, louvres, shutters can be classified in local shading.

3.6.1.1 Overhangs

The sun's seasonal altitude and orientation impact shading device design. Overhangs are useful in all directions especially on south. On the east and west they do provide shade, however, when the sky is higher in the sky [35,25].

Horizontally projecting components or light-control elements on south facing facades are particularly suitable in climatic zones with a high proportion of direct radiation, and are most effective in geographic regions where the solar altitude in summer is high. It is only under these conditions that large areas of a façade can be shaded by an overhang with dimensions small enough to be acceptable to an architect. In order to completely shade a window that is 1.5m high at the summer solstice in Rome, an overhang of 0.5m is needed; in Stockholm, the projection would be twice as wide [25].

Overhangs are attached to a glass curtain wall in Office Building in Finsbury Avenue, London, UK as in Figure 3.7. (Designed by Arup Associates). Façade is developed with metal framework exterior shading devices.



Figure 3.7: Metal overhangs of Office Building in Finsbury Avenue, London [12].

An overhang can take the form of a roof overhang, a slab projection and verandahs, or combined with fixed or adjustable louvres. It can be a horizontal slatted baffle that is capable of supporting snow loading and allowing free air movements as examples in Figure 3.8 [31,38].

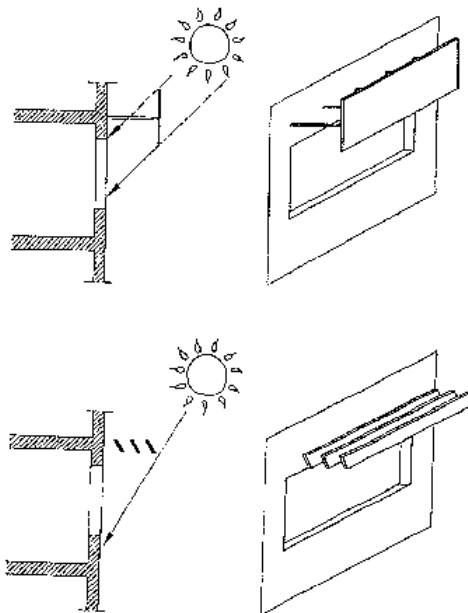


Figure 3.8: Overhangs with slatted components [31].

A horizontal overhang above a southern window, extending sufficiently in front and on both sides, can provide complete shading from the direct sun during midsummer,

and still enable solar penetration in winter. However, an overhang does not provide any protection from the radiation reflected from the ground in front of the window. Furthermore, in the late-summer and early-fall months (mid-August to mid-October in the Northern Hemisphere), the ambient air temperature in hot-dry regions may still be quite high while the sun is already low enough in the sky to strike most of the window area. In this situation the shading by an overhang may not be enough to prevent significant solar penetration and overheating [39].

3.6.1.2 Fins

Fins (also named as sidefins) are the vertical elements which are effective in blocking the very low rising and setting sun but they restrict view [35].

Figure 3.9 is the view from Valencia Congress Center in Spain (Architect: Foster & Partners). Fins are placed at east façade.



Figure 3.9: Fins on the east façade of Valencia Congress Center in Spain[40].

In the case of eastern and western orientations, fins are more effective than horizontal overhangs of the same depth. However neither can provide complete shading in these orientations. Optimal efficiency can be obtained with movable elements [39,31].

Fins can be inclined to improve the efficiency as in Figure 3.10.

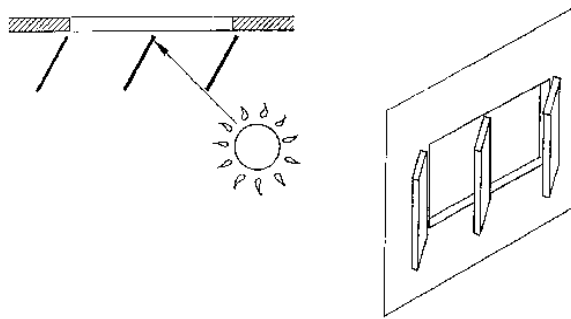


Figure 3.10: Inclined fins [31].

In hot climates for northern windows, vertical fins, especially on the western side and extending above the windows height, can provide protection from the late afternoon sun [39].

3.6.1.3 Egg crates

A frame made of a horizontal projection and vertical fins is often referred to as egg crate as shown in Figure 3.11 [39].

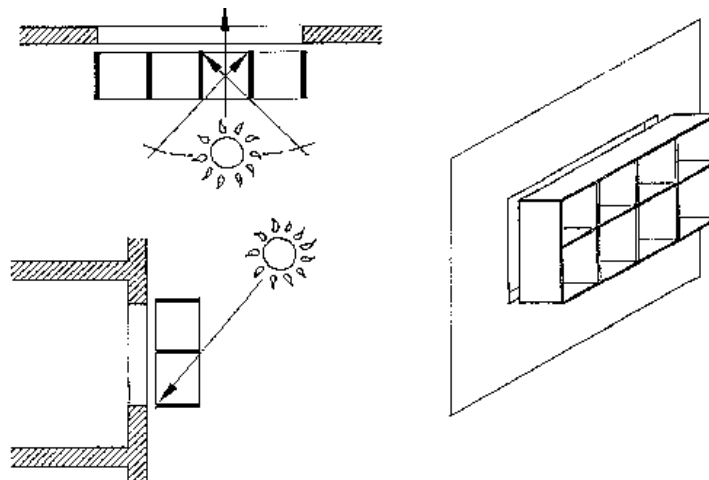


Figure 3.11: Egg crated devices [31].

Egg crate is a more elaborate device, combination of both horizontal and vertical shading properties. They may be used where only horizontal or vertical protection alone would not provide shade. It may be required on east to southeast and on west to southwest oriented surfaces. It could be made of precast concrete or brick elements, timber or other similar material [27,31].

They are useful for very hot climates. The disadvantages of egg crates are that view is very restricted and hot air is trapped in the device.

The only way by which an eastern or a western window can be shaded effectively by fixed devices is by a frame consisting of horizontal overhang and a vertical fin oblique at 45 degrees towards the south [39].

3.6.1.4 Awnings

The Roman word still used today ‘velarium’ a large awning, especially one suspended over a Roman theatre or amphitheater. Fabric awnings as shown in Figure 3.12 have long provided shade [35].



Figure 3.12: Awnings [41].

Awnings are more efficient on south façade than on a west or east façade [38].

Disadvantage of awnings is that tall windows need far out projecting awnings, which is therefore more exposed to wind damage. In addition, the further the projection, the greater the side opening through which solar radiation is admitted. The awning should be 15cm to 20cm wider than the window opening to reduce sun penetration from the sides [38].

Italian awnings are more suitable for tall windows. The top part is located in side runners and the bottom part projects outwards in the same way as an ordinary awning [38].

Dark coloured awnings are more efficient. A light colour will increase the primary solar transmittance of the fabric and also increase the solar gains reflected from the light backside of the awning into the room. A very light-coloured awning captures reflected solar radiation from the façade and the ground. The window with a blue awning has a g-value of approximately 9% during the summer period. The window with a beige awning has a g-value of 16% during the same period [38].

3.6.1.5 Louvres

Louvres are externally mounted sun shading devices standing at a distance from the glazing. Figure 3.13 is schematic view of external louvres.

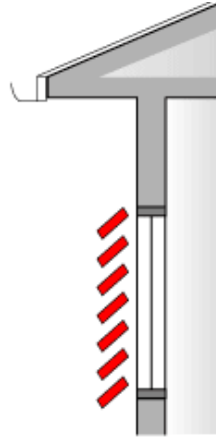


Figure 3.13: Schematic view of external louvres [42].

The greatest degree of solar control is generally achieved with an externally mounted sun-shading device. A disadvantage is their exposure to wind loads- particularly for awnings- and the higher production and maintenance costs, both related to the effects of weathering. With regard to the passive use of solar energy for heating in winter, the reduction of solar gains by an external sun-shading device is a disadvantage. However, experience has shown that this has a little effect on the energy balance of low-energy office buildings in a Central European climate [25].

Vertical louvres of aluminium sheet serve as solar control at west side of GSW Headquarters building in Berlin as in Figure 3.14 [32].

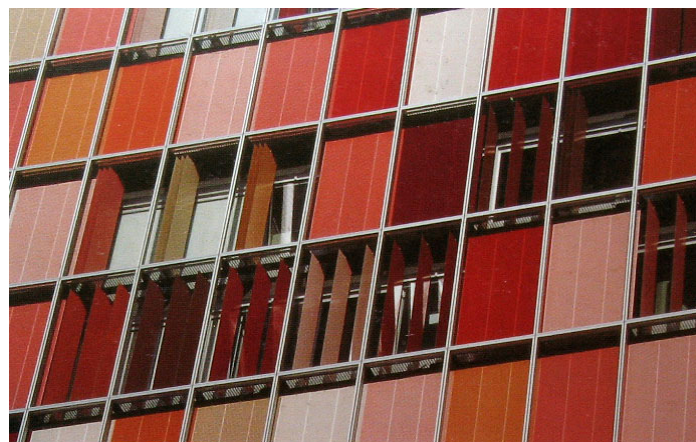


Figure 3.14: Vertical louvres at double-skin façade of GSW Headquarters [32].

They are on the outer part of the double-skin façade. In the rest position they are folded back vertically in groups of three [32].

3.6.2 Window shading

Window shading components are external, internal or mid-pane elements associated with the window.

3.6.2.1 Slatted blinds

Slatted blinds can be classified as; blinds with high or low reflectivity slats.

3.6.2.2 Diffusing blinds

Diffusing blinds can be classified as; Venetian blinds, roller blinds, roller screens and drapes.

Venetian blinds

Regardless of the slat form or colour, if the slats are completely closed, g-values of 10% and less can almost always be achieved if the blinds are mounted in front of glazing units with U-values of $1.1\text{W/m}^2/\text{K}$ or better. When the blind is closed the lowest g-values are obtained with highly reflective slats (eg. white slats). In the cut-off position highly reflective slats lead to a higher g-value than less reflective slats because of multiple reflections. Thus with this blind position, the situation is reversed: better daylighting is achieved, but less solar control with the more reflective slats. The g-value for externally mounted Venetian blinds in the cut-off position can be higher than 15% [25]. Figure 3.15 is an example of Venetian blind.



Figure 3.15: External Venetian Blinds [43].

Perforated slats offer a certain degree of visual contact even when the blind is almost closed. Blinds that allow divided adjustment of the slats in the lower and upper part of the window improve glare protection and daylighting [25].

A standard construction has aluminium slats in widths from 50mm that can be tilted. Slats wider than 50mm are stronger and have a stiffened edge. The shading performance is not very different due to the slat width [38].

Roller blinds

External roller blinds are made of either water repellent, weather resistant textiles or stainless steel. Textile roller blinds expose a large continuous area to the wind and are therefore more susceptible to wind loads than Venetian blinds. In contrast to Venetian blinds, roller blinds, which can largely be moved vertically only, do not allow angle selective blocking of direct solar radiation to achieve solar control. Thus the solar control effect of a textile blind is mainly determined by its transmittance. A stainless steel blind is more wind resistant due to its greater mass and can offer some angular selectivity depending upon the rod profiles [25].

Roller screens

Roller screens are external screens that can be rolled up and down. The fabric is translucent PVC-coated polyester or glass fibre. It is transparent from the dark side to the light side [38].

The screens provide a relatively good view out but less privacy at night. A disadvantage is small particles like dust, sand etc. may clog up the fabric, with the result that it is less transparent and the view of the outside is restricted. However the fabric is easy to clean. Also a screen requires less room above the window than, for example an external Venetian blind [38].

3.7 Operation of Shading Devices

Shading devices can be either fixed or movable.

3.7.1 Fixed devices

Solar control can be achieved without moving parts– to a limited extend- by large external structures on the building envelope. They are designed individually as a part

of the architecture. They improve the robustness of the indoor climatic concept as the solar control effect is independent of user behaviour. Furthermore, they allow an undisturbed view of the surroundings for a longer period of the year since the supplementary movable systems that are generally needed can be used less frequently. However, the view is already restricted to a greater or lesser extent by the external structure itself [25].

Like reflective profile elements or Venetian blinds, the transmission behaviour of external structures is not rotationally symmetric with respect to the incident direction of the radiation. The fundamental concept in dimensioning the sun-shading devices is to block the largest possible angular range of direct radiation in summer. Highly reflective surfaces are not necessary here to achieve solar control as the heat generated absorption in the structures is transferred completely to the ambient air. The solar control effect that can be achieved with these fixed components fluctuates with the seasonally varying angle of incidence of the direct radiation [25].

3.7.2 Movable devices

Fixed shading will reduce daylighting levels all year round creating a need for artificial lighting. Movable devices should be used to allow for greater control than fixed devices. To ensure that comfort conditions are maintained, louvered systems or retractable blinds are recommended. A degree of occupant control over their own environmental conditions helps to improve their perception of comfort and their acceptance of a wider comfort range [44,27].

Automated Venetian blinds or louveres are wide-spread. Products with an adjustable angle of tilt have the advantage that they can be angled to suit all light and weather conditions. The disadvantage of small louveres is that they have little resistance to wind pressure [32].

Large, rotating louveres however offer effective solar protection and have good wind stability. They consist mostly of extruded aluminium profiles or bent metal sheets; recently large sized glass louveres have also become popular [32].

Glass louveres with holograms are a further possibility for transparent solar protection. They deflect the direct solar radiation and diffuse light however can enter unimpeded [32].

For Debis Headquarters building in Berlin (Architect: Renzo Piano), a double-skin facade was developed with an outer skin of frameless, pivoting glass louvres [32]. Two modes of shading devices are described in Figure 3.16.

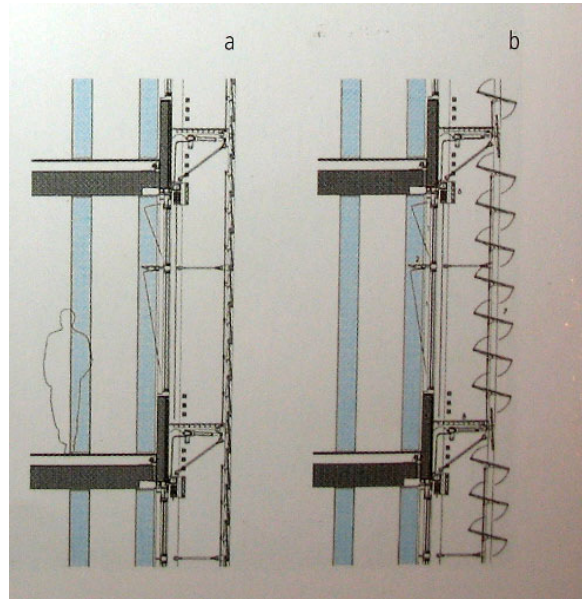


Figure 3.16: Movable glass louvres at the double skin-façade of Debis Headquarters [32].

Most of the operable shading devices can be applied with about the same effectiveness to all orientations and to any shape of window [39].

Manual control can be effective for small buildings and/or with educated and committed building users, but for larger shared and public spaces and/or for different uses of buildings, automated systems are essential. Movable shading devices are quite common and have been installed for over fifty years in Europe. The advantages of automated systems are their ability to optimise energy use and control interior conditions without relying on occupants [45,35].

In addition to fixed and manually operable sun controls are those that automatically track the sun or respond to solar heat gain and light levels. Such sun-control technologies have been raised to an art form in recent projects [35].

3.7.2.1 Advanced sun control elements

The word ‘intelligent’ indicates the dynamic, almost living capability of a façade to adapt to changing daily or seasonal conditions in order to achieve a reduction in a building’s consumption of primary energy [32].

At south wall of Jean Nouvel's Arab Institute in Paris, exquisite metal irises (sandwiched between sheets of glass in patterns) open and close like the aperture of a camera to control the level and intensity of daylight entering the building [35]. Figure 3.17 is view of the façade of Arab Institute from interior.

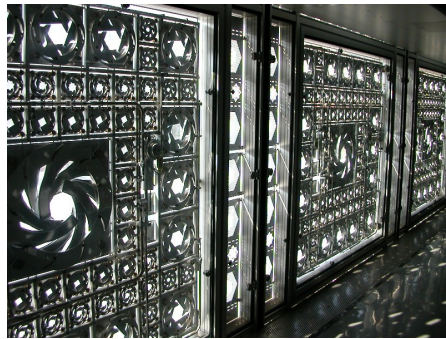


Figure 3.17: Arab Institute building façade detail [46].

However, moving parts are vulnerable to mechanical failure and the future may lie not with the mechanisms but with computer-controlled systems with a few moving parts [29]. Also such dynamic control would not be suited to all situations because, as the automatic switching of artificial lighting with its internal effects can be distracting for the occupants.

In Siemens Pavillon at Expo '92 in Seville- Spain, (designed by Gunter Standke), full-height curved solar shield moves around the circular pavillon tracking the position of the sun [32,35]. Figure 3.18 is the view of the Siemens Pavillon.



Figure 3.18: Siemens Pavillon in Seville, Spain [32].

The movable horizontal louvres are made up of prismatic acrylic panels, and are automatically adjusted with the position of the sun. A central electronic control system governs the tracking of the shield around the building, and automatically adjusts the angle of the prismatic louvres. The ever-changing position of the shield and the angle of the louvres give the pavillon continuously a new appearance [32].

A sophisticated shading and daylighting control system was developed for the administration building ‘Soka-Bau’ in Wiesbaden, Germany. (Architect: Herzog and Partners). The different uses of the building created a façade design which would meet the correct lighting and shading for each type of workspace. Specially designed aluminium shading and light deflection panels were built into the external façades. On the southern side, automated solar shading and daylight redirecting devices are employed. On the northern side the reflectors provide only additional light [47,48]. Figure 3.19 and Figure 3.20 shows the different modes of device.

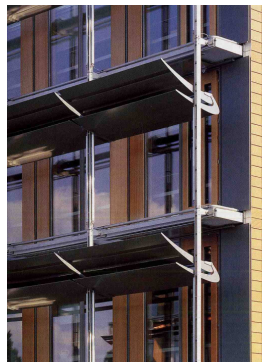


Figure 3.19: Daylight reflecting mode of devices at Soka-Bau [49].

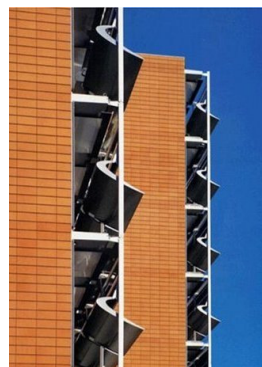


Figure 3.20: Shading mode of devices at Soka-Bau [50].

The modules are automatically moved. The system also allows individual control of each office room. The external appearance of the building constantly changes as the positions of the panels are altered in response to the weather [51,47].

By designing the façade in an integrated and holistic way, very low energy consumption is achieved [47].

3.7.2.2 Photovoltaic integrated shading

Both solar shading and photovoltaic power generation need alignment with the sun to maximise their effect. Rotating glass louvres with integrated PV cells can be combined for this target. They can be moved mechanically to track the sun [52,32].

When required, the louvres open fully to allow the maximum amount of light in. The photovoltaic louvres, which follow the position of the sun on a single axis movement, automatically provide a shading function. In the closed position, the louvres form a completely flat surface. They are available in a variety of specifications, including the choice of opaque or semi-transparent shading [52].

The principle of PV integrated movable shading system is shown in Figure 3.21.

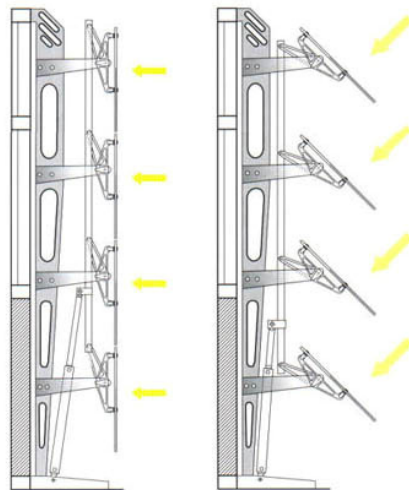


Figure 3.21: Photovoltaic integrated shading [52].

The surface of the plain glass louvres can be treated to reflect light whilst maintaining the view out of the window. A glass fibre screen is also available as a lamination for plain glass or photovoltaic louvres to provide a semi-transparent backing in a variety of colours [52].

3.8 Situation of Shading Devices

Shading devices can be applied external, internal or mid-pane. The effects of external versus internal shades on internal heat flow are shown in Figure 3.22.

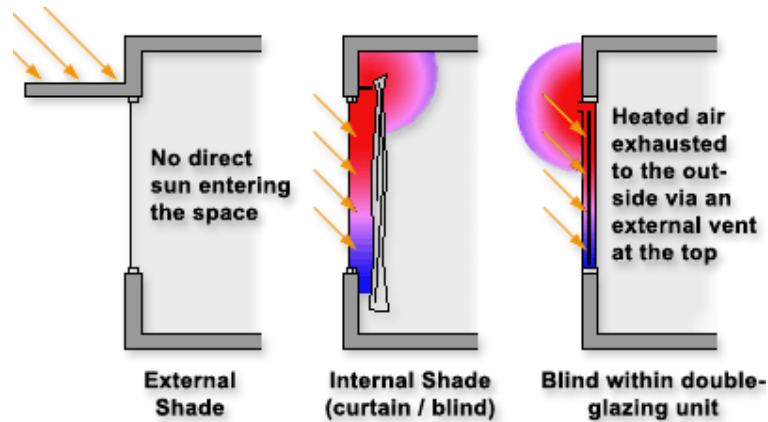


Figure 3.22: Heat flow through glazing with different shading situations [53].

Interior shading devices are less effective since the absorbed heat is largely dissipated to the indoor air. If user control is necessary, blinds would better be encased in a double-glazed unit where excess heat gains are vented to the outside [38,53].

3.8.1 External solar control devices

The advantage of exterior solar control devices is that the heat, resulting from re-radiation from the device itself remains on the outside of the building. A typical g-value for a facade with exterior devices is around 0.10. A disadvantage is the fact that the devices in the form of fabric blinds or louvres are exposed to the effects of weather which can give rise to high costs for regular cleaning and maintenance [32].

3.8.2 Internal solar control devices

Internal shades include, Venetian blinds (with wooden, metal or plastic slats), roller shades, drapes and blackout screens. Usually these can be lifted, rolled or drawn back from the window at any time by the users [22,35,15].

The advantages of indoor devices are the ease of installation and their comparatively favourable purchasing and their maintenance costs since they are not exposed to weathering. They can be applied in tall or exposed buildings with high wind loads. In order to achieve adequate solar control for a building with purely passive cooling, indoor sun shading devices are almost always combined with solar control glazing. Its higher price reduces the cost advantage. With special Venetian or roller blinds, similarly low g-values to externally mounted devices can then be achieved [25].

An example of internal roller blind is shown in Figure 3.23.



Figure 3.23: Internal roller blinds [54].

A disadvantage of all internally mounted devices is the doubled path length for radiation through the glazing unit due to reflection by the sun-shading device, with the corresponding absorption of some of the radiation in the glass. Depending upon the type of the fitting, the solar control effect is negligible or limited if the windows are opened [25].

However when shading devices are positioned well away from and above the occupants, re-emission of heat by radiation and convection is far less significant. If the devices are light coloured and well ventilated, then internal shading can be highly effective. This has the advantage of significant cost reductions compared with external devices, and facilitates control and maintenance [44].

For interior shading devices, the reflectance of the fabric is the most important parameter in obtaining low g -values. This is contrary to exterior shading devices. For example, dark coloured awnings (with low reflectance and high absorptance) provide lower g -values than light ones [38].

3.8.3 Mid-pane solar control devices

Solar control devices integrated into a glazing unit are less common at present. Costs associated with cleaning are much lower, but maintenance may be more expensive, especially in cases where electric motors are also incorporated in the cavity between panes. An alternative is the system with use of magnetic control placed outside the insulating glass [32].

Only thin sun-shading devices can be mounted within the hermetically sealed gap of an insulating glazing unit (maximum gap width is about 40mm). Roller or small Venetian blinds can be installed [25].

The mechanical protection for the devices is better than for indoor devices. The solar control performance of the system is between that of externally mounted and indoor devices. Glazed double-skin facades have frequently been equipped with these systems in recent years [25].

3.8.4 Comparing Efficiency of Shading Devices in Reducing Solar Heat Gain

Solar heat gain reduction of variable shading devices are given in Table 3.3. Plain single glazing is assumed as zero. There are external, mid-pane and internal devices with different properties. The most efficient device is external dark colored miniature louvred blinds.

Table 3.3 : Relative efficiency of shading devices in reducing solar heat gain [2].

Type of solar protection		Relative exclusion efficiency (%)	
		Single glazing	Double glazing
External miniature louvred blind	dark green	83	87
External roller blind	canvas	82	85
External louvred sunbreaker, 45° blades	white	82	85
External open weave plastic blind	dark green	71	78
Mid-pane Venetian blind	white	-	63
Internal holland blind	cream	57	61
Internal cotton curtain	white	46	47
Internal Venetian blind	white	39	39
Internal open weave plastic blind	dark green	18	26
Clear glass in double window	-	-	16

3.9 Providing Comfort Requirements with Shading Design

Two issues, solar heat gains and intense sunlight deteriorate the comfort level.

Intense daylight of working areas affects the intention and visual performance of the occupant, while thermal discomfort in overheated or cold office rooms can lead to physical stresses, which are commonly responsible for illness and poor performance [55].

These problems, caused by insufficient consideration of the negative influences of glazing on the comfort level during the design process, affect how occupants use their buildings and interfere with architects' intended expressions. According to a

study, productivity was increased by 15% when office workers were satisfied with their environments. To avoid the thermal and glare discomforts, office workers may turn on the air-conditioning system for the entire working hours and use shading devices (such as roller shades) in all the working hours [55].

Physical fundamentals for solar control can be classified into two groups; thermal and lighting comfort.

3.9.1 Thermal comfort

The purpose of natural heating and cooling methods is to provide a comfortable internal thermal environment. Thermal comfort is a rather difficult and complicated concept as it depends on various influencing parameters. Four main physical parameters characterize the thermal environment and determine the thermal comfort sensation [15,56]:

1. ambient air temperature
2. air velocity
3. relative humidity
4. mean radiant temperature [56].

Moreover, the following external parameters should be considered for the thermal comfort conditions calculation:

1. activity level
2. clothing [56].

There are many factors that influence thermal acceptability assessment and correspondingly energy consumption behaviour of individuals, such as gender, age and socio-demographic conditions. For instance; in a region occupants may be thermally satisfied and feel thermally comfortable at an effective temperature which is above the upper boundary of ASHRAE thermal comfort zone [5,57].

Shade can also reduce the effective temperature, as experienced by an occupant by up to 8°C [44].

Two fundamental principles are applied to achieve solar control with respect to thermal comfort:

1. Limitation of solar loads: this directly reduces the heating of a room. The solar loads do not act immediately but only after a certain time delay determined by the heat storage capacity of the building construction.
2. Protection against direct irradiation by the sun: If a person is irradiated directly by the sun the body surface absorbs the solar energy immediately and perceptibly. Under summer conditions this is generally not desirable for the work environment. This also ensures glare protection [25].

3.9.2 Lighting comfort

Generally, an optimum level of working area illuminance for agreeable working conditions depends upon the task performed. Recommended level of illuminance for offices is 500 lux [27].

For lighting comfort, daylighting and glare control should be maintained carefully.

3.9.2.1 Daylighting

German building regulations mandate that all office workers must be less than 25 feet from a window and natural light. Daylighting is important because of its influence on occupants. One of the factors influencing levels of daylight is shading devices. They act as obstructions to light admission, unless carefully designed (e.g. louvered and light coloured) [35,27].

Fixed architectural shading, like overhangs, are problematic. It permanently blocks valuable zenith sky light, which is the strongest light direction in overcast skies. However, internal shades allow the individual adjustment of the illumination. The most appropriate for the daylighting of spaces are louvres, which pass the light from the brightest part of the sky at the zenith and shade the spaces from direct solar radiation, especially in summer when the sun is high and there is no fear of glare [58,27].

It is relatively easy to achieve uniform illumination with artificial lighting. However, it is much more difficult to ensure this with daylight because the condition of the sky changes constantly and because the room illumination decreases rapidly with the distance of the window [27]. In this case the uniformity of the illumination can be improved by the following methods:

- Diverting the sun's rays to the ceiling with reflective жалousies, prismatic elements and halographic films. These elements use two basic optical principles: reflection and refraction; (reflection with reflective shades and refraction with prismatic elements). The optical characteristics of these elements must be adapted to the orientation of windows and the longitude of the site of the building.
- Attaching highly reflective surfaces to the inner or outer sides of the window, such as windowsills and lightshelves to reflect light (and other radiation components) into a building [27].

The form, material, and position of a lightshelf determine the distribution of incoming daylight. A lightshelf may be placed on the exterior or interior of a building or both; the defining element is that there is glazing directly above the plane of the shelf [12]. Some of these systems are shown at Figure 3.24.

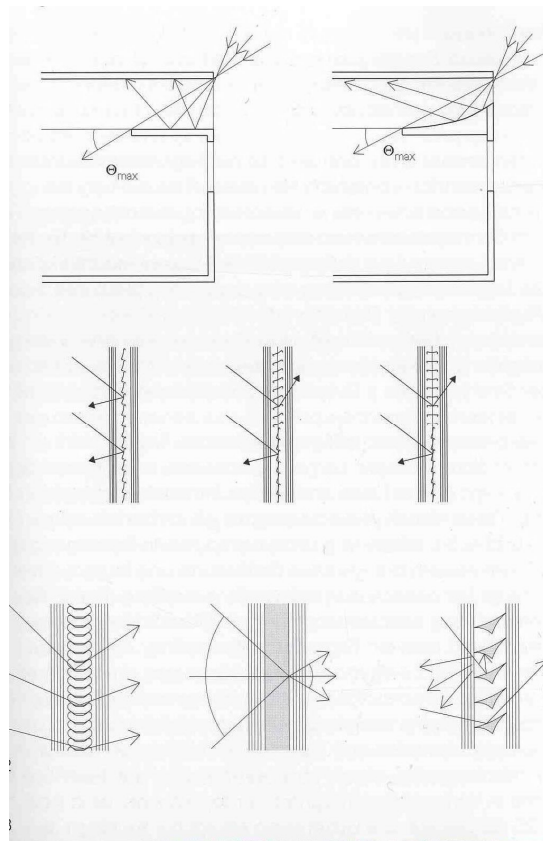


Figure 3.24: Systems for shading and daylight [49].

Figure 3.25 is an example of daylighting system which shades occupants from direct sunlight while redirecting daylight deep into the open office space. Series of fixed

horizontal reflective louvres of a unique compound geometry redirects daylight uniformly across the ceiling surface. The illuminated ceiling surface provides ambient light to the space below [35].

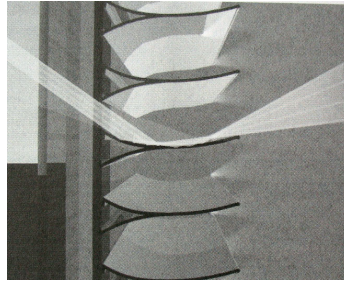


Figure 3.25: Detail of a light redirecting system [35].

3.9.2.2 Glare control

Glare occurs with very high levels of direct sunlight enter a space, especially low-angle sunlight. Glare index for offices is 22. Glare control is possible with attaching shades to the inner or outer sides of the glass, which can be movable or fixed [27].

Fixed shades on south façade efficiently shade interiors and still allow quality daylighting; but at lower altitudes of the sun (<30 degrees) they do not prevent glare. Glare can be avoided efficiently with the use of movable devices –for example, жалouses, shutters, roller blinds or blades –that can be attached on the inner or outer side of the window [27].

Conventional Venetian blinds, even with white slats, obstruct much daylight in every tilt angle. Even if the slats are set horizontally, only a minimal amount of light is reflected to the ceiling. The room impression is then of a bright window and a dim room [58].

Internal movable shades enable an individual regulation of natural lighting and glare, but they heat up because of the absorbed solar radiation and after that they radiate heat into the space. Even highly reflective roller blinds at a low outside temperature (5°C) heat up to 45 °C and can cause local thermal discomfort [27].

Curtains are effective in reducing glare, but they also reduce daylight levels. Short curtains on the upper part of the window impede daylight from the important sky zenith from projecting into the room. For side curtains, the tracks should extend beyond the window to allow the curtains to be pulled completely clear of the window opening [58].

3.10 Shading Control Systems

Manual control can be effective for small buildings and/or educated and committed building users, but automated systems are essential for larger shared and public spaces [45].

Automatic solar control is of primary importance to protect rooms oriented towards the east from overheating in the early morning in advance of the building utilisation time. Also automatic control ensures that solar load is minimised when building is unoccupied such as weekends or at single unoccupied rooms [25].

In many buildings, fully automatic control does not appeal to the buildings' users. A mixed form of automatic and manual operation (integrated control) is preferable. Control systems are more acceptable to both occupants and facility managers when they are simple and easy to use [25,59].

Daylight linked shading control systems are quite often used with correlation with lighting systems with dimming mechanisms.

3.10.1 User behaviour

Occupant behaviour concerning the operation of sun-shading devices has been investigated in several field tests [25].

According to findings of a field study, a strong correlation was found between the amount of sunshine, the sun position and the Venetian blind use [59].

1. Blinds were moved more frequently on the south façade than on any other façade.
2. Blinds were mostly operated in response to the sun's position, a horizontal angle of incidence between 25-70° triggering closing.
3. People mostly put up their blinds either early in the morning or at the end of the day.
4. Short periods of sunshine had little effect on the blind movement; however, long periods of sunshine of over 1 hour generally triggered the blinds to be lowered.
5. Fear of overheating caused some occupants to keep their blinds lowered at all times (even though there was no conclusive evidence to suggest that blind

movement was influenced more by either thermal or visual considerations, it was more likely that glare caused the blinds to be changed.

6. People with poor outdoor views were less likely to manipulate their blinds.
7. In the buildings where desks were located further from the window there was less blind manipulation [59].

So; it can be stated that the sky condition and the sun position, as well as the task and the desk location influenced the blind position and the slat angle chosen by the occupants [59].

Experience shows that users are more willing to accept automatic opening than closing of sun shading devices. One of the main reasons for this result is the importance of an undisturbed visual contact with the outdoors. Visual contact to the surroundings is obstructed or at least reduced by most sun-shading devices [25].

Windows provide a view out and time orientation for occupants. As part of a user survey on glare, 41 test persons in an office setting were asked about the importance of visual contact with surroundings [25]. Figure 3.26 presents the results of this survey.

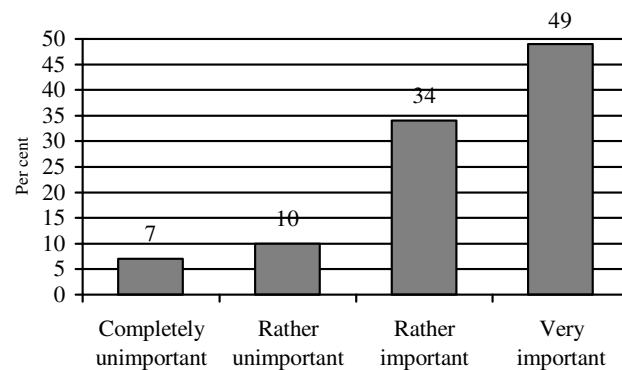


Figure 3.26: Importance of a view outdoors [25].

In addition, the survey revealed that a certain amount of glare is acceptable if this means that the view can be retained [25].

As a result, the user makes a decision between glare protection, solar control and view retention. How frequently a sun-shading device is operated also depends upon culture and climatic boundary conditions. Investigations in North America and Japan

demonstrated that a sun shading device once it has been closed is seldom opened, whereas in Europe this happens more frequently [25].

3.11 Criteria of Solar Control System Selection

Highly effective solar control concepts can be achieved either with a single component or the combination of several components [25].

Exterior shading devices are the most efficient solution to avoid overheating. Architectural overhangs are less efficient, cannot be retracted and should be avoided because they are less effective in preventing overheating than other devices and they block daylight all year. For a south orientation, a dark awning, external Venetian blinds or screen are good choices. For a west -or east- oriented window, vertical sunshades (parallel to the window) are the most effective [38].

Visual contact with surroundings is one of the criteria which has a high priority for users [25].

Many of the movable externally installed sun-shading devices cannot be installed in all buildings, such as tall buildings with high wind loads. Durability, maintenance and aesthetic point of view are another matters [25,45].

Interpane sunshades are an acceptable alternative, especially when they are placed in the outermost air gap. Especially for windy sites, they are a good alternative and could perform even better than some exterior shadings. The interpane sunshades should have a high reflectance facing out [38].

If interior shades must be used, it is even more important that they should have a high reflectance. Even so, they offer a poor overheating protection and are, at best, only good at reducing glare and providing privacy [38].

Eventually, combination of adjustable external and internal blinds can provide solar control and glare while permitting user control of daylighting levels.

Selected performance criteria for solar control systems for office rooms are compared in Table 3.4.

Table 3.4 : Selected performance criteria for solar control systems for office rooms [25].

		Mechanical shading devices			Fixed shading devices	
		Venetian blind	Roller with opaque slats	Transparent polymer roller blind	Overhang	Lightshelf
Solar control	Load reduction**	High to moderate depending on the position and slat angle			Moderate, seasonal variation	
	User or control dependent	Yes	Yes	Yes	No	No
	Visual contact	Variable	Variable	Variable, excellent	Good	Good
Daylighting	Glare protection	Variable	Variable	Variable	Seasonal	Seasonal
	Main daylight effects	Light-guiding	Variable, diffusing	Variable, reducing	Seasonal direct light cut-off	Seasonal direct light cut-off, light-guiding
Single system sufficient to tackle both issues? (daylighting and solar control)		Generally yes, but not all products			No	No
	Passive solar gain reduction (winter)	No	No	No	Slightly	Slightly
Economy	Investment costs	Low to moderate, depending on position			High	High
	Maintenance	Moderate to high, depending on position			Low	Low
	Site-dependent solution?	No	No	No	Yes	Yes
Selected architectural design consideration	Identical system for all orientations?	Yes	Yes	Yes	No	No
	Potential synergetic effects	No	No	No	Yes (security path, façade cleaning)	
	Design dominance	Moderate to high, depending on mounting position			High	High
Mounting position	Exterior	x	x		x	
	Interior	x	x	x	x (no load reduction)	
	Inter-pane	x	x	x	x (second skin façade)	

Notes: ** high: $g < 20$ per cent; moderate: $20 < g < 40$ per cent; poor: $g > 40$ per cent.

3.12 Conclusion

The ‘intelligence’ of a facade is not necessarily determined by the complexity of its control mechanisms or material combinations used, but also by the ability of the facade to take account of climatic considerations and use natural energy sources– and to do this with a minimum of technical equipment [32].

Shading should be considered as an integral part of fenestration system design for commercial and office buildings, in order to balance daylighting requirements versus the need to reduce solar gains. It should be considered by all specialists involved in consistent implementation as a part of an integrated planning approach [60,25].

As a review of the analyses an effective combination of shading includes fixed exterior devices to manage solar heat gain, and operable interior systems to manage daylighting. Movable devices offer significantly higher performance for east and west orientations due to variable low sun angles. Durability, maintenance, and wind factors should be considered when designing dynamic facades [61,45].

Best shading control system would be daylight linked, integrated (user involved) and simple one. Integration allows the user to make a decision between glare protection, solar control and view retention [25,59].

4. CASE STUDY RESEARCH OF ENERGY EFFICIENT SOLAR CONTROL STRATEGIES ON BUILDING FACADES

4.1 Purpose

The purpose of the thesis is to analyze energy demands of a building among different façade shading alternatives. The aim is to examine the façade shading alternatives in order to make an energy conscious design regarding the location, orientation and choice of materials for external sunshades which can significantly help to increase the thermal performance of glazing (and the building) as well as ensuring the thermal and lighting comfort of interior spaces.

Fourth and the fifth chapters are the main part of the thesis. In the fourth chapter, the Case Study building is described. The environmental conditions, building physical properties, thermal characteristics of building components, building technical specifications, and internal gains are determined. In the fifth chapter, building is analysed with ‘EnergyPlus’ building energy simulation programme for comparing several shading design options of case study building.

4.2 SARA- Sustainable Architecture Applied to Replicable Public Access

Buildings



SUSTAINABLE
Architecture Applied to
Replicable Public Access
BUILDINGS

The Case Study Building; ‘The Roger de Flor Primary Health Care Centre’ is one of the SARA buildings. Sustainable Architecture Applied to Replicable Public Access Buildings - SARA - is aimed to construct six sustainable, cost effective, high energy performance, public-access eco-buildings that are immediately replicable at large

scale in many locations and demonstrate the cost-effective potential for improving the energy performance of Europe's buildings [62].

4.3 Local and Environmental Factors

As an approach to make building energy analysis, the first step is examining local and environmental factors.

4.3.1 Local climate of Barcelona

Barcelona is located at 41.4 latitude and 2.17 longitudes; in the Southern Europe sub-region. It has mild winters with high radiation and longer days; hot summers-Southern and Mediterranean climate type. The annual average temperature is 16.5° C [63,64,65]. Location of Barcelona can be seen on map of Europe in Figure 4.1.



Figure 4.1: Location of Barcelona [66].

Figure 4.2 presents the long term monthly average solar energy and surface meteorology of Barcelona in a chart.

Variable	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Insolation, kWh/m ² /day	1.87	2.90	4.14	5.06	5.78	6.44	6.60	5.69	4.43	3.01	1.99	1.60
Clearness, 0 - 1	0.47	0.53	0.55	0.53	0.53	0.56	0.59	0.57	0.54	0.49	0.45	0.45
Temperature, °C	9.45	9.70	11.36	13.01	16.24	20.08	22.88	23.21	20.79	17.67	13.18	10.59
Wind speed, m/s	5.41	5.57	5.42	5.03	4.06	3.75	3.98	4.01	3.91	4.45	5.28	5.51
Precipitation, mm	42	36	47	50	52	38	23	53	73	86	58	50
Wet days, d	12.8	11.5	11.7	11.1	10.8	7.9	5.2	8.2	8.6	10.6	11.1	12.3

Figure 4.2: Barcelona, solar energy and surface meteorology [63].

4.3.2 Site description

Site is described with location, surroundings and vegetation.

4.3.2.1 Location

Building site is located in Barcelona–Spain, with 41.42° North latitude and 2.15° West longitude. Location is Central Barcelona, Eixample district. The Eixample is a dense building urban area as seen in Figure 4.3 [67].



Figure 4.3: Aerial view from Google Earth, 2008 [68].

4.3.2.2 Surroundings

There are adjoining buildings on the two lateral facades of the building and buildings of similar heights both in front and behind. Taller buildings in nearby streets cast shadows on principal façade during certain hours of the day during some of the year [67].

The building is facing the main (south-west) façade shade on the ground floor in winter. The neighboring buildings on the other sides do not shade the building as only the building to the north is higher. The north-east façade is partially shaded during the early hours of the day during summer.

Figure 4.4. is the site plan and Figure 4.5 is the perspective view of building [67].

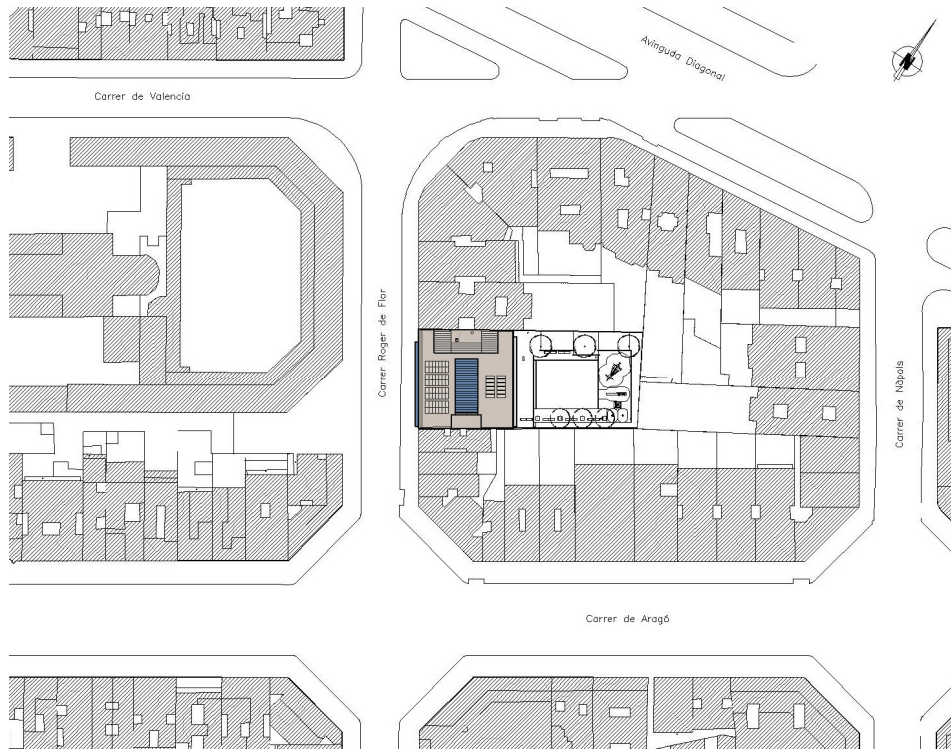


Figure 4.4: Site plan.

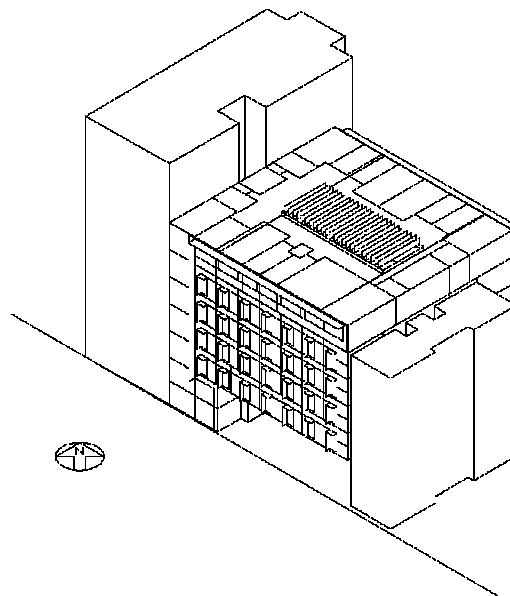


Figure 4.5: Perspective view.

4.3.2.3 Vegetation

The trees in the main street partially shade the ground floor offices in summer and penetrate sunlight to the building in winter. Front view in summer and front view in winter are given in Figure 4.6 and Figure 4.7 [67].



Figure 4.6: Front view in summer [69].



Figure 4.7: Front view in winter [69].

4.4 Building Description

Building specifications should be in compatible with the balance between external and internal conditions. The physical properties, thermal characteristics, technical equipments and internal gains of the building are described in this topic.

4.4.1 Physical properties

The Roger de Flor Primary Health Care Centre is a 7 storey building with an atrium and adjoining buildings on two sides. The building has 3000m² Gross area. Physical measures of the building are given in the Table 4.1 [70].

Table 4.1: Building physical description [71].

Building	
Heated building volume	11,832m ³
Total envelope area	3,679m ²
Useful floor area	3,000m ²

The architect of the building is Francisco Gallardo. Building has office-type visiting rooms and public areas. It was finished in 2007 (completion and occupation: by

September 2007). Building monitoring started in February 2008 [70]. Figure 4.8 is a perspective view through the storeys and the atrium.

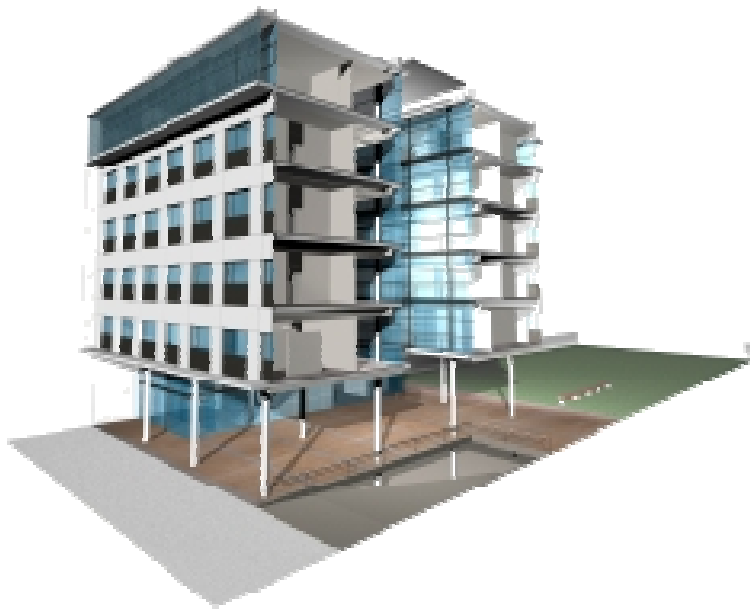


Figure 4.8: Perspective view showing the storeys [70].

Building has consult rooms on two sides and waiting hall adjacent to atrium. Typical floor plan is given in Figure 4.9. All architectural plans are submitted in Appendices A. The two cross sections of the building are presented in Figure 4.10 and Figure 4.11.

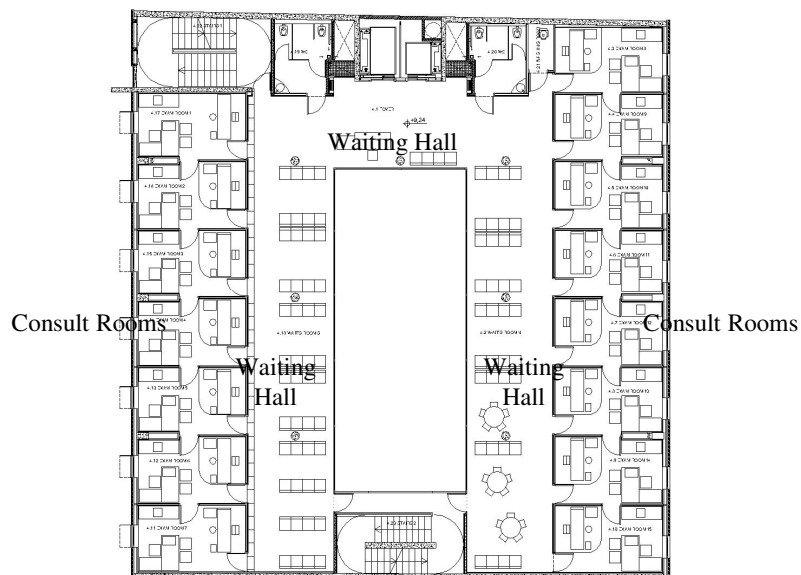


Figure 4.9: Typical floor plan of the building.

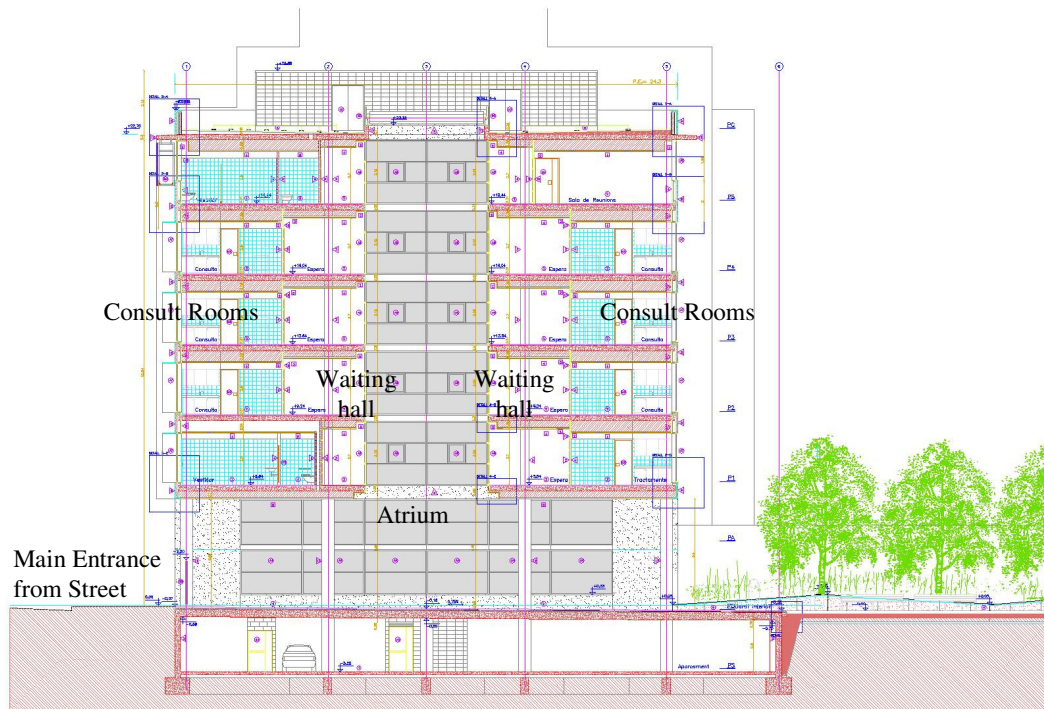


Figure 4.10: Cross section 1.

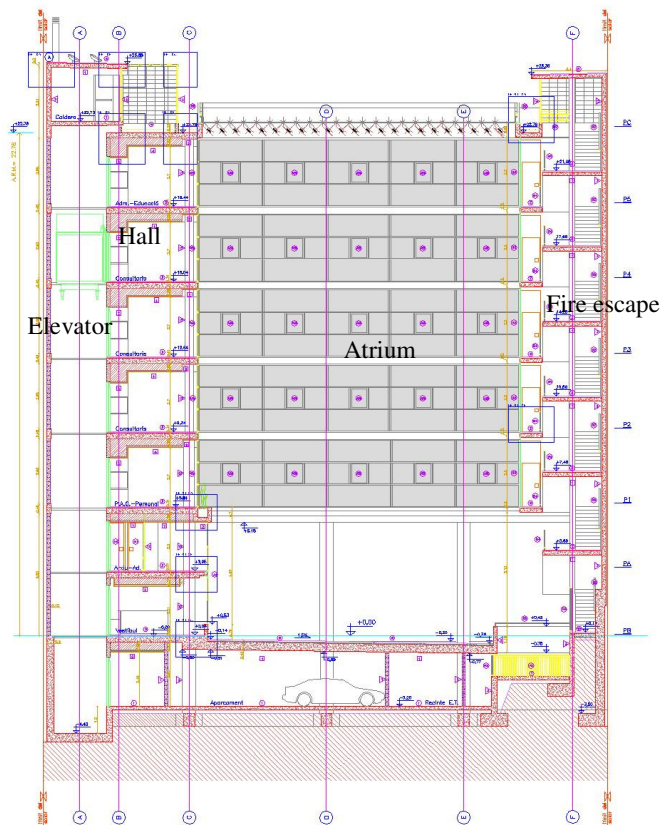


Figure 4.11: Cross section 2.

4.4.2 Thermal characteristics

Energy demonstration features are closely related with thermal characteristics of building materials that are used in the walls, floors, roof and glazing. Properties of opaque and transparent components of building envelope are given in the following tables. Conductivity, specific heat and density of building envelope materials are described in these tables.

4.4.2.1 Opaque components

Thermal characteristics of exterior walls are defined in Table 4.2 (from the outermost to the innermost layer). Cork board is used as insulation material in exterior walls.

Table 4.2: Thermal characteristics of exterior walls [67].

Exterior Walls		Thermal Bulk Properties		
Layers	Thickness m	Conductivity (λ) W/mK	Specific Heat J/kgK	Density kg/m ³
Concrete, reinforced (with 1% steel)	0,08	2,300	1000,0000	2300,00
Air Gap	0,21	Thermal Resistance (m ² K/W) 0,2300		
Cork Board	0,06	0,040	1888,0000	160,00
Cardboard-gypsum	0,015	0,400	1000,0000	1000,00
U-value (W/m ² K)		0,507		

Thermal characteristics of flat roof are defined in Table 4.3 (from the outermost to the innermost layer). Gravel is used on the roof for thermal insulation.

Table 4.3: Thermal characteristics of flat roof [67].

Flat Roof		Thermal Bulk Properties		
Layers	Thickness m	Conductivity (λ) W/mK	Specific Heat J/kgK	Density kg/m ³
Gravel	0,30	0,360	840,0000	1840,00
Cork Board	(initially 0,06) 0,10	0,040	1888,0000	160,00
Sheet rubber (raincoat)	0,003	0,240	1400,0000	1200,00
Screed	≥0,05 (0,08)	0,410	840,0000	1200,00
Steam barrier	0,002	0,190	837,0000	960,00
Concrete, reinforced (with 2% steel)	0,25	2,500	1000,0000	2400,00
U-value (W/m ² K)		0,365		

Ground floor is the floor between the entrance floor and the car parking at basement floor. Thermal characteristics of ground floor are defined in Table 4.4 (from the bottom to the top layer).

Table 4.4: Thermal characteristics of ground floor [67].

Ground floor		Thermal Bulk Properties		
Layers	Thickness m	Conductivity (λ) W/mK	Specific Heat J/kgK	Density kg/m ³
Cardboard-gypsum	0,015	0,180	1000,0000	600,00
Cork Board	0,06	0,040	1888,0000	160,00
Concrete, reinforced (with 2% steel)	0,25	2,500	1000,0000	2400,00
Stony flooring	0,06	2,800	1000,0000	2600,00
U-value (W/m ² K)		0,522		

Thermal characteristics of external floors are defined in Table 4.5 (from the outermost to the innermost layer). ‘External floor’ represents the floors that are adjacent to outside air, e.g. the floor of a cantilevered part of the building or where for any other reason there is no ground or other zone below. In cold climates the external floor construction will generally include an insulating layer [72]. Cork board is used for insulating in this building.

Table 4.5: Thermal characteristics of external floors.

External Floor		Thermal Bulk Properties		
Layers	Thickness m	Conductivity (λ) W/mK	Specific Heat J/kgK	Density kg/m ³
Cork Board	0,06	0,040	1888,0000	160,00
Concrete, Reinforced (with 2% steel)	0,25	2,500	1000,0000	2400,00
Screed	0,06	0,410	840,0000	1200,00
Granite	0,06	2,800	1000,0000	2600,00
U-value (W/m ² K)		0,506		

Internal floors are the vertical boundary of ‘zones’ which will be referred in fifth chapter. Thermal characteristics of internal floors are defined in Table 4.6. The table is arranged from the outermost to the innermost layer.

Table 4.6: Thermal characteristics of internal floors.

Internal Floor		Thermal Bulk Properties		
Layers	Thickness m	Conductivity (λ) W/mK	Specific Heat J/kgK	Density kg/m ³
Concrete, Reinforced (with 2% steel)	0,25	2,500	1000,0000	2400,00
Screed	0,06	0,410	840,0000	1200,00
Granite	0,06	2,800	1000,0000	2600,00
U-value (W/m ² K)		2,093		

In the building, pre-fabricated concrete structure and cork insulation are used. Pre-fabricated concrete improves quality control, reduces construction time and risk of complication. Cork is considered as an “ecological” material with a relatively low environmental impact [70].

Surface properties of building envelope is important for calculating passive gains from solar radiation. Surface properties of walls and flat roof are given in Table 4.7.

Table 4.7: Surface properties of building envelope.

Building envelope		Surface Properties		
Location	Surface	Thermal Absorptance (emissivity)	Solar Absorptance	Visible Absorptance
Walls	Concrete, reinforced (with 1% steel)	0,900	0,600	0,600
Roof	Gravel	0,900	0,290	0,290

4.4.2.2 Glazings

The U-value of glazing materials are higher than opaque materials. Therefore, glazed surfaces need careful consideration. The glass used in the building is low-e glass with a U-value of 1,79 W/m²K with frame as given in Table 4.8.

Table 4.8: Properties of glazing components [71].

Windows			Technical values			
Layers	Location					U-value (W/m²K)
Glazing *6/12/6	SW façade	Clear 6mm*	Air gap 12mm	Clear 6mm		1,70
Glazing *6/16/6	NE façade	Clear 6mm*	Air gap 16mm	Clear 6mm		1,38
Frame						2,37
Window						1,79

* : with low emissivity coating

Table 4.9 presents a comparison between requirements of Spanish New Building Standards and U-values of Primary Health Care Center building envelope materials. It can be seen that with lower U-values, Health Care building envelope is better than the Spanish standards.

Table 4.9: Building insulation levels compared with the Spanish Standards [70].

Zone	Spanish New Building Standards (CTE 2006) U-values (W/m ² K)	Characteristics of the Primary Health Care Centre, Barcelona U-values (W/m ² K)
Façade	0.73	0.50
Roof	0.41	0.35
Ground floor	0.5	0.45
Glazing	4.4	1.79

4.4.3 Technical specifications

Technical specifications are important in determining building energy use. Appliances of HVAC system, lighting, shading, solar, water etc. components determine energy flows in the building such as temperature, lighting, humidity etc. But, first it is resonable to have a look at the building technical requirements.

4.4.3.1 Building technical requirements

Required comfort levels of buildings vary with building functions. The technical requirements of Health Care building are given in Table 4.10.

Table 4.10 : Technical requirements of Health Care building [67].

Inside conditions	Units	Summer	Winter
Air temperature	°C	24.5	22
Surface components temperature	°C	Wall and ceiling temperature 20-24 (radiant cooling desired)	Wall and ceiling temperature 23-27 (radiant heating desired)
Air speed	m/s	<0,3	<0,3
Humidity	%	50	50
Acoustic noise	dB(A)	≤50	≤50
Lighting	lux	200 (in the floor) (high daylight ratio desired)	200 (in the floor) (high daylight ratio desired)
Air quality	CO2 concentration in ppm	≤800	≤800

The mechanical systems and passive systems should be designed with enough capacity and performance to achieve these levels. The building has been conceived to be responsive to seasonal comfort requirements and at the same time to contribute to the reduction of energy costs. The main energy savings measures are listed below:

4.4.3.2 Solar control strategy

The building's energy demand is reduced by means of architectural design and a special attention to the building envelope, especially by shading devices. Passive elements, such as a fixed shading device upon the central patio and vertical and horizontal solar protections on the Southwest (SW) façade regulate the relationship between natural daylighting and solar protection [70].

Specifications of interior patio shading devices

Top of the interior patio is shaded with black-velvet cloured fixed lamellas with a reflectance level of 10% as seen in Figure 4.12 and Figure 4.13.



Figure 4.12: Lamellas over central patio seen from below [70].



Figure 4.13: Detail of interior patio lamellas [69].

Specifications of main façade shading devices

Perforated vertical and horizontal shading devices have been designed as an optimal compromise between daylighting and solar protection on the principal (Southwest) façade whilst keeping within the project's budget [70]. Solar protections around windows are made of galvanized, sheet steel 35% perforated by 5mm diameter holes and protected by a double coat of oven baked, clear coloured paint. Window shading device is shown in Figure 4.14. Also Figure 4.15 is the front façade view with fixed shading.

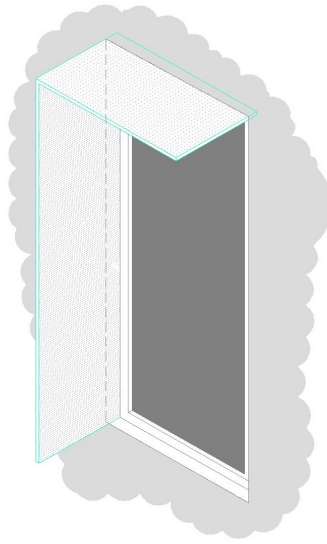


Figure 4.14: Window shading device.



Figure 4.15: Front façade view with fixed shading [69].

4.4.3.3 HVAC system

The specific air quality characteristics of a health sector building pre-determine many design decisions regarding ventilation and thus also heating and cooling. The humid summer climate of Barcelona is also a decisive factor. The result is the need for a closed (not naturally ventilated) system including dehumidification [70].

Heating and cooling system

In the building energy efficient HVAC and lighting systems are used. The heating and cooling system with a high coefficient of energy performance (CoP) is based on radiant ceiling panels. This configuration allows operating the cooling system with fluid temperatures of 15-17°C instead of the 7°C of a conventional air conditioning system, while heating fluid temperature of the boilers is 35°C instead of 45-70°C (Low temperature distribution). Radiant ceiling based heating and cooling system which, in combination with the other factors is expected to achieve a 25% saving relative to standard performance [70].

Heating set temperature is 22°C between hours 07:00-21:00 during weekdays and 19°C in non-occupied period.

Cooling system is operated between hours 07:00-21:00 during weekdays with a set temperature of 24.5°C and for non-occupied hours 28°C.

Ventilation system

The system requires independent ventilation and an air treatment which adjusts the humidity to prevent condensation on the cooled ceilings and maintain comfort levels. An innovative energy efficient desiccant (dehumidifier) liquid with lithium chloride solution is integrated in the ventilation system in order to control humidity and prevent condensation on the cooled ceilings. This solution, compared to conventional alternatives, offers lower energy consumption and very efficient air filtering and hygiene. Heat exchangers are used to recuperate heat from the return-air and preheat the intake-air in winter (Heat recovery) [70].

The system has been operated 24 hours/day between 10/2007 and 04/2008. Since 05/2008, the ventilation regime has arranged dependent to a schedule. According to the schedule; Mondays to Fridays between 06:30 to 21:00 and Saturdays between 08:00 to 20:00 are ON and Sundays are OFF.

Natural ventilation

Regulations for health sector buildings and the cooling requirements in Barcelona's climate (requiring dehumidification) combine to preclude a full naturally ventilated building design solution. The building has closed system but also free-cooling strategy in spring & autumn. Free-cooling controlled by the building management system integrated in the AHU (air handling unit)s accounts for further energy savings during the intermediate seasons [70]. In Table 4.11 technical data of building equipments are summarized.

Table 4.11: Technical data of building equipments [71].

System	Description	CoP
Heating System	Electrical Heat Pump (245 kW)	4,0
	Gas condensing boiler (270 kW) peak load unit	0,93/1,06
	Distribution: ceiling panels	40/35°C
	Sensible cooling:	3,0
Cooling System	Electrical Heat Pump (245 kW)	3,0
	Dehumidification:	3,0
	Electrical heat pump	
	Distribution: ceiling panels	15/21 °C
Mechanical	air exchange/hr	25m ³ /h per person (7 l/s)
Ventilation System	heat recovery	>50%
Lighting System	Fluorescent lamps	

4.4.3.4 Renewable systems

Environmental friendly solar and water systems are implemented in the building.

Renewable energy systems

There is integration of renewable energy systems with PV panels for electricity production and solar thermal installation for heating and domestic hot water. Total renewable contribution from Solar Energy is 34,342 kWh/yr.

Building integrated photovoltaic system

Building Integrated Photovoltaic System (BIPV), has 126m² with integration in the façade (PV_1) and a conventional roof-top installation (PV_2) with 10 kWp installed

power, grid-connected and an expected energy production of 12,371 kWh/yr [70]. All the energy is sold to the grid.

PV_1: 55m² semi-transparent modules are integrated in the vertical façade as shading device. It enables solar protection and degree of transparency. Principal of PV module installation on façade is shown in Figure 4.16. Also Figure 4.17 is view of PV panels from interior [70].

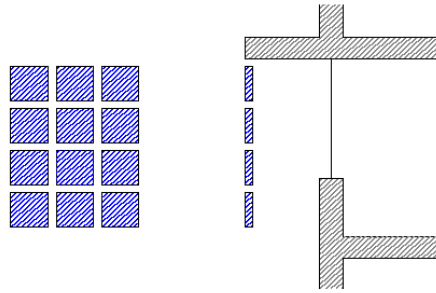


Figure 4.16: Principal of PV module installation on façade [73].



Figure 4.17: PV installation on façade [70].

PV_2: 71m² opaque modules are applied as conventional roof-top installation. Roof panels are shown in the Figure 4.18 [70].



Figure 4.18: PV installation on the roof [69].

Solar thermal (THW)

23m², roof-top, flat plate collector installation was designed to produce 21,971 kWh/yr energy to contribute to the domestic (sanitary) 60% of the hot water demands of the building and also to the low temperature space heating demands in winter [70].

Water management

Water recovery includes rainwater harvesting and grey water reuse. 15m³ tank in the basement is for collecting rainwater from the roof and waste-water from hand washing basins which is re-used for toilet flushing [70].

4.4.3.5 BMS and monitoring

Building Management System (BMS) and the planned monitoring contributes to reduce the energy demand of the building, controlling the heating, cooling, ventilation, and lighting systems. Energy consumption is being monitored (in chillers, boiler, heat-recovery units, dehumidifiers...) in order to find the optimum operational conditions to ensure user comforts is compatible with energy efficiency criteria. They optimize energy and operational performance of the building and provide data for optimization of control mechanisms, performance monitoring and dissemination purposes [70].

Detectors and photosensitive cells are used to save electricity, by modulating lights intensity depending on the natural light received [70].

4.4.3.6 Lighting

The required lighting level is 200 lux on the floor, 500 lux on desk level. Also high daylight ratio is desired. Glare should be avoided.

Daylighting

First it is useful to define the characteristics of daylight at site: Direct solar radiance has illuminance of approximately 10,000 lux on a cloudy day, up to 100,000 lux on a clear summer day. This illuminance decreases according to the depth of the space inside the building and to the reflecting elements on interior surfaces [69].

The interior patio with its glazed façade allows a high level of daylighting, while fixed perforated horizontal lamellas spanning the interior patio protect this part of the

building from excess solar radiation in summer [70]. Figure 4.19 and Figure 4.20 are views from the interior.



Figure 4.19: View of the interior patio [70].



Figure 4.20: View from hall [70].

Lighting control

Presence of sensors in certain areas and automatic control of electrical lighting depending on daylighting combine to allow expected energy savings of 25% compared to conventional lighting solutions in similar buildings [70].

4.4.4 Internal gains

Artificial lighting, equipments, occupancy hours and persons define internal gains.

4.4.4.1 Artificial lighting

High efficient, electronic ballast fluorescent lighting is used throughout the building [70]. Lighting plan of the typical floors (2nd, 3rd, 4th floors) is given in Figure 4.21. Lighting plans of all floors are given in Appendices B.

The lighting appliances used in the building are classified in Table 4.12.

Table 4.12: Classification of artificial lighting depending on location.

Lamp Type	Unit/ Watt	Location
Fluorescent Marca: Phillips Model: TBS421	2x58	Foyer, Corridor, Education Room, Staff Room, Dressing Room, Wait's Room, Exam Rooms, Offices, Library, Stock Rooms
Fluorescent Marca: Phillips Model: TBS421	2x36	Foyer, Corridor, Surgery Room, Exam Rooms, Wait's Room, Dressing Room, Stock Rooms, Offices
Fluorescent Marca: Phillips Model: Pacific TCW215	2x36	WCs
Halogen, IP 44 Marca: Lumiance Model: Instar 90	50	Surgery Room, Bath, WCs, Sanitary and Medical Rooms.
Halogen Marca: Martini Model: Deco	50	Foyer

In General Patient Care Areas, Lobbies, and Staff Rooms; 2x36W and 2x58W fluorescent lamps are used. Also 50W halogen lamps are used additional to main lighting in some areas such as the Foyer and Surgery Rooms. Mostly 2x36W fluorescent TBS42 model lamp is used. Figure 4.22 is a view of the fluorescent lamps used in Exam Rooms.



Figure 4.22: A suspended fluorescent lamp [69].

4.4.4.2 Occupancy hours

Occupancy period of Health Care Buildings are longer than offices. Generally the building is occupied in the period from 08:00 to 21:00 during the week and Saturday but occupancies of the rooms vary according to usage.

4.4.4.3 Equipments

The office equipment gains mainly result from the computers. All loads are listed in the Table 4.13.

Table 4.13: Building internal gains from office equipments.

Equipment Type	Unit/Watt	Unit	Watt	Daily (hours/day)
Work station (PC with color monitor)	230	77	17710	12
Photocopy	1200	1	1200	12
Networking Printer	750	2	1500	12
Projector	200	2	400	1
Fax Machine	350	1	350	12
Ice Box	1220	2	2440	24
Microwave	600	1	600	1

Figure 4.23 shows the distribution of office equipment and lighting loads.

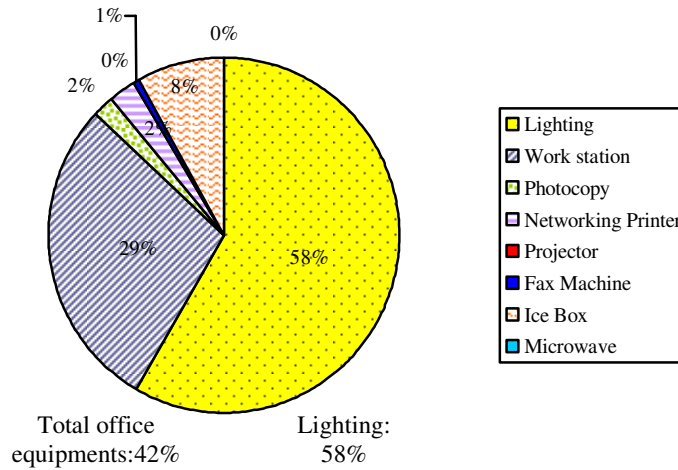


Figure 4.23: Building lighting and equipment gains.

4.4.4.4 Persons

The building activity is described as 'light office work'. As the factor for this activity is variable according to gender, (Men: 1.00, Women: 0.85 and Children: 0.75) 90W/person heat described as an average. Building occupancy is 369 people. Density of the building is 0,12 people/m² including patients and staff.

Clothing is defined as; winter clothing: 1.00 clo and summer clothing: 0.50 clo.

4.5 Conclusion

Energy demands of Health Care buildings are similar to office buildings, only the lighting demand less than office buildings. Good thermal insulation, small window areas, a shaded atrium and a reasonable rate of air infiltration are clearly beneficial in either season. The Health Care building is a well insulated, high efficient building with passive and active properties. Using external shading, high cooling energy savings are obtained in summer [67].

Economic considerations of the building is remarked in the following: The estimated total system cost including structural elements (according to the architectural project) is 548.650 € (investment cost) and the estimated annual energy savings is 32.800 €, so; simple payback period is 16.7 years [67].

Solar shading strategies for this building will be elaborated by energy simulations in the following section.

5. BUILDING ENERGY SIMULATION

5.1 Introduction

Computer simulations are carried out to see buildings' behaviour against external and internal effects. This chapter includes the energy calculations of the Primary Health Care Building described in previous chapter evaluating the benefit of using shading devices.

5.2 Computer Based Energy Performance Simulation

As referred in Chapter 3, many energy flows take place between building and its environment. One of the challenges in the design process is to understand the interaction between various aspects of building performance and their implications on complex building control systems. There is considerable uncertainty in assessing the performance of a design if the dynamic and integrated response of the building and its environmental systems is not taken into account [74].

Building energy simulation is a computer model of the several energy transfer processes within a building. Over the past 50 years, a wide variety of building energy simulation programs have been developed, enhanced and are in use. The core tools are the whole-building energy simulation programs that provide users with key building performance indicators such as energy use and demand, temperature, humidity and costs [75].

In the case study work, 'DesignBuilder' simulation program is used in assessing the energy performance of the building. Several data about climate, site, physical properties such as geometry and the building constructions, performance of the HVAC systems, lighting systems and building activities are the required. These are the input for the advanced modelling and calculations. First the virtual building is modelled, then input data is loaded to this model, then building is analysed and results are obtained.

5.2.1 DesignBuilder simulation program features



DesignBuilder is the user friendly graphical interface of EnergyPlus dynamic thermal simulation engine. It combines building modeling with dynamic energy simulation. [72]. DesignBuilder version 1.8 is used for the simulations in this work.

Data templates allow loading common building constructions, activities, HVAC and lighting systems into design. Heating and cooling loads are calculated using the ASHRAE-approved 'Heat Balance' method implemented in EnergyPlus. It provides a comprehensive range of simulation data such as; calculating building energy performance; heating and cooling loads (energy consumption), calculating heating and cooling (HVAC) equipment sizes, heat transmission through building fabric including walls, roofs, infiltration, ventilation etc., multizone air flow simulation, thermal simulation of naturally ventilated buildings, evaluating façade options for overheating and visual appearance, daylighting - models lighting control systems and calculates savings in electric lighting, visualisation of site layouts and solar shading, site weather data, internal air, mean radiant and operative temperatures and humidity CO₂ generation, comfort output including underheating and overheating hours, fuel use and... etc. Simulation data is shown in annual, monthly, daily, hourly or sub-hourly intervals [72].

DesignBuilder enables many detailed modelling options related to building facades:

- Glazing systems including frames, dividers, reveals are modelled in detail.
- Shading by louvres, overhangs and sidefins as well as internal and mid-pane blinds can be optimised. Also, application of electrochromic glazing and transparent insulation are possible.
- Glazed cavities such as double facades and trombe walls can be modelled.
- Architectural features such as columns, awnings and complex shading devices can be treated including the effect of shading and reflection.
- Daylighting-lighting control systems can be modelled using one or two lighting sensors per zone and savings in electric lighting can be calculated [72].

5.2.2 Simulation application of case study building

Blocks are the basic objects used to create a DesignBuilder model. A block represents the outer shell of the model or part of the model. A finished block comprises a set of building elements, which may include external walls, roofs and floor slabs, the thickness of which are determined from the current building construction model data. Similarly, using opening model data, block facades are automatically created with the required configuration of windows, doors, vents and solar shading devices. A block may be divided internally into any number of zones by drawing partitions and where needed, voids or courtyards can also be incorporated. Standard zone is considered to be occupied and heated or cooled space [72].

5.2.2.1 Zones

The building is analysed via 4 thermal zones as shown in Figure 5.1.

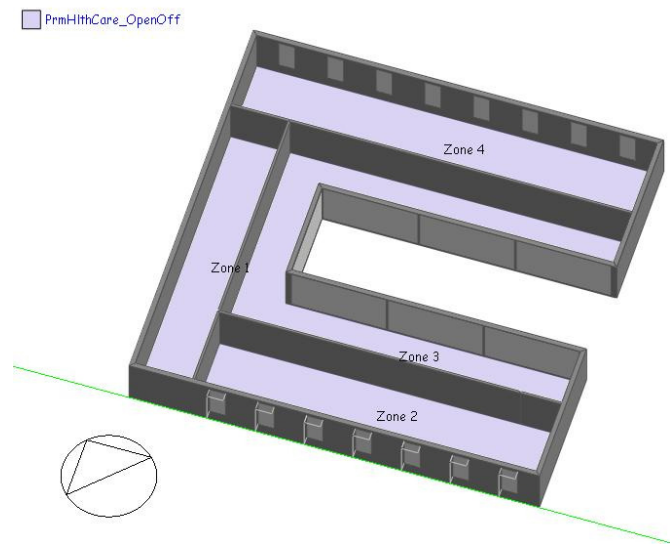


Figure 5.1: Zones of typical floor from DesignBuilder.

In entrance and mezzanine floors building has only one zone; Zone 1 which compromises service and circulation areas (stairs, lifts and toilets) in the upper floors. The consult rooms on two facades of building define different thermal zones because of the orientation. While Southwest facade rooms constitute Zone 2, Northeast facade rooms constitute Zone 4. The atrium in the middle of building is not enclosed therefore it is not one of the building zones. However, it affects the thermal behaviour of the waiting halls adjacent to it. The zone surrounding atrium is named

as Zone 3. In addition, there is an enclosed fire escape beside atrium and Zone 3, which is not included in any zones. All zones are shown plan in Figure 5.2.

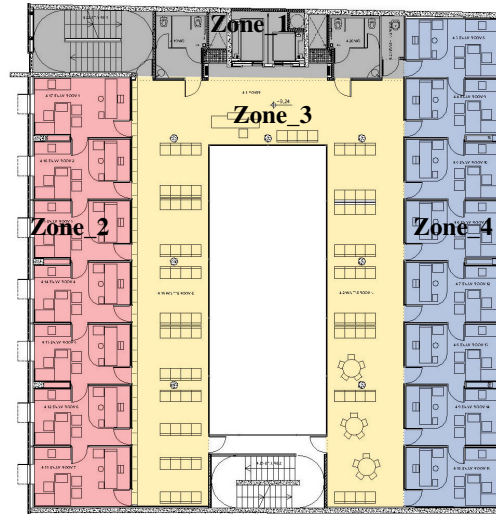


Figure 5.2: Zones shown on plan.

So a typical floor has four zones and each floor is accepted as a block. Entrance and mezzanine floors have only one Zone; Zone 1. This building has seven storeys, which mean seven blocks. The car park in the basement floor is not included in the calculations. The building model and adjoining buildings on two sides of building can be seen in Figure 5.3.

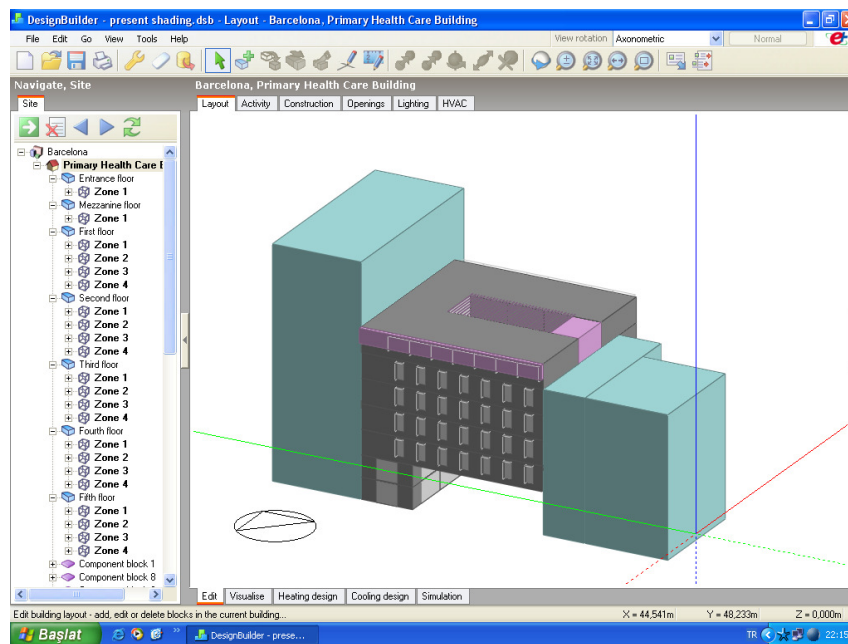


Figure 5.3: 3D virtual model of the building.

After the modelling task is completed, mechanical system is defined. Energy performance of a building is related with physical properties as well as mechanical system properties. Building technical requirements determine the mechanical system sizes. These requirements -such as air temperature, air speed, humidity, acoustic noise, lighting, and air quality- are closely related with building function.

Before defining the mechanical system, Model Options data is configured in the edit screen. Edit screen tab consists;

5.2.2.2 Gains data

There are three levels of gains model detail: Lumped, Early and Detailed. Detailed gains is chosen in this model. Gains are specified by listing information on each item of energy using equipment and its' operation in detail at the zone level.

5.2.2.3 Timing

There are two approaches for timing: Typical workday and Schedules. Schedules, which is more flexible is chosen. Timing is defined using the schedules and profiles mechanism which allows each day of the week to have a different profile than a typical workday approach. Also; HVAC, natural ventilation and internal gains are allowed to operate with occupancy.

5.2.2.4 HVAC

HVAC can be defined as Simple or Compact. Options for HVAC sizing are Adequate, Manual, Autosize and Autosize when not set. Here, Simple HVAC with Manual sizing is chosen. HVAC systems are defined using plant seasonal efficiency data and are modelled outside EnergyPlus.

5.2.2.5 Natural ventilation

Natural ventilation can either be Scheduled or Calculated. In this model Scheduled ventilation is chosen. Ventilation is defined as an air-change rate modified by an operation schedule and controlled using a set point temperature.

After Model Options data is completed, then mechanical system input file is defined. Heating and cooling set points, ventilation and infiltration rates and heat recovery efficiency are applied to model for calculations. Mechanical system input file is given in Table 5.1.

Table 5.1: Mechanical system input data.

System	Set point
Heating set point	23° C (assumes shading and ventilation)
Maximum room temperatures	26° C for June, July and August
Ventilation rate	0.45 ac/h
Infiltration rate	0.05 ac/h
Heat recovery efficiency	80%

(°C: degree Celcius, ac/h: air change per hour, %: percentage)

These data is edited under Activity tab at building level. When it is applied in building level, it is available for all blocks and zones within the building. The Figure 5.4 shows the components of Activity tab.

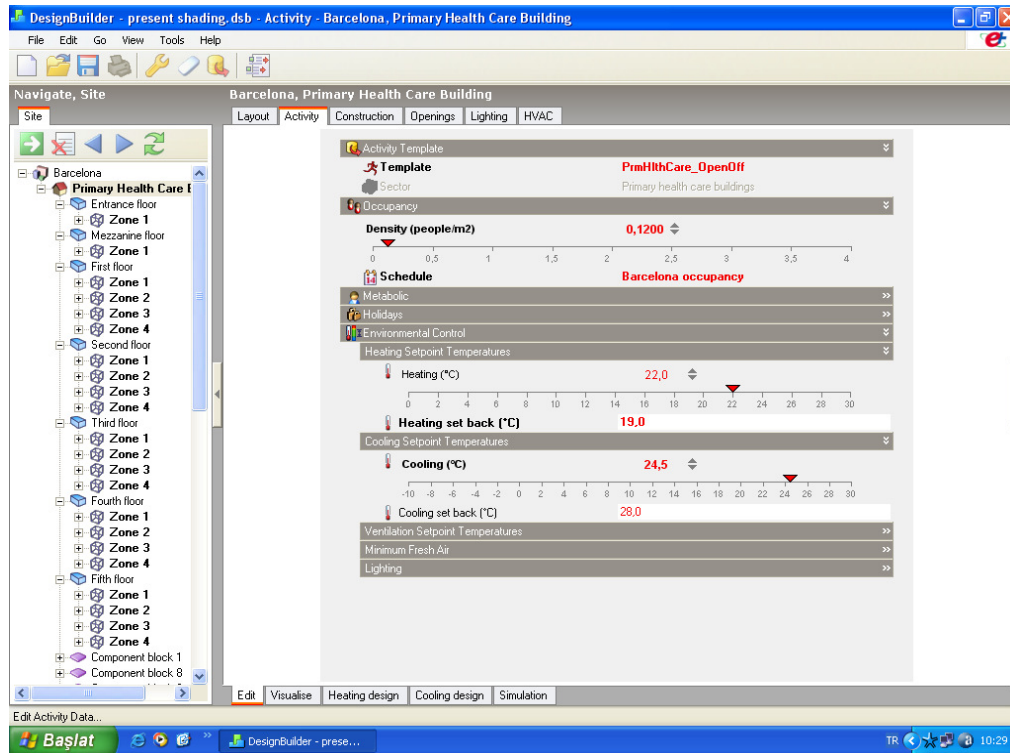


Figure 5.4: Activity tab from program.

There is lighting control system in the building, and all simulations are defined with lighting control. This data is edited in Lighting tab at zone level.

5.3 Building Energy Analysis

Generally 1%-5% indicative energy saving can be achieved with shading (depends upon scale) [72]. Building will be analysed with different shading alternatives to evaluate the most efficient device.

5.3.1 Base case (without facade shading)

In order to see the impact of facade shading devices on energy demands, first the building is assumed without any shading on the windows and simulation is done. This case will be the base case for the comparisons with different shading devices. Figure 5.5 shows the model of base case.

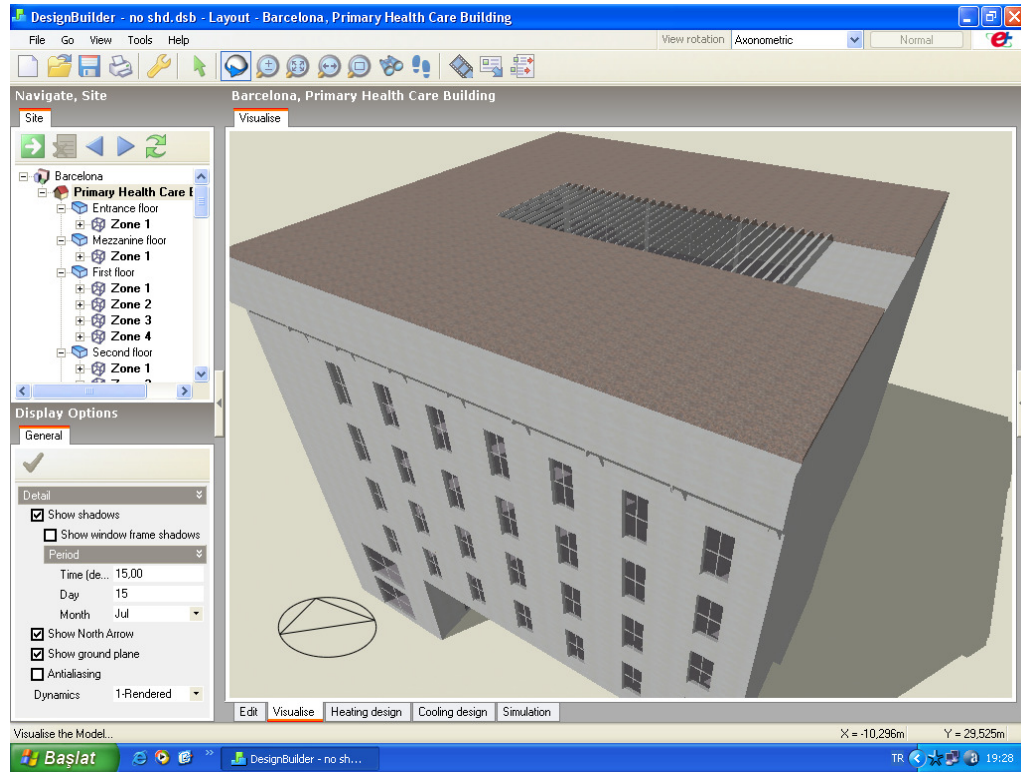


Figure 5.5: Base case building model.

If there was no shading on the facades of the building, the building energy distribution would be as in Figure 5.6. The figure presents annual distribution of general lighting, heating and cooling energy; heat gains from computer and equipments, occupancy, catering, miscellaneous and process. Calculations are completed for 365 days and for occupied areas.

According to the figure; general lighting demand is $29,25 \text{ kWh/m}^2$, sensible heating demand is $43,48 \text{ kWh/m}^2$ and sensible cooling demand is $52,71 \text{ kWh/m}^2$. It can be seen that building cooling demand is higher than heating demand. Therefore it is important to decrease the cooling demand.

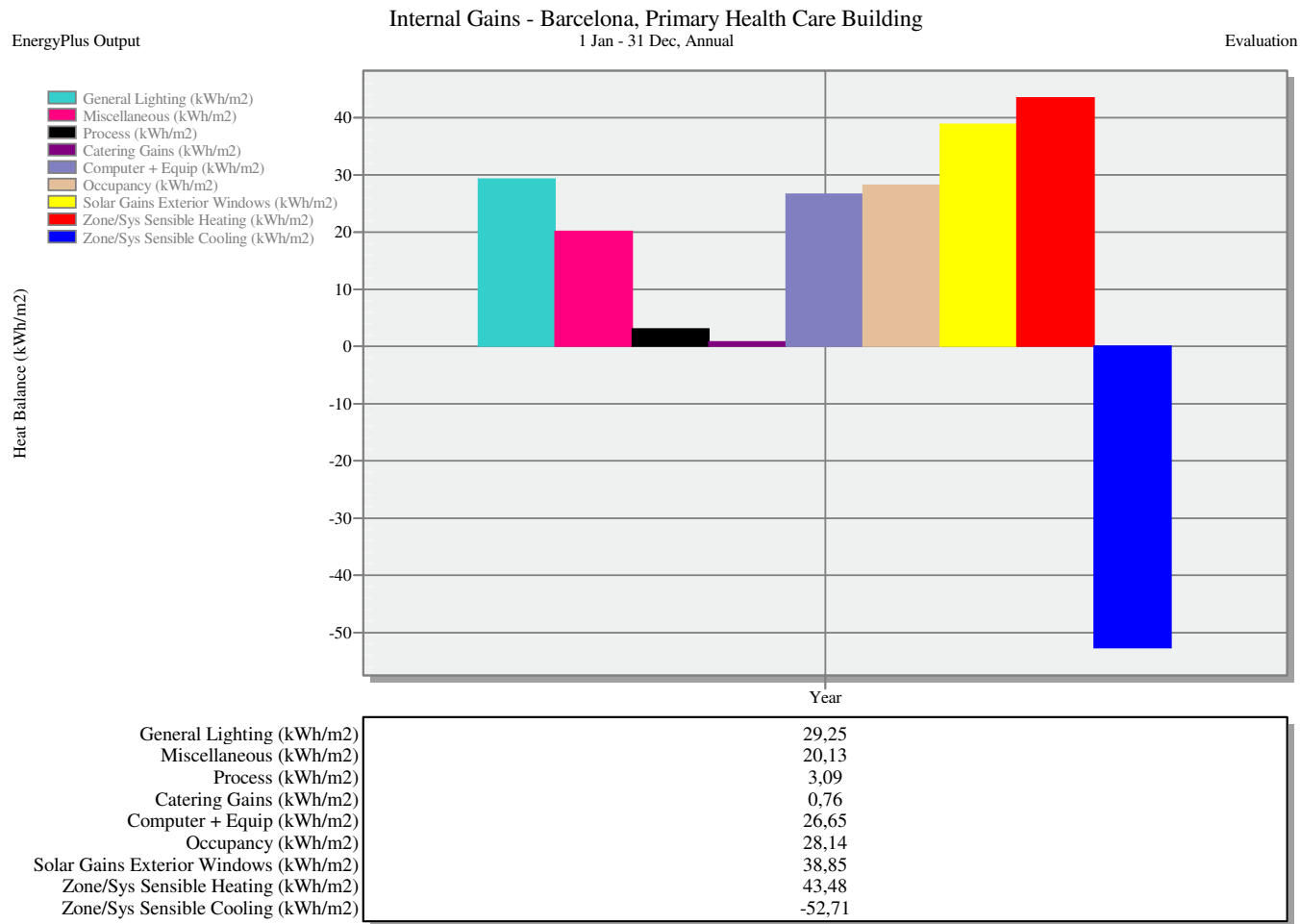


Figure 5.6: Base case annual energy analysis of building.

5.3.1.1 Effect of atrium shading

The design of atrium should also be taken into consideration when analysing energy behaviour of a building. Atrium in a building serves as a buffer zone even when not totally bounded. This building is permeable in the ground floor, with inclined horizontal fixed lamellas in the top of interior patio as shown in Figure 5.7. Also Figure 5.8 is a view from the interior patio.

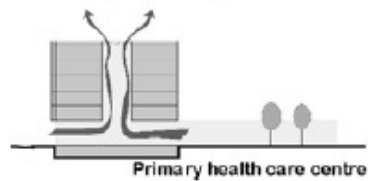


Figure 5.7: Schematic view of atrium [71].



Figure 5.8: View from the interior patio [69].

The space between lamellas allow air flow while preventing Zone_3 from overheating. So the atrium space is neither interior nor exterior. Figure 5.9 is the building model with atrium shading.

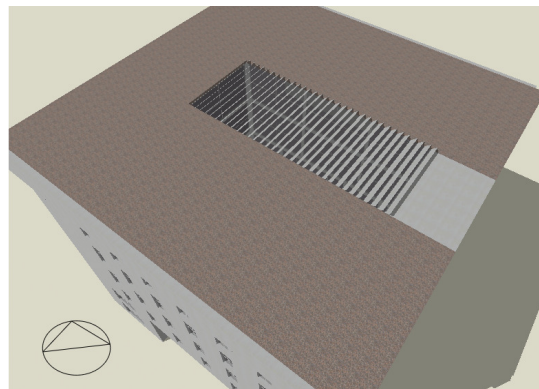


Figure 5.9: Atrium with shading.

To see the effect of atrium shading on building energy use, shading devices above atrium are removed. Figure 5.10 is the model without atrium shading.

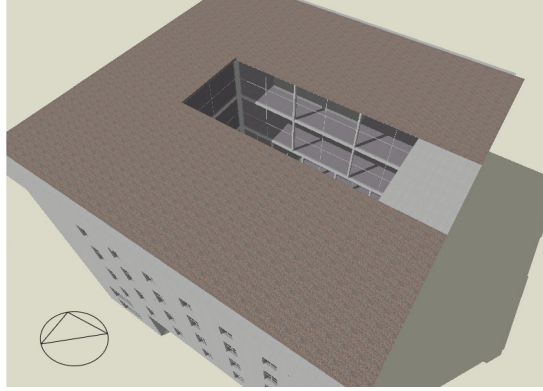


Figure 5.10: Atrium without shading.

For this case, energy calculations are also carried out in DesignBuilder. Table 5.2 shows comparison of annual energy demands of building between not shaded and shaded atrium situations. Total load is the sum of lighting, heating and cooling loads. Comparison of two cases can also be seen in Figure 5.11. (Ql: General lighting load, Qh: Sensible heating load, Qc: Sensible cooling load)

Table 5.2: Effect of atrium shading for base case.

Situations of Atrium	Solar Gains from Windows kWh/m ²	General Lighting kWh/m ²	Sensible Heating kWh/m ²	Sensible Cooling kWh/m ²
Not Shaded Atrium	48,66	27,91	41,60	56,56
Total: 126,07 kWh/m²				
Shaded Atrium	38,85	29,25	43,48	52,71
Total: 125,44 kWh/m²				

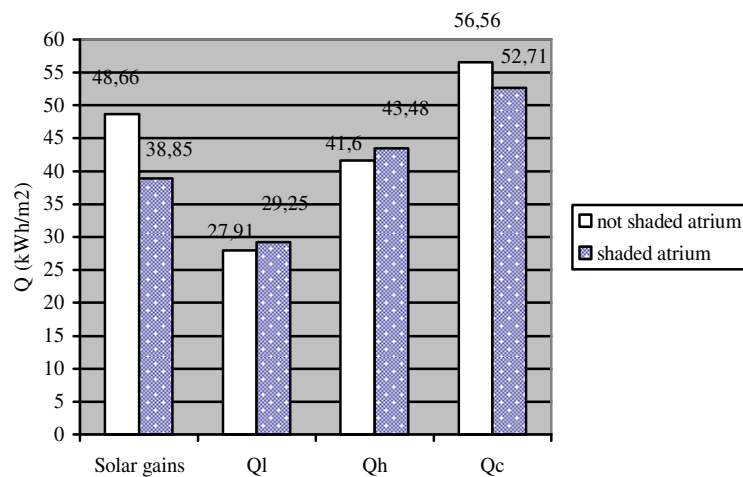


Figure 5.11: Effect of atrium shading on energy distribution.

According to the simulation results; lighting load increases by 4,8%, heating load increases by 4,5%, cooling load decreases by 6,8% and total load decreases by 0,5% with atrium shading. Fixed lamellas not only prevent overheating but also they are light transparent and enable good daylighting level in waiting areas around atrium.

5.3.1.2 Effect of lighting control

Without lighting control, all lighting source in building would be provided from artificial lighting independent from room daylighting levels, so lights would be always on. However, in the building there is lighting control depending on daylighting levels. Therefore, general lighting load decreases by 46,32%.

Table 5.3 presents the building's annual energy demand analysis with and without lighting control strategy. Total load is the sum of lighting, heating and cooling loads. Also Figure 5.12 indicates this difference more obviously. (Ql: General lighting load, Qh: Sensible heating load, Qc: Sensible cooling load)

Table 5.3: Effect of lighting control for base case.

Lighting Strategy	General Lighting kWh/m ²	Sensible Heating kWh/m ²	Sensible Cooling kWh/m ²
without lighting control	54,49	37,53	67,42
Total: 159,44 kWh/m²			
with lighting control	29,25	43,48	52,71
Total: 125,44 kWh/m²			

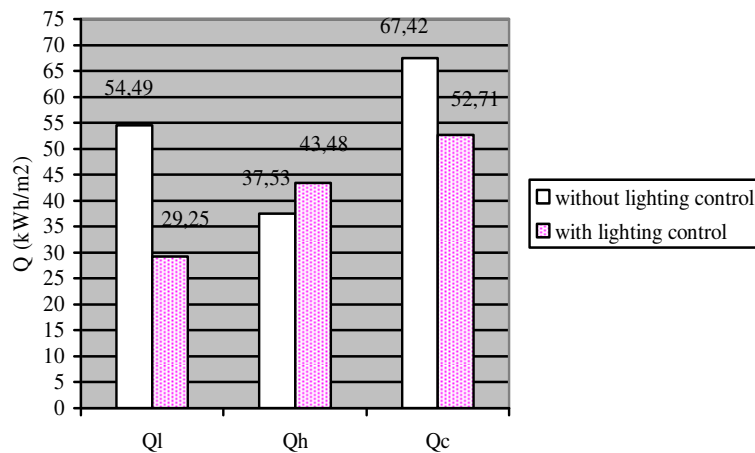


Figure 5.12: Effect of lighting control for base case.

All the following simulations will be made with lighting control to make a realistic assumption in examining energy performance of shading devices.

5.3.2 Present Case

This is the simulation of present situation of building. In addition to 0,5m overhang, one sidefin is applied from Northwest side of each window at Southwest (main) facade as seen in Figure 5.13 which is the rendered model of present case.

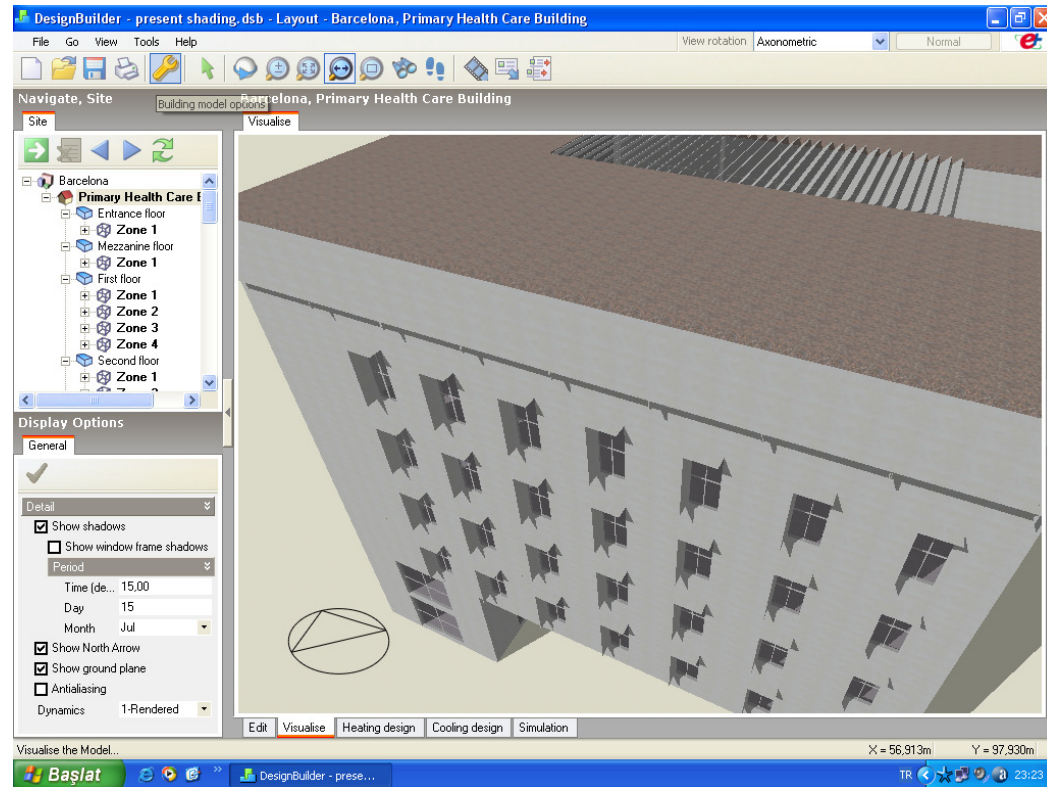


Figure 5.13: Model of present case.

Simulation results of present case are submitted in Figure 5.14. The figure presents annual distribution of general lighting, heating and cooling energy; heat gains from computer and equipments, occupancy, catering, miscellaneous and process. Calculations are completed for 365 days and for occupied areas. According to the figure; general lighting demand is $29,75 \text{ kWh/m}^2$, sensible heating demand is $44,16 \text{ kWh/m}^2$ and sensible cooling demand is $50,80 \text{ kWh/m}^2$.

5.3.2.1 Monthly analysis

Monthly energy analysis of building at present case is given in Figure 5.15 for period between January and December.

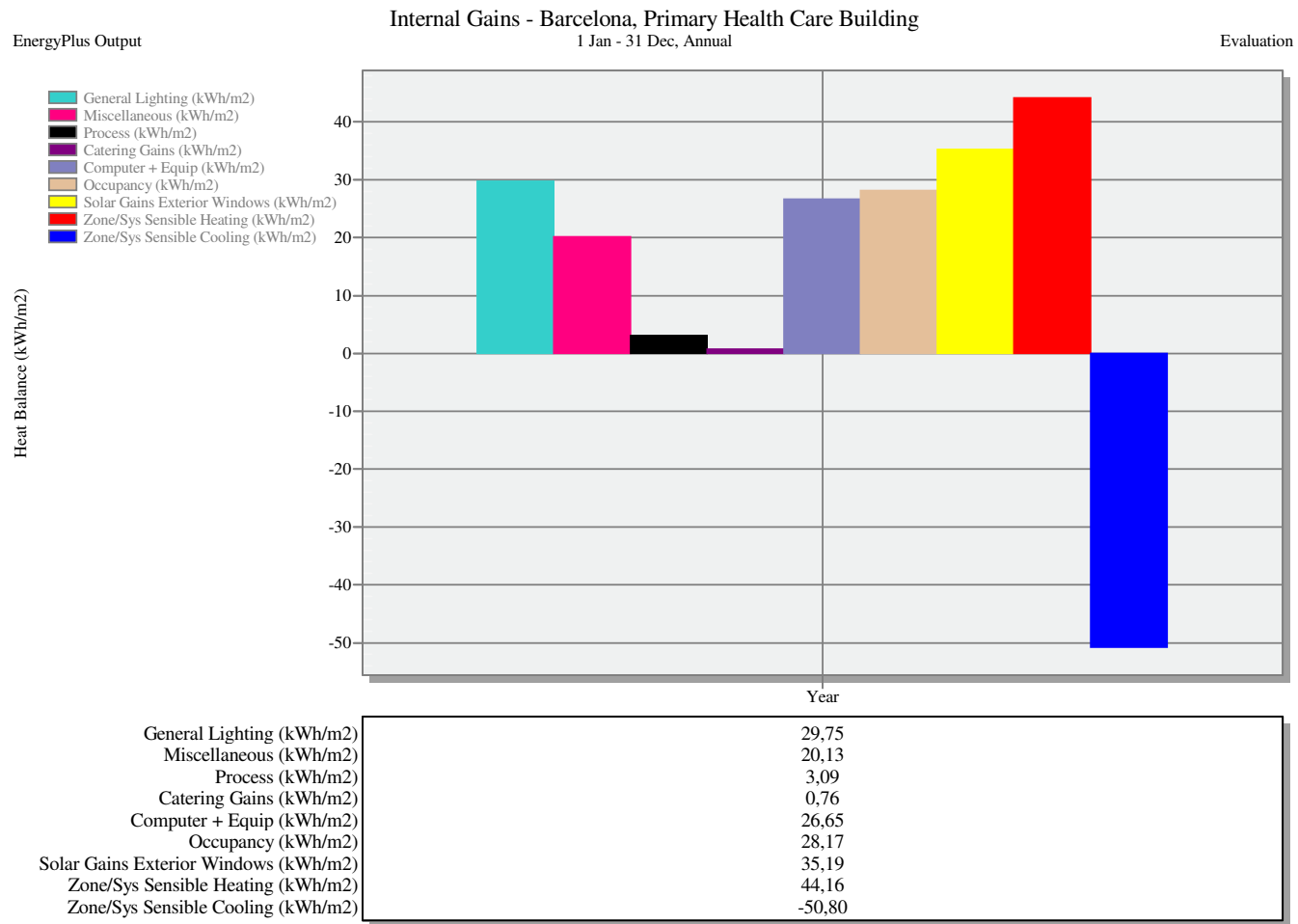


Figure 5.14: Present case annual energy analysis of building.

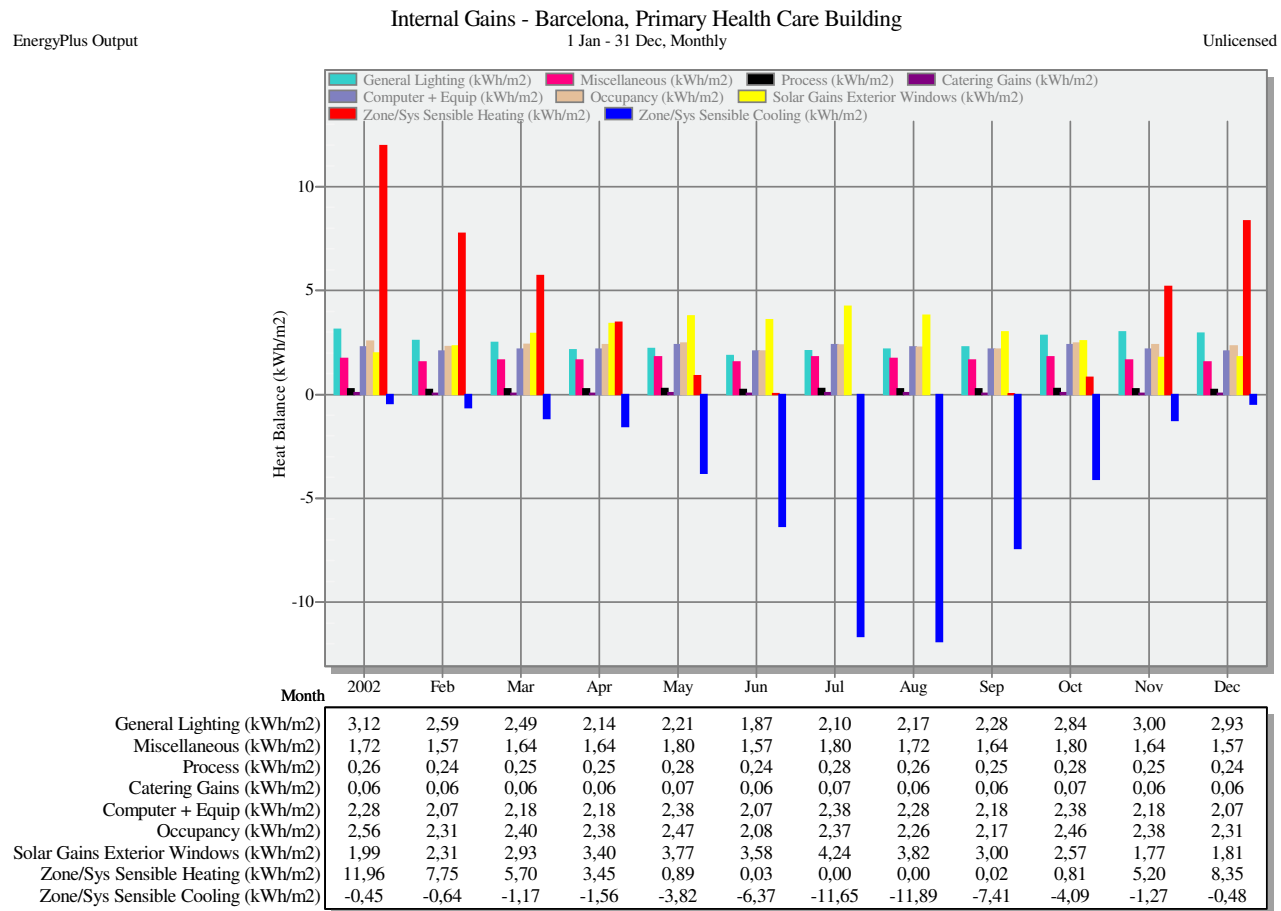


Figure 5.15: Monthly energy analysis of building.

According to table, lighting demand increases in winter because of the low solar radiation. On the other hand gains from computer, equipments and occupancy is nearly same during the year only the small difference is because of the holidays. Also catering, miscellaneous and process gains doesn't change. But solar gains from windows increase in summer period in proportion with the increase in cooling demand. It can be seen that the highest amount of internal gains are cooling load. Secondly external sources (solar gain from windows) and internal gains mainly from lighting and computers. Even in winter there is cooling demand because of the high internal gains.

5.3.2.2 Summer period analysis

It is reasonable to examine the summer period for the cooling load. June, July and August months are considered for summer period. They are the months of cooling period in which outside average temperatures are approximately 25-25.5 °C. Building is used all time of the year, therefore; daytime cooling is supported by nighttime cooling for decreasing cooling energy demands. Summer period daily temperature and humidity change is given in Figure 5.16. The figure includes air temperature, radiant temperature, operative temperature, outside-dry bulb temperature and relative humidity distribution throughout months.

Beside summer period, a summer typical week is also examined. Hourly temperature and humidity change for week of 22nd-28th June are presented in Figure 5.17.

5.3.2.3 Summer day measured analysis

In addition to the building model studies, measured data of summer day (27th June 2008) is given in Figure 5.18; (This is not given for comparing with simulation results, because DesignBuilder does not consider the 2008 weather data, but to see the summer day temperature distribution). In Figure 5.18 left axis refers temperatures T_i and T_e , right axis refers solar radiation; (T_i : internal temperature, T_e : external temperature, G : solar radiation). The temperature change is given at hourly intervals. T_e during night is also high (between 22-27°C); (Operation mode of cooling system was as submitted in previous chapter; between hours 07:00-21:00 system is operated to 24.5°C and between 21:00-07:00 it is operated to 28.5°C as night time convective cooling). Effect of night time cooling on indoor air temperature can be seen in the figure.

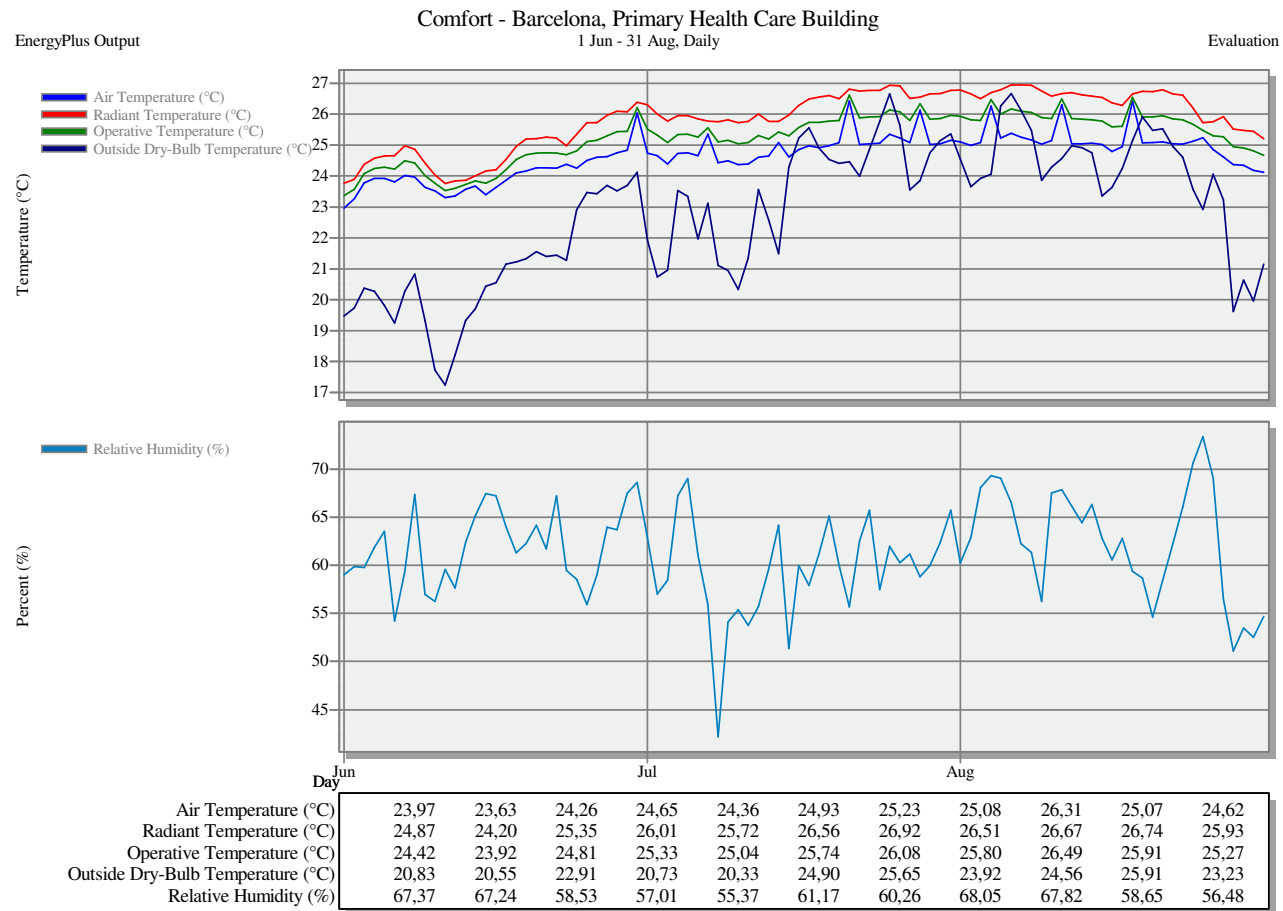


Figure 5.16: Summer period daily temperature and humidity change.

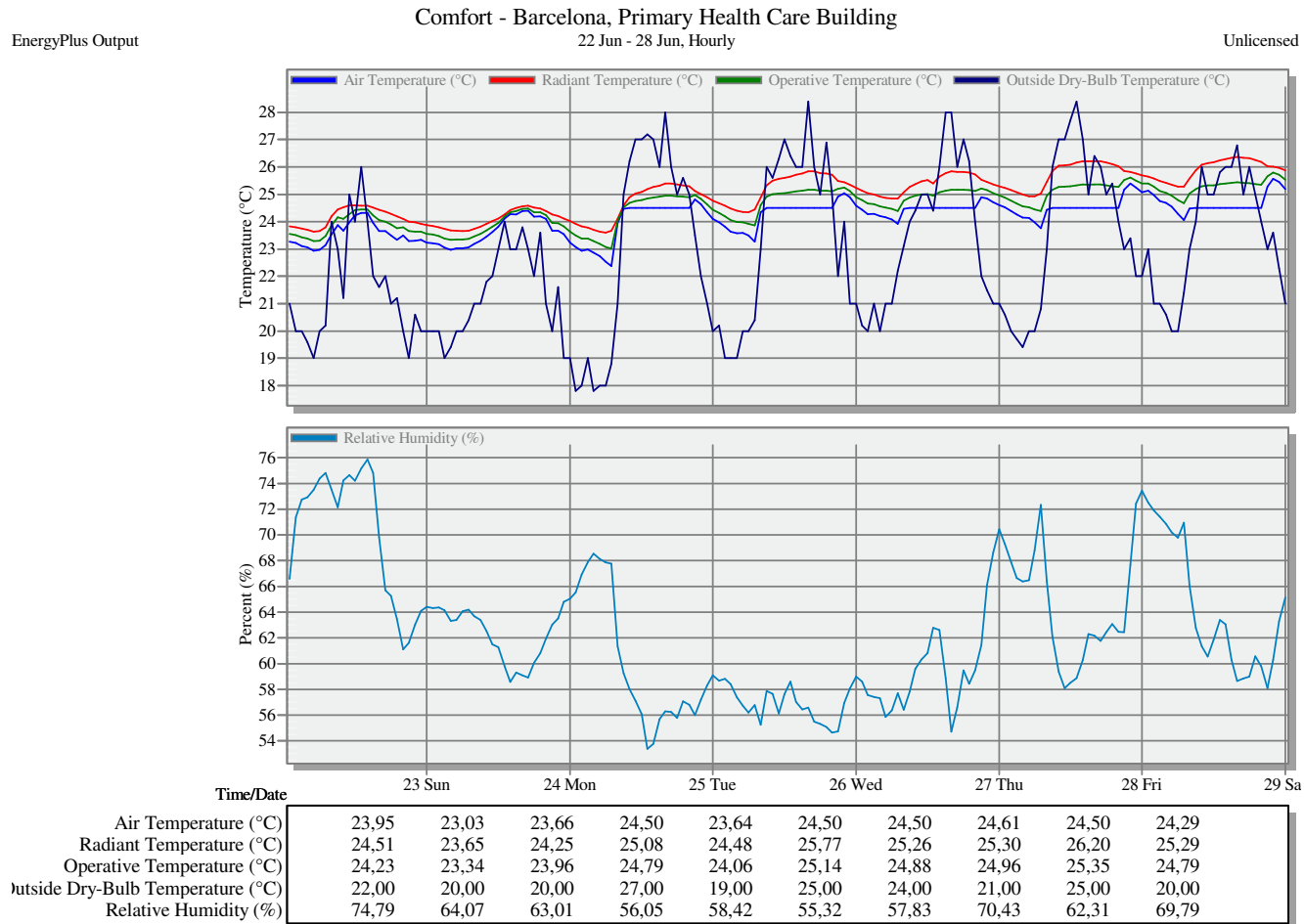


Figure 5.17: Summer typical week hourly temperature and humidity change.

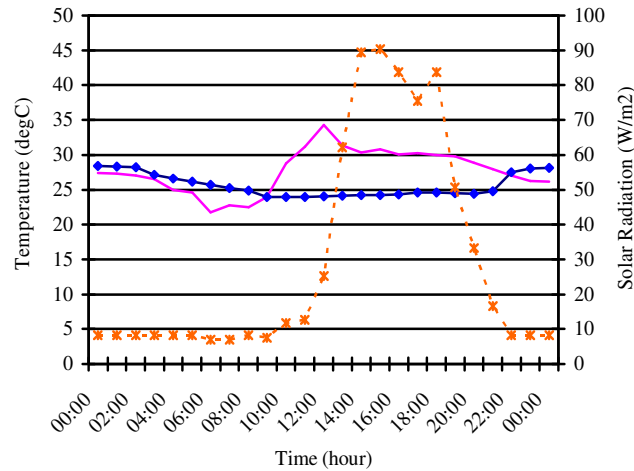
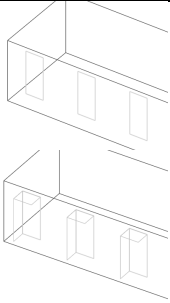
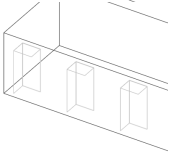


Figure 5.18: Summer day hourly measured temperature change.

5.3.3 Comparison of base case and present case

Table 5.4 presents the building annual energy demand comparison of present case with base case on Southwest facade. Total load is the sum of lighting, heating and cooling loads.

Table 5.4: Comparison of base case and present case.

Figure	Cases	Solar Gains from windows kWh/m ²	General Lighting kWh/m ²	Sensible Heating kWh/m ²	Sensible Cooling kWh/m ²
	Base case	38,85	29,25	43,48	52,71
			Total: 125,44 kWh/m²		
	Present case	35,19	29,75	44,16	50,80
			Total: 124,71 kWh/m²		

This comparison can also be seen in Figure 5.19. (Ql: General lighting load, Qh: Sensible heating load, Qc: Sensible cooling load). On Southwest facade, application of present shading (Northwest sidefin and overhang combination) caused a reduction in solar gains from windows. Therefore, cooling load has decreased by 3,62%. However, there isn't a significant decrease in total load, because; the cooling load decrease is balanced with heating and lighting load increase in present case and because of this factor total load decreased only by 0,58%.

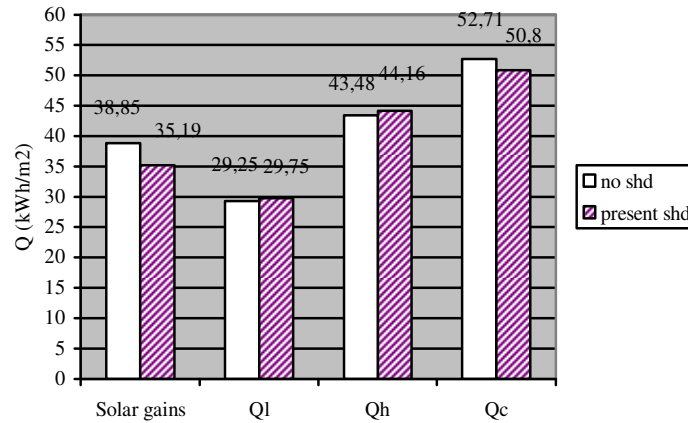


Figure 5.19: Comparison of base case and present case.

It is clear that present situation doesn't make a great difference in energy consumption levels. There is only little reduction in cooling load, besides little increase in heating and lighting which balance each other.

5.3.3.1 Effect of glazing ratio on shading

The present building envelope has 30% glazing ratio. When window to wall ratio (WWR) of the main (Southwest) facade increases, the impact of shading on energy use becomes more prominent. To examine this issue, the building is assumed to have 60% WWR as shown in the rendered model in Figure 5.20.

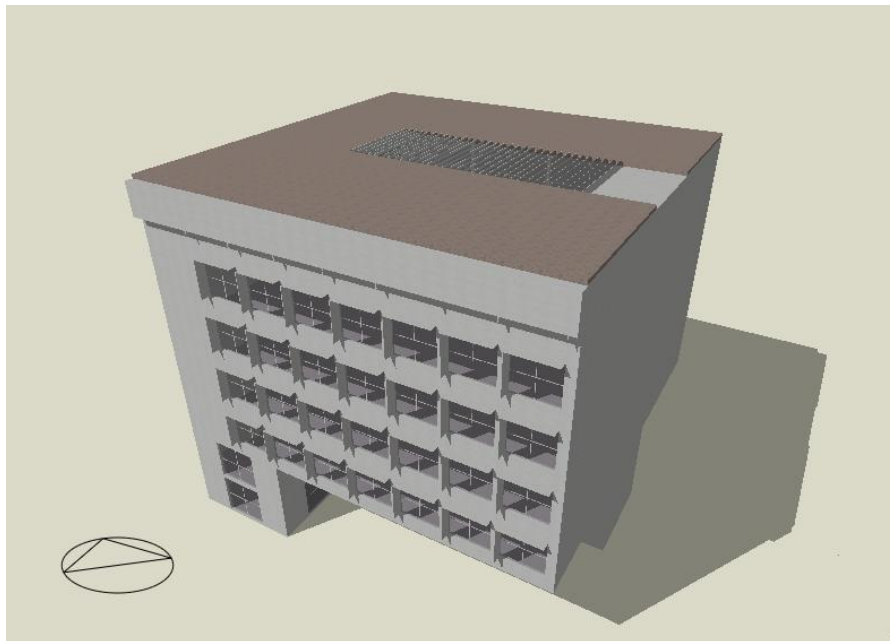


Figure 5.20: Model with 60% glazing ratio.

Building annual loads of base case is compared again with present case. The results of simulation is in Table 5.5. (Ql: General lighting load, Qh: Sensible heating load, Qc: Sensible cooling load and Qtotal: sum of lighting, heating and cooling loads).

Table 5.5: Annual load comparison of different glazing ratios.

Building Annual Loads	WWR percentage	with no facade shading	with present shading
Ql (kWh/m ²)	30%	29,25	29,75
	60%	28,62	28,72
Qh (kWh/m ²)	30%	43,48	44,16
	60%	40,69	42,29
Qc (kWh/m ²)	30%	52,71	50,80
	60%	60,56	55,00
Qtotal (kWh/m ²)	30%	125,44	124,71
	60%	129,87	126,01

For 60% glazing ratio; cooling load has an obvious decrease from 60,56 kWh/m² to 55,00 kWh/m² in case of shaded. This can be seen in Figure 5.21.

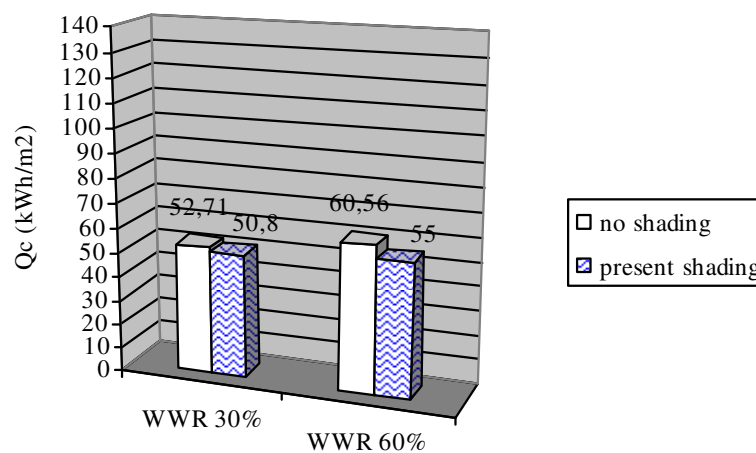


Figure 5.21: Cooling load comparison of building with different glazing ratios.

If WWR is 30%, Qc decreases by 3,62%; if WWR is 60% then Qc decreases by 9,1%. Also the Figure 5.22 points out the difference in building's total load due to WWR. If WWR is 30%, Qtotal decreases by 0,58%; if WWR is 60% then Qtotal decreases by 2,97%.

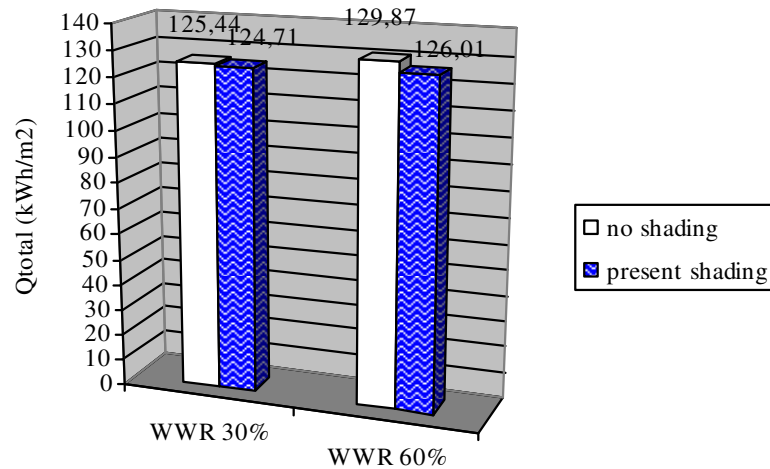


Figure 5.22: Total load comparison of building with different glazing ratios.

5.3.3.2 Comparison of external gains in the building

As mentioned before, there are four thermal zones in the building. Zone_1 is the service zone, Zone_2 compromises Southwest facade consult rooms, Zone_3 is the waiting halls adjacent to atrium, Zone_4 expresses the Northeast facade consult rooms. External gains from windows vary due to different orientation and elevations of building zones. This is presented in Table 5.6 with the comparison of shading situations. Also Figure 5.23 shows this distribution more clearly.

Table 5.6: Solar gains from windows for all zones.

Solar Gains for Building Zones (kWh/m ²)						
Floors	Zone_1	Zone_2		Zone_3		Zone_4
	present situation	no shading	present shading	no shading	present shading	present situation
Entrance Floor	107,69	-	-	-	-	-
Mezzanine Floor	78,04	-	-	-	-	-
1 st Floor	-	50,96	33,25	33,50	27,35	29,56
2 nd Floor	-	60,39	39,46	25,26	16,77	29,64
3 rd Floor	-	60,36	39,52	39,70	21,92	29,64
4 th Floor	-	59,20	39,35	81,38	38,74	29,27
5 th Floor	-	-	8,51	211,88	92,30	21,23

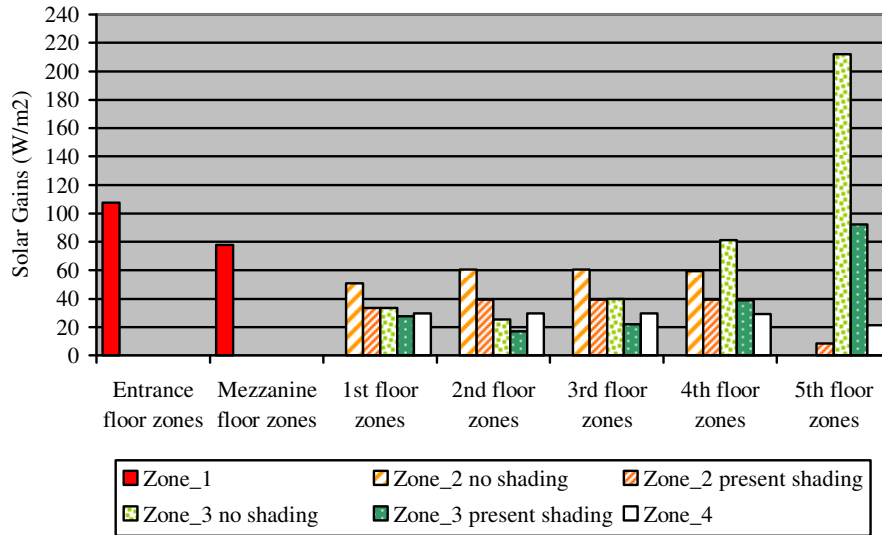


Figure 5.23: Comparison of solar gains from windows for all zones due to different floors.

The results obtained from the table can be indicated as follows;

Zone_3 gets the highest solar radiation through glazing at the top floor. Solar gains from this patio increases about 138% without atrium shading. With the shading, atrium space becomes a naturally illuminated area while avoiding from excess heat. Otherwise 212 kWh/m² energy without any prevention might have definitely increased the cooling load.

Insolation ratio of Southwest and Northeast facades are far different. Figure 5.5 shows the rendered model view of the Northeast facade.

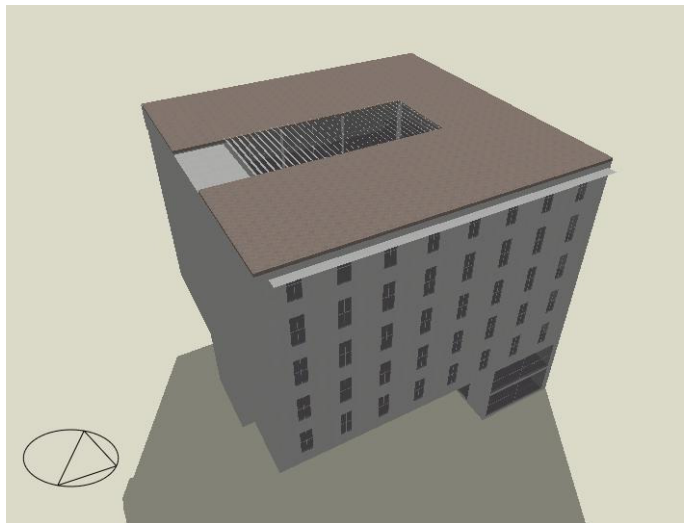


Figure 5.24: Northeast facade of the building.

When considered without shading; solar gains from exterior windows is determined about 60 kWh/m² in Zone_2 and about 30 kWh/m² in Zone_4. Therefore the consult rooms on Northeast facade don't strongly require shading but Southwest facade is suggested to be shaded. Shading devices mounted on the Southwest façade windows cause a decrement from approximately 60 kWh/m² to 40 kWh/m² in solar gains.

Semi-transparent photovoltaic panels placed at façade of 5th floor of Zone_2, decreases the solar gains by 78%. As a matter of fact, the rooms in this facade doesn't require lighting and are not occupied all the time so this is not a problem.

5.4 Southwest Façade Analysis with Examination of Different Shading Devices

After observing the whole building simulation results, it is decided to make a more elaborate focus of the main (Southwest) façade which requires shading. Therefore, Third floor of Zone_2 is chosen as shown in Figure 5.25. Thus, it is going to be analysed and shading device alternatives will be simulated for this zone in this section.

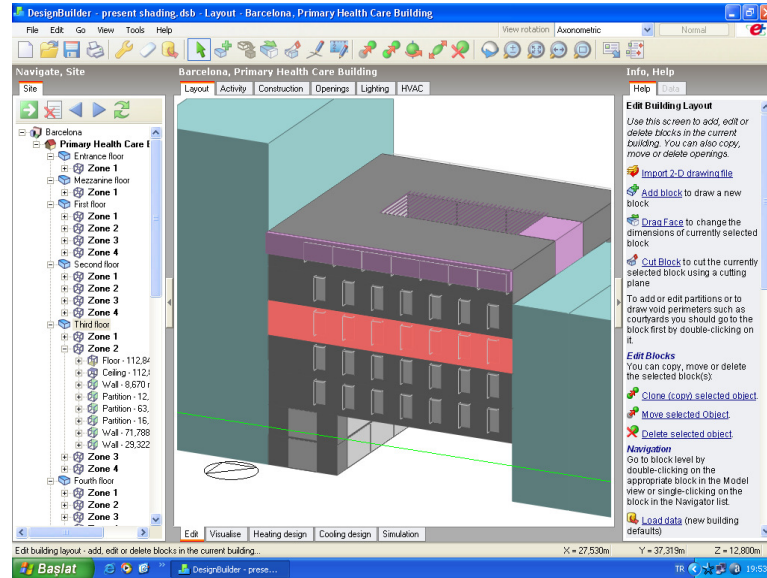
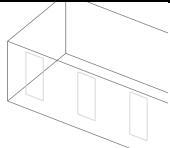
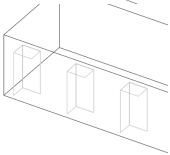


Figure 5.25: Third floor, Zone_2.

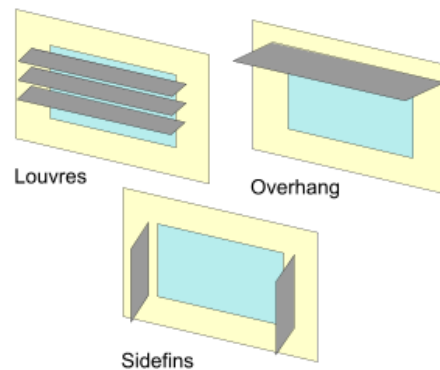
Table 5.7 shows load distributions of Third floor, Zone_2 with no shading and present shading alternatives. Total load is the sum of lighting, heating and cooling loads. There is 17,2% decrease in cooling load and 3,2% decrease in total load in case of shading. The results of following simulations with different shading devices on Southwest facade will be compared with this table in the end of this chapter.

Table 5.7: Load distributions of Third floor, Zone_2.

Figure	Facade Type	Solar Gains from Windows kWh/m ²	General Lighting kWh/m ²	Sensible Heating kWh/m ²	Sensible Cooling kWh/m ²
	No shading	60,36	18,67	24,63	47,77
			Total: 91,07 kWh/m²		
	Present shading	39,52	21,72	26,86	39,56
			Total: 88,14 kWh/m²		

5.4.1 Local shading

DesignBuilder program enables to evaluate facade options by visualisation of facade shading components besides dimensioning. Editing begins with general data for local shading as shown in Figure 5.26. Local shading devices are fixed overhangs, sidefins and louvres.

**Figure 5.26:** Types of local shading devices [72].

To include overhangs, sidefins and/or louvres local shading checkbox is checked first as in Figure 5.27.

**Figure 5.27:** Local shading checkbox from program [72].

In the following tables, detailed properties (including thermo-physical properties and surface properties) of shading device materials that are used in the simulations are given.

Table 5.8 is the thermal characteristics of materials.

Table 5.8: Thermal characteristics of shading device materials [72].

Material	Thermal Bulk Properties		
	Conductivity (λ) W/mK	Specific Heat J/kgK	Density kg/m ³
Steel	50,000	450,0000	7800,00
White-painted steel	50,000	450,0000	7800,00
Aluminium	160,000	880,0000	2800,00
Glass (soda lime glass)	1,000	750,0000	2500,00
Concrete block (Lightweight)	0,190	1000,0000	600,00
Wooden block	0,140	1200,0000	650,00
Fabric	Thermal resistance 0,1500 m ² K/W		

Table 5.9 presents surface properties of materials. The roughness in the table is described in six levels: 1-Very rough, 2-Medium rough, 3- Rough, 4-Smooth, 5-Medium smooth , 6-Very smooth.

Table 5.9: Surface properties of shading device materials [72].

Material	Surface Properties				
	Thermal Absorptance (emissivity)	Solar Absorptance	Visible Absorptance	Roughness	Texture
Steel	0,300	0,300	0,300	3-Rough	Brushed flat
White-painted steel	0,900	0,400	0,400	6-Very smooth	White
Aluminium	0,300	0,300	0,300	3-Rough	Brushed flat
Glass (soda lime glass)	0,900	0,700	0,700	3-Rough	Light grey
Concrete block (Lightweight)	0,900	0,600	0,600	3-Rough	Brushed flat concrete
Wooden block	0,900	0,780	0,780	3-Rough	Oak-veneer
Fabric	0,900	0,700	0,700	3-Rough	Blue fabric

5.4.1.1 Overhangs

There are some terms that are used in the program to determine overhangs such as;

Vertical offset from window top: Vertical distance above window (from window top to the overhang).

Projection: Horizontal length of overhang. (The projection of overhang varies with the latitude).

Horizontal window overlap: The length of extended part of overhang out of window [72].

These features of overhangs are shown in Figure 5.28.

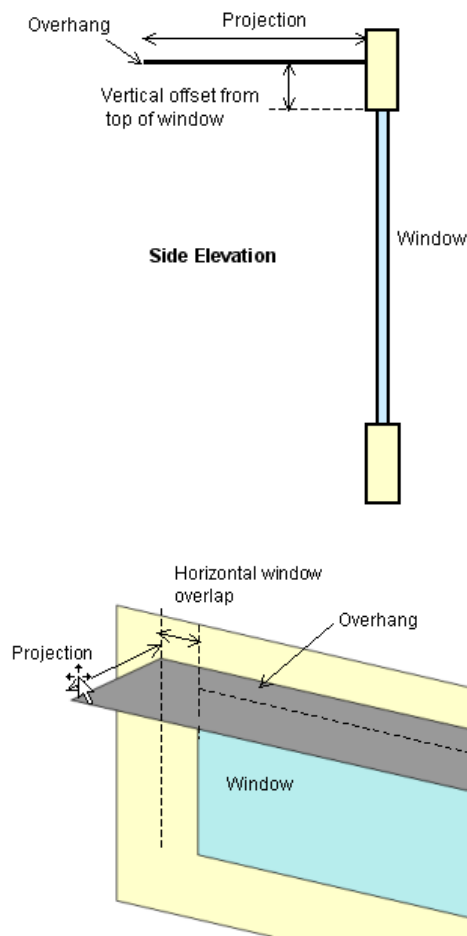


Figure 5.28: Features of overhangs [72].

Material is another issue to determine an overhang. Metal, concrete, glass, fabric and wood is chosen for the simulations. Eleven different overhangs are examined. (O refers the overhang). When horizontal window overlap is chosen as 1,00m, it became

continuous overhang. In all overhang types, vertical offset from window top is given as 0,00m. The default value in the program is zero and if a value is not mentioned in the following descriptions than it means that default value is accepted.

All properties of overhangs are briefly described in Table 5.10.

Table 5.10: Description of overhang properties.

	Type	Material	Projection	Horizontal window overlap
O_1:	1m steel overhang	Steel	1,00m.	-
O_2:	1m steel overhang-60cm overlap	Steel	1,00m.	0,60m.
O_3:	1m continuous steel overhang	Steel	1,00m.	1,00m. (continuous)
O_4:	1m continuous overhang-white painted steel	White painted steel	1,00m.	1,00m. (continuous)
O_5:	1m continuous overhang-aluminium	Aluminium	1,00m.	1,00m. (continuous)
O_6:	1m continuous overhang-concrete block	Concrete block	1,00m.	1,00m. (continuous)
O_7:	1m continuous overhang-glass	Glass	1,00m.	1,00m. (continuous)
O_8:	1m continuous overhang-wooden block	Wooden block	1,00m.	1,00m. (continuous)
O_9:	1m continuous overhang-fabric (textile)	Fabric	1,00m.	1,00m. (continuous)
O_10:	1,5m steel overhang-60cm overlap	Steel	1,50m.	0,60m.
O_11:	1,5m continuous steel overhang.	Steel	1,50m.	1,00m. (continuous)

First, steel overhang with 1m projection is examined. Secondly, when horizontal window overlap increased more and than overhang became continuous, it was seen that it has better performance. After that, same continuous overhang is simulated by changing material types with different types of metals, concrete, glass, wooden blocks and fabric. But it is observed that still steel has the best performance and they are eliminated. To improve the result of steel overhangs, projection is increased to 1,5m and better results are evaluated. 1,5m continuous steel overhang (O_11) has the

lowest total load with 87,27 kWh/m². Table 5.11 is the simulation results of Third floor, Zone_2 annual analysis with overhangs.

Table 5.11: Comparison of overhangs.

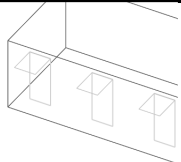
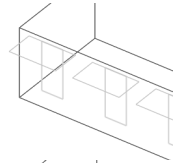
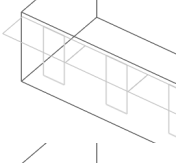
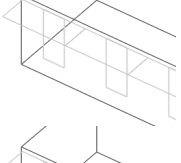
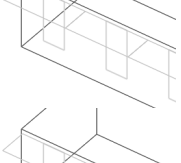
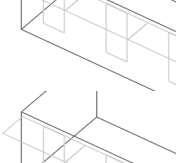
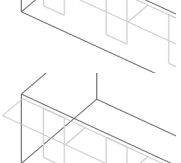
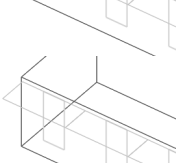
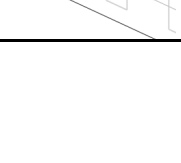
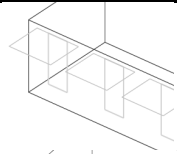
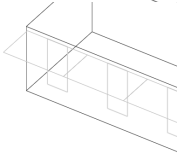
Figure	Type	Description	Solar Gains from Windows kWh/m ²	General Lighting kWh/m ²	Sensible Heating kWh/m ²	Sensible Cooling kWh/m ²
	O_1	1m steel overhang	45,42	19,91	26,69	41,48
Total: 88,08 kWh/m²						
	O_2	1m steel overhang-60cm overlap	39,07	20,85	27,80	39,18
Total: 87,83 kWh/m²						
	O_3	1m continuous steel overhang	37,23	20,94	28,39	38,43
Total: 87,76 kWh/m²						
	O_4	1m continuous overhang-white painted steel	37,23	20,95	28,40	38,44
Total: 87,79 kWh/m²						
	O_5	1m continuous overhang-aluminium	37,23	20,94	28,39	38,43
Total: 87,76 kWh/m²						
	O_6	1m continuous overhang-concrete block	37,23	20,97	28,41	38,45
Total: 87,83 kWh/m²						
	O_7	1m continuous overhang-glass	37,05	21,01	28,48	38,40
Total: 87,89 kWh/m²						
	O_8	1m continuous overhang-wooden block	37,23	20,99	28,37	38,46
Total: 87,82 kWh/m²						
	O_9	1m continuous overhang-fabric	37,23	20,98	28,39	38,45
Total: 87,82 kWh/m²						

Table 5.11 (contd.): Comparison of overhangs.

Figure	Type	Description	Solar Gains from Windows kWh/m ²	General Lighting kWh/m ²	Sensible Heating kWh/m ²	Sensible Cooling kWh/m ²
	O_10	1,5m steel overhang-60cm overlap	34,09	20,88	29,08	37,38
				Total: 87,34 kWh/m²		
	O_11	1,5m continuous steel overhang	30,88	21,09	30,00	36,18
				Total: 87,27 kWh/m²		

This comparison is also shown in Figure 5.29. (Ql: lighting load, Qh: heating load, Qc: cooling load and Qtotal: sum of lighting, heating and cooling loads). First column is the base case. Qtotal is placed in the head of all columns.

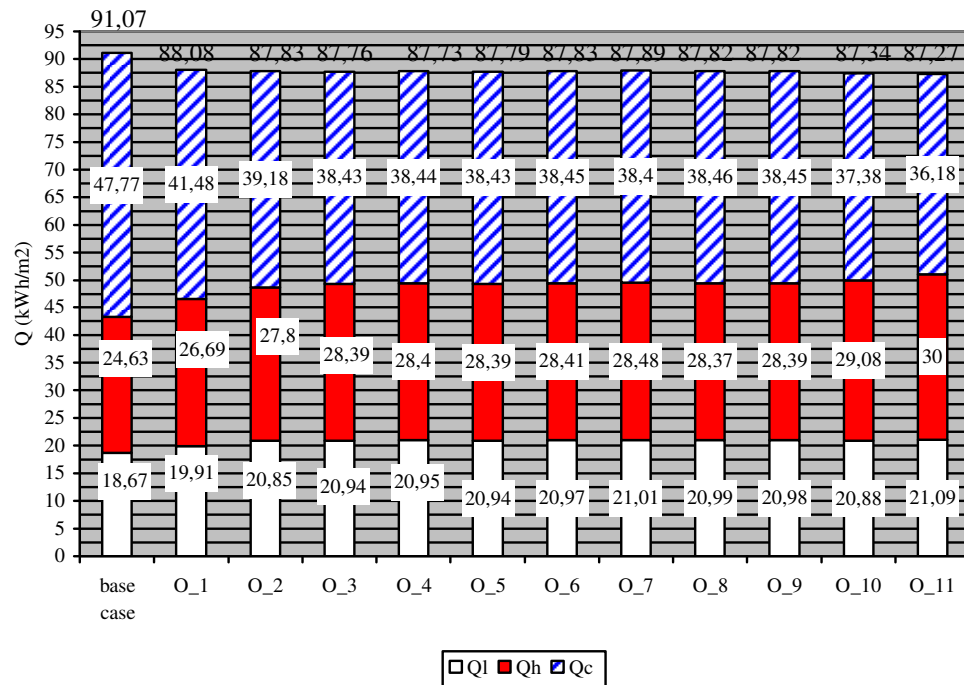


Figure 5.29: Comparison of overhangs.

Overhangs present similar energy results. When compared with base case all overhangs on Southwest façade decrease total load by decreasing the cooling load. There is not big difference between overhang types but, O_11 is the best of all by obstructing the low radiation from west with a long projection and allowing diffuse

radiation. For O_11; cooling load is 24,3% lower and total load is 4,17% lower than the base case.

5.4.1.2 Sidefin and overhang combinations

As indicated before, fins are successful in west and east rotations and overhangs are successful in south direction related with the elevation of sun. Therefore; sidefins combined with overhangs theoretically seem to be the best at southwest facade. So; various sidefin and overhangs are examined for this building.

In the program, left and right sidefins are edited separately. Each tab includes details such as;

Projection: Horizontal length of sidefin.

Horizontal offset from window left/right: Distance beside window to the point that sidefin is applied. (Left and right is described in the figure).

Top overlap: Vertical distance between top of the window to the sidefin

Bottom overlap: Vertical distance between bottom of the window to the sidefin [72].

Features of sidefins are shown in Figure 5.30 and overhang details were already been described.

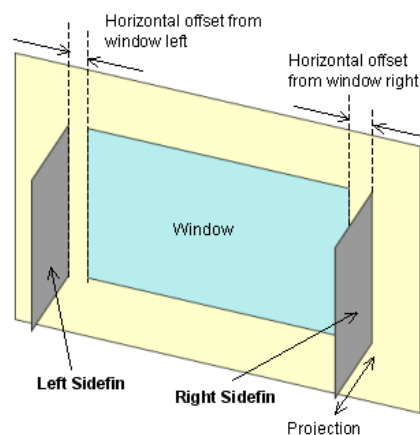


Figure 5.30: Features of sidefins [72].

Twelve sidefin and overhang combination examples are examined. All of them are assumed to be steel. Their features are as follows; (SF indicates sidefin).

For sidefins, horizontal offset from window left/right is assumed as default value; as zero in all types. Top and bottom overlap are taken zero if no value is defined.

For overhangs, vertical offset from window top is assumed as default value (zero). Horizontal window overlap is assumed as default value (zero) if a value is not given. Table 5.12 is the description of all types.

Table 5.12: Description of sidefin and overhang properties.

	Type	Left /Right sidefin projection	Top overlap	Bottom overlap	Overhang projection	Horizontal window overlap
SF_1:	0,5m Left (Northwest) sidefin and 0,5m overhang	0,50m Left			0,50m	
SF_2:	0,5m Right (Southeast) sidefin and 0,5m overhang	0,50m Right			0,50m	
SF_3:	0,5m Left (Northwest) and 0,5m Right (Southeast) sidefins with 0,5m overhang	0,50m Left and 0,50m Right			0,50m	
SF_4:	0,8m Left (Northwest) sidefin and 0,8m overhang	0,80m Left			0,80m	
SF_5:	1,0m Left (Northwest) sidefin and 1,0m overhang	1,00m Left			1,00m	
SF_6:	0,8m Left (Northwest) sidefin and 0,8m overhang with 0,3m horizontal overlap	0,80m Left			0,80m	0,30m
SF_7:	Only 1,0m Left (Northwest) sidefin, no vertical overlap	1,00m Left				
SF_8:	Only 1,0m Left (Northwest) sidefin, vertical continuous	1,00m Left	1,00m	1,00m		
SF_9:	Only 1,5m Left (Northwest) sidefin, vertical continuous	1,50m Left	1,00m	1,00m		
SF_10:	1m Left (Northwest) vertical continuous sidefin, 0,5m overhang	1,00m Left	1,00m	1,00m	0,50m	
SF_11:	1m Left (Northwest) vertical continuous sidefin, 0,5m continuous overhang	1,00m Left	1,00m	1,00m	0,50m	1,00m
SF_12:	1,0m Left (Northwest) vertical continuous sidefin and 1,5m continuous overhang	1,00m Left	1,00m	1,00m	1,50m	1,00m

First, a sidefin from left (Northwest) then from right (Southeast) is applied additional to 0,5m overhang to see efficiency according to direction. It is observed that with

left sidefin the lowest total load is obtained. SF_1 is also the present case. Northwest fin serves as a barrier from the west sun at afternoon. Also two sidefins on both sides of window increased total load because of higher lighting and heating loads.

Then projections are examined. By increasing the projection to 0,8m better solution is achieved. The result is lower solar gains and lower total load. When projection increased to 1m and more, the efficiency decreased. If overhang is modified as in SF_6; increase in horizontal overhang caused an increase in total load. So this case is also eliminated.

In SF_7 overhang is removed to see the efficiency of sidefin without effect of overhang. It is observed that SF_8 being vertically continuous with top and bottom overlaps is better than SF_7. But if the projection is increased to 1,5m, Q_{total} also increased.

SF_10, SF_11 and SF_12 are obtained by adding overhangs to 1m vertically continuous sidefin. Total loads with these ones are also high. The most efficient case is the SF_4.

All results of simulations can be seen in Table 5.13.

Table 5.13: Comparison of sidefin and overhang combinations.

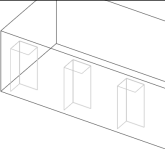
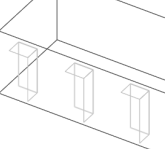
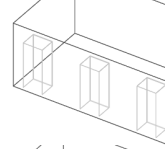
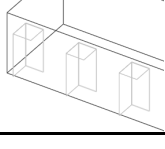
Figure	Type	Description	Solar Gains from Windows kWh/m ²	General Lighting kWh/m ²	Sensible Heating kWh/m ²	Sensible Cooling kWh/m ²
	SF_1	0,5m NW sidefin and 0,5m overhang (present case)	39,52	21,72	26,86	39,56
				Total: 88,14 kWh/m²		
	SF_2	0,5m SE sidefin and 0,5m overhang	37,94	22,51	28,90	41,17
				Total: 92,58 kWh/m²		
	SF_3	0,5m both sidefins and 0,5m overhang	28,39	25,95	29,52	38,65
				Total: 94,12 kWh/m²		
	SF_4	0,8m NW sidefin and 0,8m overhang	34,40	22,23	27,69	37,67
				Total: 87,59 kWh/m²		

Table 5.13 (contd.): Comparison of sidefin and overhang combinations.

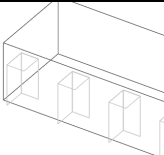
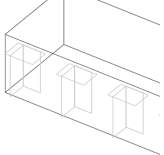
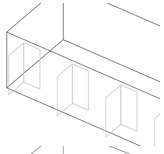
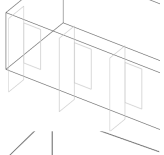
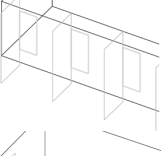
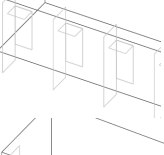
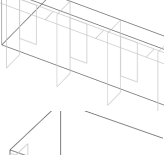
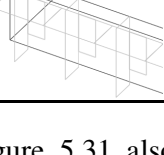
Figure	Type	Description	Solar Gains from Windows kWh/m ²	General Lighting kWh/m ²	Sensible Heating kWh/m ²	Sensible Cooling kWh/m ²
	SF_5	1m NW sidefin and 1m overhang	31,91	22,59	28,15	36,90
				Total: 87,64 kWh/m²		
	SF_6	0,8m NW sidefin and 0,8m overhang with 0,3m overlap	32,39	23,08	28,07	37,36
				Total: 88,51 kWh/m²		
	SF_7	only 1m NW sidefin, no vertical overlap	46,59	20,18	26,21	41,86
				Total: 88,25 kWh/m²		
	SF_8	only 1m NW sidefin, vertical continuous	43,59	20,75	26,64	40,57
				Total: 87,96 kWh/m²		
	SF_9	only 1,5m NW sidefin, vertical continuous	39,34	21,85	27,31	39,49
				Total: 88,65 kWh/m²		
	SF_10	1m NW vert. cont sidefin and 0,5m overhang	34,97	22,32	27,89	37,88
				Total: 88,09 kWh/m²		
	SF_11	1m NW vert. cont. sidefin, 0,5m cont. overhang	32,99	23,27	28,29	37,42
				Total: 88,98 kWh/m²		
	SF_12	1m NW vert. cont. sidefin and 1,5m cont. overhang	22,64	24,38	30,88	34,64
				Total: 89,90 kWh/m²		

Figure 5.31 also presents this difference with base case. (Ql: lighting load, Qh: heating load, Qc: cooling load and Qtotal: sum of lighting, heating and cooling loads). Total load is placed in top of all columns.

SF_4 is the most efficient device with Qt: 87,59 kWh/m². For SF_4, total load is 3,8% lower and cooling load is 21,14% lower when compared with base case.

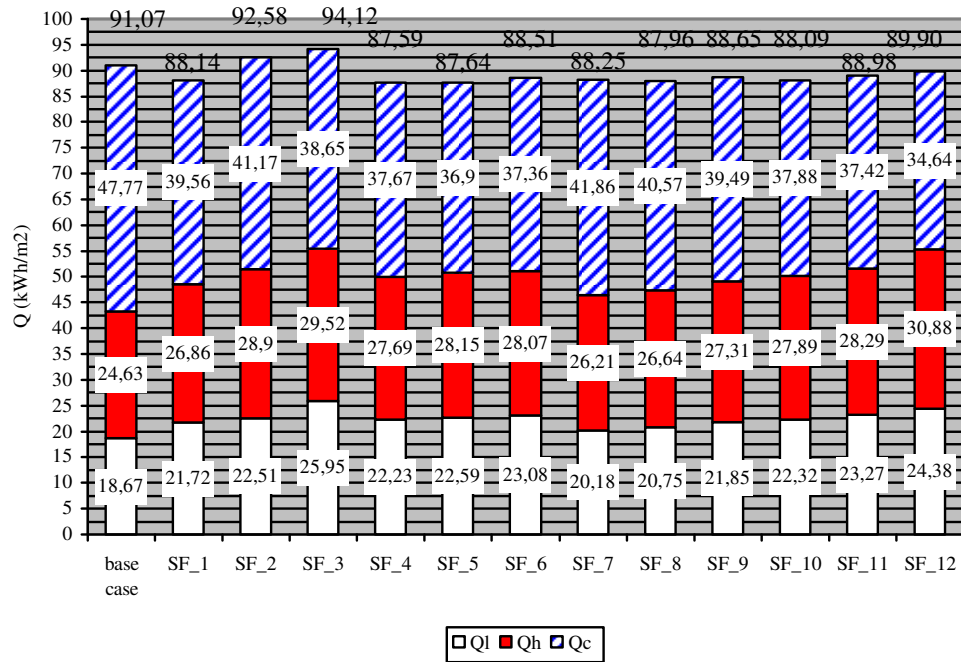


Figure 5.31: Comparison of sidefin and overhang combinations.

5.4.1.3 Louvres

In the previous chapter, louvres were defined as externally mounted shading devices standing at a distance from the glazing. There are some terms that are used in the program to define louvres;

Number of blades: Pieces of louvres.

Vertical spacing: Vertical distance between two blades.

Angle: Angle that a blade makes with horizontal surface.

Distance from window: How far it is from glazing.

Blade depth: The length of blade.

Vertical offset from window top: Vertical distance from the top of window. (Considers how much glazing is unshaded at the top of window).

Horizontal window overlap: Length of the blade extended out of window [72].

Features of louvres are shown in Figure 5.32.

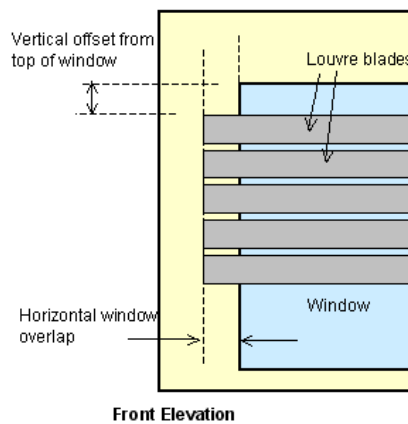
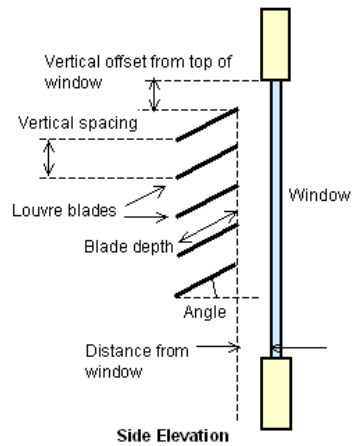


Figure 5.32: Features of louvres [72].

Program allows to observe the performance of fixed louvres. Thirteen louvres are examined; (L refers louvres). Properties of louvres are listed below:

L_1: Steel, 1 blade, 30°, 0,30m distance, 1m blade depth, no vertical offset, 0,60m horizontal window overlap.

L_2: L_1 with 0,60m vertical offset from window top.

L_3: Steel, 1 blade, 45°, no distance from window, 1m blade depth, no vertical offset, no horizontal window overlap.

L_4: Fabric of L_3.

L_5: L_3 with 0,50m blade depth.

L_6: Steel, 1 blade, 30°, 0,30m distance, 0,50m blade depth, no vertical offset, 0,50m horizontal window overlap.

L_7: Glass of L_6.

L_8: Glass, 6 blades, 0,40m vertical spacing, 30°, 0,10m distance, 0,30m blade depth, no vertical offset, 0,40m horizontal window overlap.

L_9: L_8 with 5 blades and 0,30m vertical offset from window top.

L_10: L_8 with 0,10m horizontal window overlap.

L_11: Steel, 4 blades, 0,60m vertical spacing, 30°, 0,20m distance, 0,40m blade depth, no vertical offset, no horizontal window overlap.

L_12: L_11 with 3 blades.

L_13: L_12 with 45°.

Table 5.14 is the brief description of all louvres.

Table 5.14: Description of louvres.

Type	Material	Number of blades	Vertical spacing	Angle	Distance from window	Blade depth	Vertical offset from window top	Horizontal window overlap
L_1	Steel	1	-	30°	0,30m	1,00m	0,00m	0,60m
L_2	Steel	1	-	30°	0,30m	1,00m	0,60m	0,60m
L_3	Steel	1	-	45°	0,00m	1,00m	0,00m	0,00m
L_4	Fabric	1	-	45°	0,00m	1,00m	0,00m	0,00m
L_5	Steel	1	-	45°	0,00m	0,50m	0,00m	0,00m
L_6	Steel	1	-	30°	0,30m	0,50m	0,00m	0,50m
L_7	Glass	1	-	30°	0,30m	0,50m	0,00m	0,50m
L_8	Glass	6	0,40m	30°	0,10m	0,30m	0,00m	0,40m
L_9	Glass	5	0,40m	30°	0,10m	0,30m	0,30m	0,40m
L_10	Glass	6	0,40m	30°	0,10m	0,30m	0,00m	0,10m
L_11	Steel	4	0,60m	30°	0,20m	0,40m	0,00m	0,00m
L_12	Steel	3	0,60m	30°	0,20m	0,40m	0,00m	0,00m
L_13	Steel	3	0,60m	45°	0,20m	0,40m	0,00m	0,00m

L_1, is like an inclined overhang of 1m. With L_1 total load is found as 89,54 kWh/m². If vertical offset from window top is defined as 0,60m as in L_2, then Q_{total} increases. L_3 is a modified L_1 with angle 45°, having no distance from window, and with no horizontal overlap; L_3 has better energy savings than L_1.

In L_5, with reference to L_3, blade depth is decreased from 1m to 0,5m and an increase in Q_{total} is observed.

L_6 is defined as a steel overhang with a single blade which is 30° inclined with 0,50m blade depth and 0,50m horizontal window overlap; has the highest contribution to energy savings.

Comparisons between L_3 and L_4 (steel and fabric louvres) and between L_6 and L_7 (steel and glass louvres) showed that material types don't make effect on total loads. (Glass in the simulations is assumed as opaque). There is not great difference; other types have equal or higher energy demands than steel.

When blade depth decreases and number of blades increase as in L_8, it causes higher total load. L_9, being modified from L_8, with making 0,30m vertical offset from window top, allows more daylight to interior; therefore lighting demand and total energy demand decrease is observed. L_10 is L_8 with 0,10m horizontal window overlap. When horizontal window overlap decreases, Q_{total} also decreases as in L_10.

In the last three examples, vertical spacing of blades is increased from 0,40m to 0,60m. Allowing more daylight via louvres, total energy level was observed to be lower. The degree of the inclination is also important for shading design. In this façade, 45° angle is better than 30° as in case L_13 when compared with L_12.

Table 5.15 submits the annual loads for louvres for Third floor, Zone_2.

Table 5.15: Comparison of louvres.

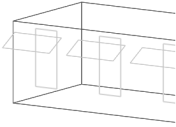
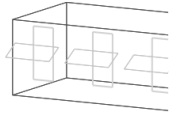
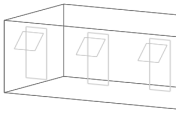
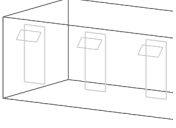
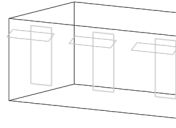
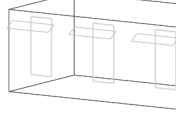
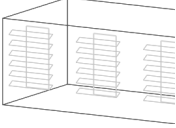
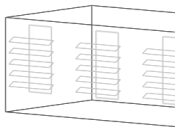
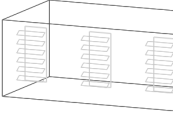
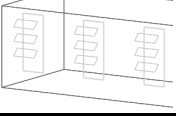
Figure	Type	Description	Solar Gains from windows kWh/m ²	General Lighting kWh/m ²	Sensible Heating kWh/m ²	Sensible Cooling kWh/m ²
	L_1	Steel, 1 blade, 30°, 0,30m dist., 1m blade depth, no vert. offset, 0,60m hor. wind. overlap	39,12	20,93	28,50	40,11
				Total: 89,54 kWh/m²		
	L_2	L_1 with 0,60m vertical offset	41,49	21,15	28,05	41,37
				Total: 90,57 kWh/m²		
	L_3	Steel, 1 blade, 45°, no dist. from window, 1m blade depth, no vert. offset, no hor. wind. overlap	41,54	19,96	28,02	40,78
				Total: 88,76 kWh/m²		

Table 5.15 (contd.): Comparison of louvres.

Figure	Type	Description	Solar Gains from windows kWh/m ²	General Lighting kWh/m ²	Sensible Heating kWh/m ²	Sensible Cooling kWh/m ²
	L_4	Fabric of L_3	41,54	19,96	28,01	40,79
Total: 88,76 kWh/m²						
	L_5	L_3 with 0,50m blade depth	49,58	18,83	26,62	43,39
Total: 88,84 kWh/m²						
	L_6	Steel, 1 blade, 30°, 0,30m distance, 0,50m blade depth, no vert. offset, 0,50m hor. window overlap	48,88	18,90	26,80	42,96
Total: 88,66 kWh/m²						
	L_7	Glass of L_6	48,88	18,91	26,84	42,96
Total: 88,71 kWh/m²						
	L_8	Glass, 6 blades, 0,40m vert. spac., 30°, 0,10m dist., 0,30m blade depth, no vert. offset, 0,40m hor. window overlap	28,22	24,43	30,40	38,24
Total: 93,07 kWh/m²						
	L_9	L_8 with 5 blades and 0,30m vert offset	32,97	21,13	30,29	38,46
Total: 89,88 kWh/m²						
	L_10	L_8 with 0,10m hor. window overlap	33,26	22,82	29,48	39,46
Total: 91,76 kWh/m²						
	L_11	Steel, 4 blades, 0,60m vert. spac., 30°, 0,20m dist., 0,40m blade depth, no vert. offset, no hor. window overlap	40,27	20,24	28,54	40,70
Total: 89,48 kWh/m²						
	L_12	L_11 with 3 blades	42,61	19,94	27,95	41,36
Total: 89,25 kWh/m²						
	L_13	L_12 with 45°	40,14	19,47	28,78	40,47
Total: 88,72 kWh/m²						

The results for examined louvres can also be seen in Figure 5.33. (Ql: lighting load, Qh: heating load, Qc: cooling load and Qtotal: sum of lighting, heating and cooling loads). Total load is placed in top of all columns.

As the total load in base case is 91,07 kWh/m², The best louvre is L_6 with 88,66 kWh/m², which makes a 2,64% decrease in building total energy demand.

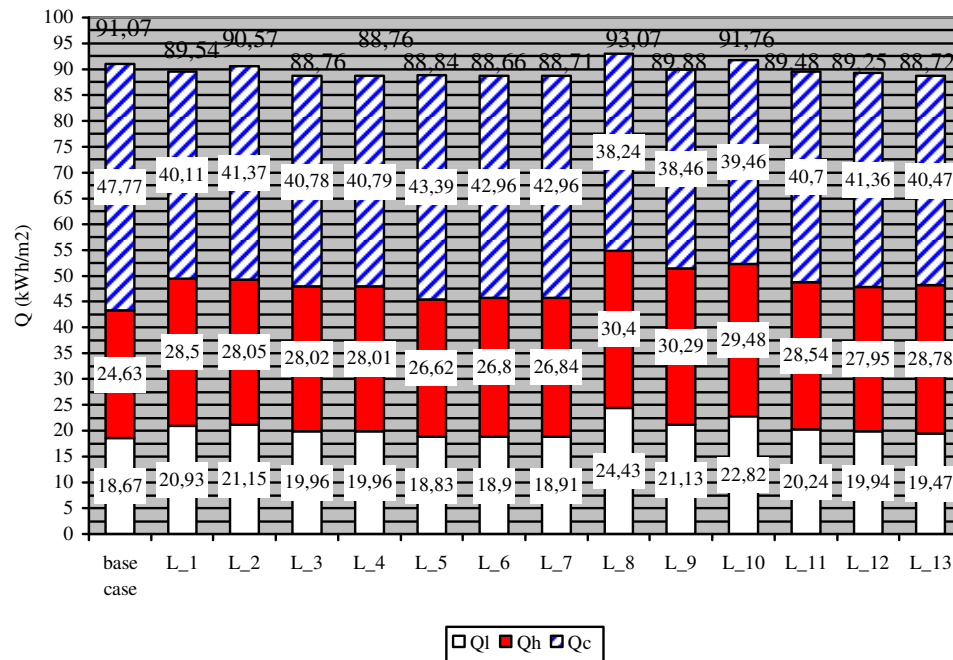


Figure 5.33: Comparison of louvres.

5.4.2 Window shading

Window shading devices can be inside, outside or mid-pane and they can be operated. Positions of window shading devices is shown in Figure 5.34.

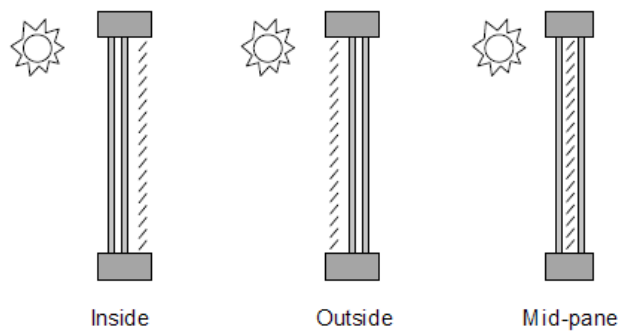


Figure 5.34: Position of window shading devices [72].

First window shading checkbox should be modified as in Figure 5.35. Type, position and control type is adjusted under this checkbox.



Figure 5.35: Window shading checkbox from program [72].

5.4.2.1 Control types

Before examining window shading, it is necessary to examine shading control types. They are in the listed following;

1. *Always On*: Shading is always on.

The following six control types are used primarily to reduce zone cooling load due to window solar gain.

2. *Daylight*: Used only with Position=4-Switchable in zones with daylighting controls. In this case the transmittance of the glazing is adjusted to just meet the daylight illuminance setpoint at the first daylighting reference point. The daylight illuminance setpoint is specified under Environmental Control on the Activity tab.

3. *Schedule*: Shading operation is defined by a schedule.

4. *Solar*: Shading is on if beam plus diffuse solar radiation incident on the window exceeds setpoint.

5. *Glare*: Shading is on if the total daylight glare index at the zone's first daylighting sensor from all of the exterior windows in the zone exceeds the maximum glare index specified in the daylighting input for zone.

Note: Glare control requires lighting control to be switched on in the zone.

6. *Outside air temp*: Shading is on if outside air temperature exceeds setpoint.

7. *Inside air temp*: Shading is on if zone air temperature in the previous time step exceeds setpoint.

8. *Cooling*: Shading is on if zone cooling rate in the previous time step is non-zero.

The following two control types can be used to reduce zone cooling load. They are applicable to any shading type but are most appropriate for interior or exterior blinds, interior or exterior shades with low insulating value, or switchable glazing.

9. *Day cooling and solar + night*: Shading is on at night. Shading is on during the day the solar radiation incident on the window exceeds setpoint and if the zone cooling rate in the previous time step is non-zero.

10. *Day cooling and solar*: Shading is off at night. Shading is on during the day when the solar radiation incident on the window exceeds setpoint and if the zone cooling rate in the previous time step is non-zero [72].

5.4.2.2 Slatted blinds

Slatted blinds specify the properties of a window blind consisting of flat, equally-spaced slats. Unlike window shades, which are modelled as perfect diffusers, window blinds have solar and visible transmission and reflection properties that strongly depend on slat angle and angle of incidence of solar radiation (solar position).

When in place, the blind is assumed to cover all of the glazed part of the window, including dividers; it does not cover any of the window frame, if present. The plane of the blind is assumed to be parallel to the glazing. When the blind is retracted it is assumed to cover none of the window. The solar and thermal effects of the blind's support strings, tapes or rods are ignored. Slat curvature, if present, is ignored [72].

Features of slats are shown in Figure 5.36.

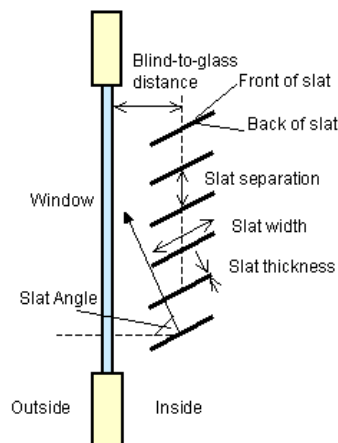


Figure 5.36: Features of slats [72].

The slat angle is the angle between the glazing outward normal to the slat outward normal. A slat angle of 0° sets slats to be vertical and an angle of 90° sets them to be horizontal. The openings data allows to define the distance between the blind and the

window and also define the fraction of the shade surface that is open to air flow on each side of the blind. A slatted blind can be applied inside, outside or mid-pane. If the blind is applied mid-pane, the gap between the inner pane and the second pane must be at least large enough to accommodate the slat width [72].

There are four types of slatted blinds in the program;

1. Blind with high reflectivity slats.
2. Blind with low reflectivity slats.
3. Blind with medium reflectivity slats.
4. Mid pane blind with medium reflectivity slats.

Window blind edit tab includes many components. For example ‘Blind with medium reflectivity slats’ data is shown in Figure 5.37.

General	
Name	Blind with medium reflectivity slats
Category	Slatted blind
Slat Properties	
Slat orientation	Horizontal
Slat width	0.025
Slat separation	0.019
Slat thickness	0.001
Slat angle	45.0
Slat conductivity	0.900
Minimum slat angle	0
Maximum slat angle	180
Slat Beam Solar Properties	
Slat beam solar transmittance	0.000
Slat beam solar reflectance, front ...	0.500
Slat beam solar reflectance, back ...	0.500
Slat Diffuse Solar Properties	
Slat diffuse solar transmittance	0.000
Slat diffuse solar reflectance, front ...	0.500
Slat diffuse solar reflectance, back...	0.500
Slat Beam Visible Properties	
Slat beam visible transmittance	0.000
Slat beam visible reflectance, front...	0.500
Slat beam visible reflectance, bac...	0.500
Slat Diffuse Visible Properties	
Slat diffuse Visible transmittance	0.000
Slat diffuse visible reflectance, fro...	0.500
Slat diffuse visible reflectance, ba...	0.500
Slat IR (Thermal) Properties	
Slat hemispherical transmittance	0.000
Slat hemispherical emissivity, front si...	0.900
Slat hemispherical emissivity, back ...	0.900
Openings	
Blind-to-glass distance	0.050
Blind top opening multiplier	0.500
Blind bottom opening multiplier	0.500
Blind left-side opening multiplier	0.500
Blind right-side opening multiplier	0.500

Figure 5.37: Properties of slats [72].

Depending on the position, control type and slat properties, nine different types of slatted blinds are shaped. First, blind with high reflectivity slats is chosen which is positioned outside. In order to observe the effect of control types, several control types are examined on same case SB_1 to SB_6. In case SB_3 which is controlled by glare, glare index: 22 is chosen. The worst case is SB_1 with Always On control type. The slats are always on, so that lighting level is low in the zone. Daylighting control type is the most successful one. The cases control type depending on outside air temperature and solar setpoint are decisive; they increase total load.

For outside positioned and daylight controlled blinds, the reflectivity ratio of slats doesn't have difference; all the results of high, low and medium reflectivity slats are the same.

The simulations also show that for daylight controlled high reflectivity slats, the position of blinds doesn't change energy use; either outside or inside, total load is the same.

Table 5.16 submits the results for Third floor, Zone_2.

Table 5.16: Comparison of slatted blinds.

Type	Description	Solar Gains from windows kWh/m ²	General Lighting kWh/m ²	Sensible Heating kWh/m ²	Sensible Cooling kWh/m ²
SB_1	Type: Blind with high reflectivity slats Position: Outside Control type: Always On	37,85	32,23	25,34	46,43
			Total: 104,00 kWh/m²		
SB_2	Type: Blind with high reflectivity slats Position: Outside Control type: Daylight	38,95	18,67	30,49	40,27
			Total: 89,43 kWh/m²		
SB_3	Type: Blind with high reflectivity slats Position: Outside Control Type: Glare	58,26	19,28	24,73	47,15
			Total: 91,16 kWh/m²		
SB_4	Type: Blind with high reflectivity slats Position: Outside Control type: Solar Solar setpoint (W/m2): 120	39,70	24,17	27,75	43,33
			Total: 95,25 kWh/m²		
SB_5	Type: Blind with high reflectivity slats Position: Outside Control Type: Cooling	49,75	25,74	24,89	47,27
			Total: 97,90 kWh/m²		

Table 5.16 (contd.): Comparison of slatted blinds.

Type	Description	Solar Gains from windows kWh/m ²	General Lighting kWh/m ²	Sensible Heating kWh/m ²	Sensible Cooling kWh/m ²
SB_6	Type: Blind with high reflectivity slats	59,60	18,95	24,63	47,43
	Position: Outside				
	Control Type: Outs. air temp				
			Total: 91,01 kWh/m ²		
SB_7	Type: Blind with low reflectivity slats	38,95	18,67	30,49	40,27
	Position: Outside				
	Control Type: Daylight				
			Total: 89,43 kWh/m ²		
SB_8	Type: Blind with medium reflectivity slats	38,95	18,67	30,49	40,27
	Position: Outside				
	Control Type: Daylight				
			Total: 89,43 kWh/m ²		
SB_9	Type: Blind with high reflectivity slats	38,95	18,67	30,49	40,27
	Position: Inside				
	Control Type: Daylight				
			Total: 89,43 kWh/m ²		

Simulation results can also be seen in Figure 5.38. (Ql: lighting load, Qh: heating load, Qc: cooling load and Qtotal: sum of lighting, heating and cooling loads). Qtotal is placed in head of all columns. Daylighting controlled slatted blinds SB_2, SB_7, SB_8, and SB_9 have the lowest energy demand with Qtotal: 89,43 kWh/m² which is 1,8% lower than base case.

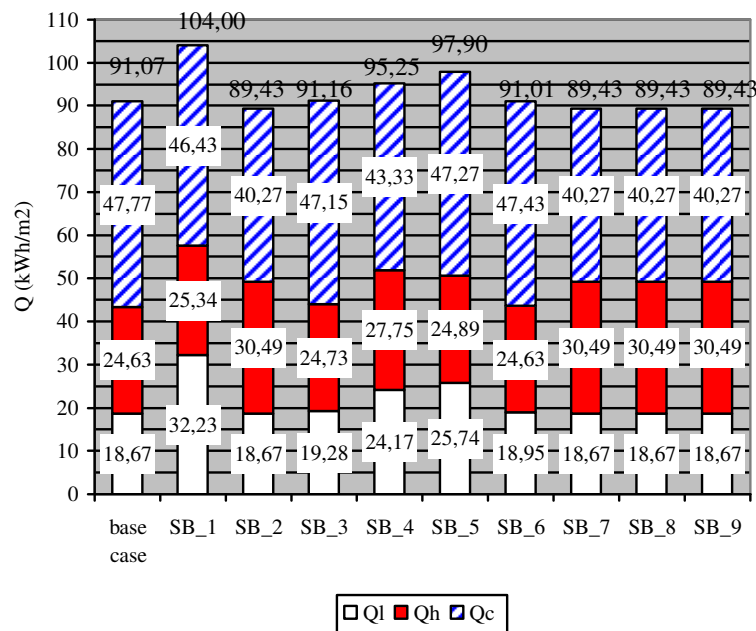


Figure 5.38: Comparison of slatted blinds.

5.4.2.3 Diffusing blinds

Drapes, Shades, Shade Rolls and Venetian blinds are classified as diffusing blinds.

Shades

Shades are assumed as perfectly diffusing. Table 5.17 submits the annual results for shades for Third floor, Zone_2. Six types of shades are examined. SH_1 is found as the best performing device with 87,27 kWh/m² total load. It is a high reflectance low transmittance shade. The worst is the opposite of this as low reflectance and high transmittance shade. So; it can be remarked as when reflectance increases and transmittance decreases low amount of radiation enters inside so solar gains and cooling load is found lower than the others. (The lighting load is all same in all types as all are controlled with daylight).

Table 5.17: Comparison of shades.

Type	Description	Solar Gains from windows kWh/m ²	General Lighting kWh/m ²	Sensible Heating kWh/m ²	Sensible Cooling kWh/m ²
SH_1	Type: High reflectance- low transmittance shade	12,72	18,67	37,59	31,01
	Position: Outside				
	Control type: Daylight				
			Total: 87,27 kWh/m ²		
SH_2	Type: Low reflectance- high transmittance shade	45,41	18,67	28,27	42,08
	Position: Outside				
	Control type: Daylight				
			Total: 89,02 kWh/m ²		
SH_3	Type: Low reflectance- low transmittance shade	22,45	18,67	34,58	34,28
	Position: Outside				
	Control type: Daylight				
			Total: 87,53 kWh/m ²		
SH_4	Type: Low reflectance- medium transmittance shade	30,26	18,67	32,21	36,67
	Position: Outside				
	Control type: Daylight				
			Total: 87,55 kWh/m ²		
SH_5	Type: Medium reflectance- low transmittance shade	22,47	18,67	34,61	34,28
	Position: Outside				
	Control type: Daylight				
			Total: 87,56 kWh/m ²		
SH_6	Type: Low reflectance- medium transmittance shade	31,41	18,67	31,90	37,06
	Position: Outside				
	Control type: Daylight				
			Total: 87,63 kWh/m ²		

This comparison can also be seen in Figure 5.39. (Ql: lighting load, Qh: heating load, Qc: cooling load and Qtotal: sum of lighting, heating and cooling loads). Total load is placed in top of all columns. Total load of SH_1 is 4,17% lower than base case.

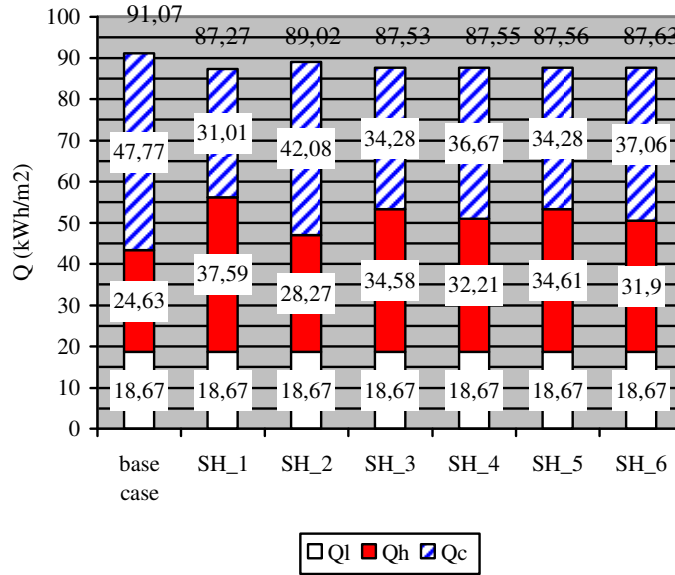


Figure 5.39: Comparison of shades.

Shade rolls

The properties of window shade materials can be specified. Shade rolls are of translucent materials. Reflectance and emissivity properties are assumed to be the same on both sides of the shade. Shades are considered to be perfect diffusers (all transmitted and reflected radiation is hemispherically-diffuse) with transmittance and reflectance independent of angle of incidence. When in place, the shade is assumed to cover all of the glazed part of the window, including dividers; it does not cover any of the window frame, if present. The plane of the shade is assumed to be parallel to the glazing. Transmittance and reflectance values for drapery material varies with different colour and openness of weave [72].

There are four types of shade rolls in the program;

1. Shade roll-light opaque
2. Shade roll-light translucent
3. Shade roll-medium opaque
4. Shade roll-medium translucent.

Seven shade rolls are examined for the SW façade. In the following simulations, these types are mainly compared with outside and daylight controlled situation because other control types are not efficient as daylight control.

SR_3 (solar control type) better than SR_2 (Always On) but worse than SR_4 (daylight controlled). Although SR_1 and SR_5 has lowest cooling demand with 34,16 kWh/m², SR_7 (medium translucent shade roll) has the lowest total load of all as 87,37 kWh/m² because its heating load is smaller. SR_2, SR_3 and SR_6 have higher total loads than the base case.

In Table 5.18 the annual results for shade rolls for Third floor, Zone_2 are given. This can also be seen in Figure 5.40; (Ql: lighting load, Qh: heating load, Qc: cooling load and Qtotal: sum of lighting, heating and cooling loads). Total load is placed in top of all columns. Total load of best shade rolls; SR_7 is 4,06% lower than base case.

Table 5.18: Comparison of shade rolls.

Type	Description	Solar Gains from windows kWh/m ²	General Lighting kWh/m ²	Sensible Heating kWh/m ²	Sensible Cooling kWh/m ²
SR_1	Type: Shade Roll- light opaque	21,97	18,67	34,77	34,16
	Position: Outside				
	Control type: Daylight				
Total: 87,60 kWh/m ²					
SR_2	Type: Shade Roll- light transclouscent	26,52	29,32	28,18	42,13
	Position: Outside				
	Control type: Always On				
Total: 99,63 kWh/m ²					
SR_3	Type : Shade Roll- light translucent	29,65	22,14	30,89	39,53
	Position: Outside				
	Control type: Solar				
Solar setpoint (W/m ²): 120					
Total: 92,56 kWh/m ²					
SR_4	Type: Shade Roll- light transclouscent	31,20	18,67	31,95	36,99
	Position: Outside				
	Control type: Daylight				
Total: 87,61 kWh/m ²					
SR_5	Type: Shade Roll- Medium opaque	21,97	18,67	34,79	34,16
	Position: Outside				
	Control type: Daylight				
Total: 87,62 kWh/m ²					
SR_6	Type: Shade Roll- Medium translucent	23,00	24,97	31,54	39,47
	Position: Outside				
	Control type: Solar				
Solar setpoint (W/m ²): 120					
Total: 95,98 kWh/m ²					
SR_7	Type: Shade Roll- Medium transclouscent	26,28	18,67	33,34	35,36
	Position: Outside				
	Control type: Daylight				
Total: 87,37 kWh/m ²					

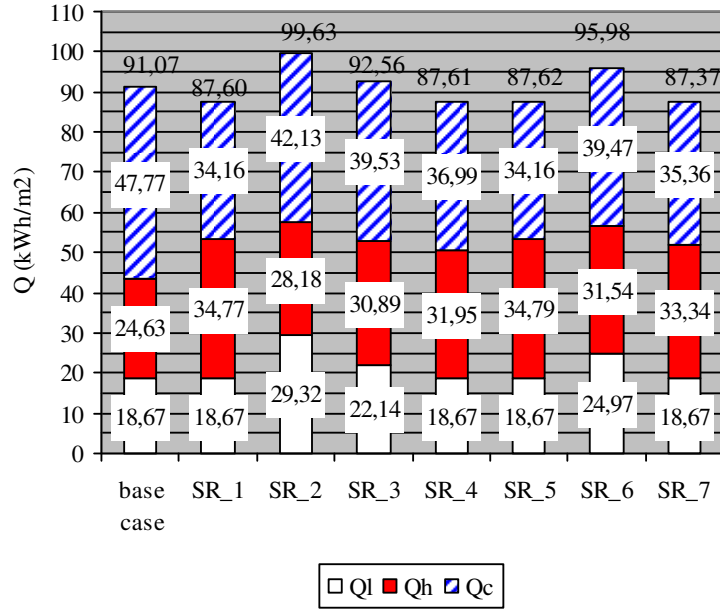


Figure 5.40: Comparison of shade rolls.

Venetian blinds

Venetian blinds are slat-type shading devices that have a strong angular dependence of transmission, absorption and reflection [72]. There are two types of Venetian blinds in the program;

1. Venetian blinds-light (modelled as diffusing)
2. Venetian blinds-medium (modelled as diffusing)

Five types of Venetian blinds are simulated for the SW façade. When the blind is placed inside, the results show that it is not as efficient as it is outside. Also when control type is chosen as Always on; lighting and cooling demand increases which effects total load.

When light and medium Venetian blinds are compared (both placed outside and controlled with daylight), total load of VB_5 (medium) is lower. Both lighting demand are the same, so this difference of total load originates from cooling load difference. Cooling load of VB_5 is lower than VB_4. Also, VB_1 and VB_3 increase the total load when compared with base case; so they are eliminated.

In Table 5.19 the annual results for Venetian blinds for Third floor, Zone_2 are given. This can also be seen in Figure 5.41; (Ql: lighting load, Qh: heating load, Qc:

cooling load and Q_{total} : sum of lighting, heating and cooling loads). Total load is placed in top of all columns. VB_5 has the lowest total load with 88,34 kWh/m² which is 3,00% lower than base case total load.

Table 5.19: Comparison of Venetian blinds.

Type	Description	Solar Gains from windows kWh/m ²	General Lighting kWh/m ²	Sensible Heating kWh/m ²	Sensible Cooling kWh/m ²
VB_1	Venetian Blinds-light (modelled as diffusing)	41,41	24,36	24,89	49,58
	Position: Inside				
	Control Type: Always On				
VB_2	Venetian Blinds-light (modelled as diffusing)	43,15	18,67	27,29	43,52
	Position: Inside				
	Control Type: Daylight				
VB_3	Venetian Blinds-light (modelled as diffusing)	41,42	24,42	25,83	45,09
	Position: Outside				
	Control Type: Always On				
VB_4	Venetian Blinds-light (modelled as diffusing)	43,08	18,67	28,83	41,08
	Position: Outside				
	Control Type: Daylight				
VB_5	Venetian Blinds-medium (modelled as diffusing)	39,59	18,67	29,74	39,93
	Position: Outside				
	Control Type: Daylight				

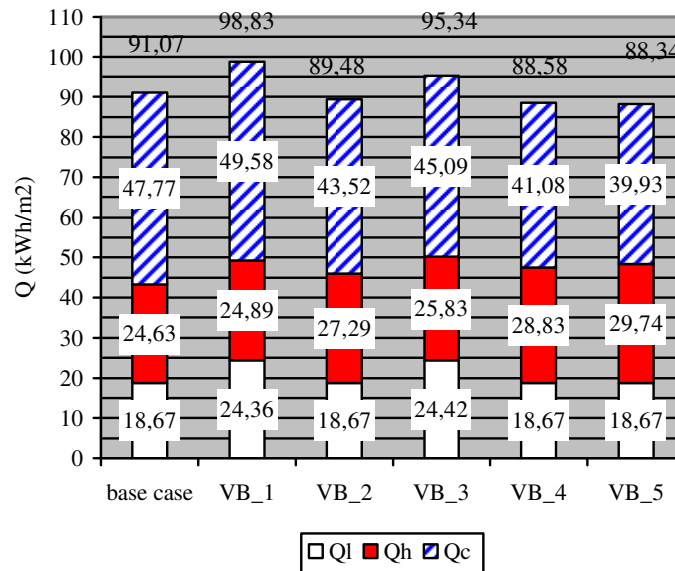


Figure 5.41: Comparison of Venetian blinds.

5.5 Comparing the Efficiencies of Shading Devices

In Table 5.20; the most efficient device from each shading device type are compared with each other. It is the comparison of loads of each shading device for SW façade. To be an alternative, total load of a shading device should be smaller than the base case (91 kWh/m²). Present case seems to be a good choice with 88,14 kWh/m². But, it is observed that overhang O_11 and shade SH_1 have lowest total energy loads of 87,27 kWh/m² and 4,17% decrease is achieved in total load.

Table 5.20: Comparison of all types of shading devices.

Case Type	Description	Solar Gains from windows kWh/m ²	General Lighting kWh/m ²	Sensible Heating kWh/m ²	Sensible Cooling kWh/m ²
no	Base case (no shading)	60,36	18,67	24,63	47,77
			Total: 91,07 kWh/m²		-
present	Present case	39,52	21,72	26,86	39,56
			Total: 88,14 kWh/m²	(-3,20% in Qtotal)	
O_11	Overhang	30,88	21,09	30,00	36,18
			Total: 87,27 kWh/m²	(-4,17% in Qtotal)	
SF_4	Sidefin and overhang	34,40	22,23	27,69	37,67
			Total: 87,59 kWh/m²	(-3,80% in Qtotal)	
L_6	Louvres	48,88	18,90	26,80	42,96
			Total: 88,66 kWh/m²	(-2,64% in Qtotal)	
SB_2 SB_7 SB_8 SB_9	Slatted blinds	38,95	18,67	30,49	40,27
			Total: 89,43 kWh/m²	(-1,80% in Qtotal)	
SH_1	Shade	12,72	18,67	37,59	31,01
			Total: 87,27 kWh/m²	(-4,17% in Qtotal)	
SR_7	Shade Roll	26,28	18,67	33,34	35,36
			Total: 87,37 kWh/m²	(-4,06% in Qtotal)	
VB_5	Venetian blinds	39,59	18,67	29,74	39,93
			Total: 88,34 kWh/m²	(-3,00% in Qtotal)	

Figure 5.42 is the cooling load and solar gain analysis and Figure 5.43 is the total load and solar gain analysis for different shading devices. Left axis refers Q values shown by columns and right axis refers solar gain for each shading device shown by line. (Qc: cooling load and Qtotal: total load).

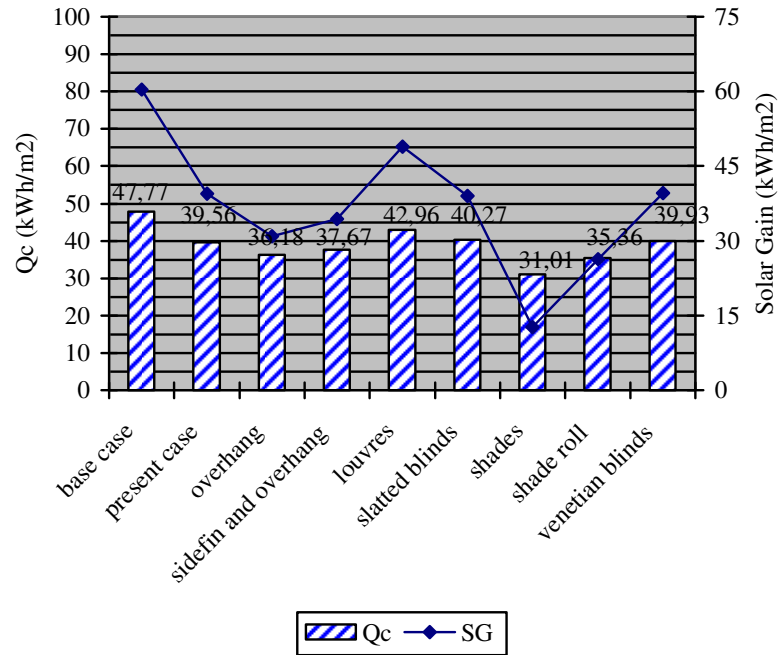


Figure 5.42: Cooling load comparison of all shading devices.

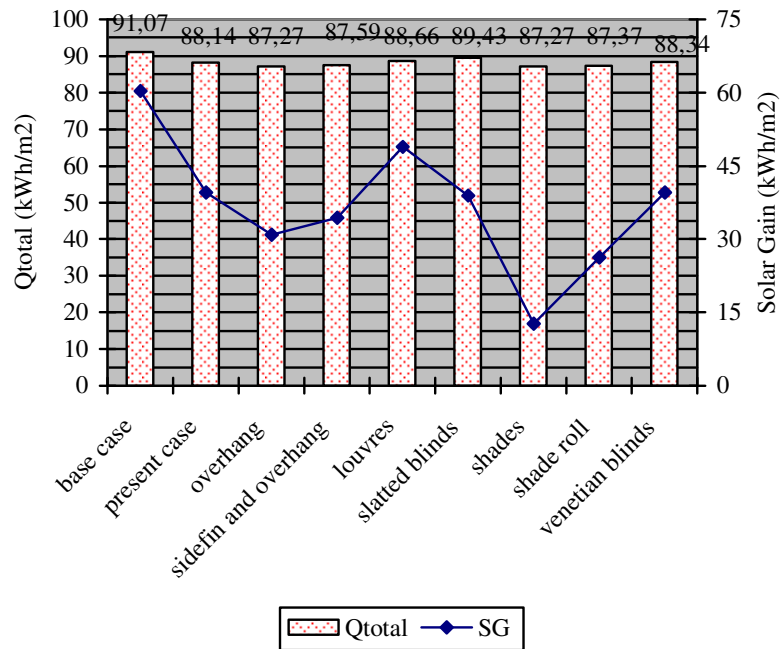


Figure 5.43: Total load comparison of all shading devices.

The values at top of the columns refer cooling load in Figure 5.42, they refer total load in Figure 5.43. According to the Figure 5.42, lowest total load can be achieved

with overhangs and shades. According to the figure, lowest cooling load can be achieved with shades.

5.6 Examining the Building Energy in Different Location

To observe the efficiency of shading devices in a different climate, same building is also simulated in Turkey, Antalya conditions. This shows the impact of external conditions on building energy use.

5.6.1 Local climate of Antalya

Antalya is located at 36.89 latitude and 30.71 longitude; in Western Asia sub-region and Southern-Mediterranean climate zone [76]. Location of Antalya is shown at Figure 5.44.



Figure 5.44: Location of Antalya [66].

Figure 5.45 presents the long term monthly average solar energy and surface meteorology of Antalya.

Variable	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Insolation, kWh/m ² /day	2.05	2.78	3.92	4.96	6.10	7.12	7.25	6.51	5.24	3.64	2.41	1.75
Clearness, 0 - 1	0.44	0.46	0.49	0.51	0.55	0.62	0.65	0.64	0.61	0.54	0.48	0.41
Temperature, °C	2.14	2.66	6.08	11.61	17.01	21.46	24.95	24.42	20.58	14.75	8.10	3.57
Wind speed, m/s	5.61	6.76	6.10	5.28	4.57	4.78	4.91	4.64	4.58	5.80	5.19	5.44
Precipitation, mm	216	156	101	46	29	9	3	5	11	73	130	246
Wet days, d	12.4	11.5	9.6	7.3	5.9	3.5	5.5	5.6	3.8	6.3	7.7	12.

Figure 5.45: Antalya - Solar energy and surface meteorology [76].

5.6.2 Comparing climate conditions of Barcelona and Antalya

Insolation degree, average temperature and wind should be known to make a reasonable comparison of two locations.

5.6.2.1 Insolation degree

The most important comparison topic is insolation value. In cooling period, Antalya has higher average insolation. It is one of the hottest cities in Turkey. Average daily insolation comparison of Barcelona and Antalya is given in Figure 5.46.

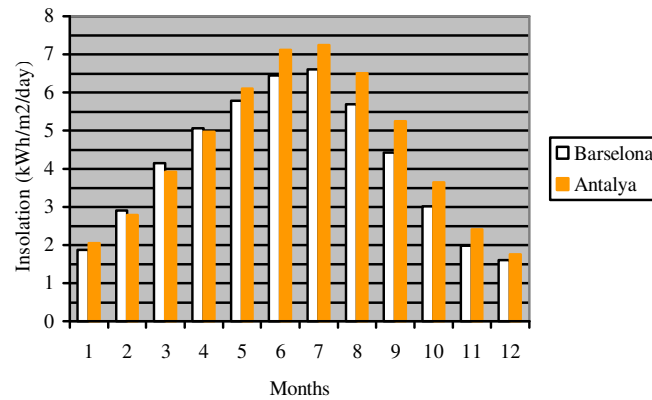


Figure 5.46: Average daily insulations of Barcelona and Antalya [63,76].

5.6.2.2 Average temperature

Antalya summertime average temperatures are higher than Barcelona. The city center is warmer than its environment. Average temperature comparison of Barcelona and Antalya are given in Figure 5.47.

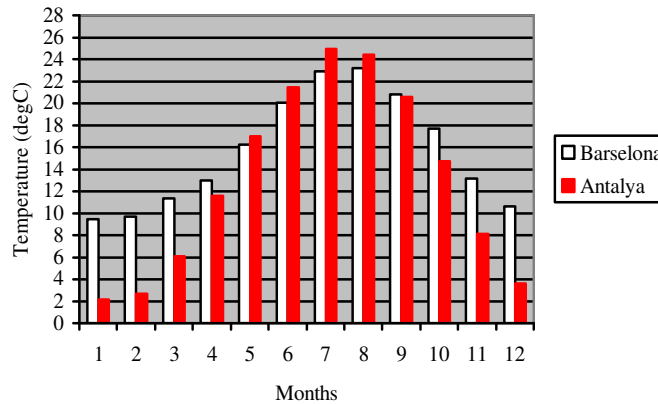


Figure 5.47: Average temperatures of Barcelona and Antalya [63,76].

5.6.2.3. Wind

Average wind speeds are higher in Antalya than in Barcelona. Average wind speed comparison of Barcelona and Antalya is given in Figure 5.48.

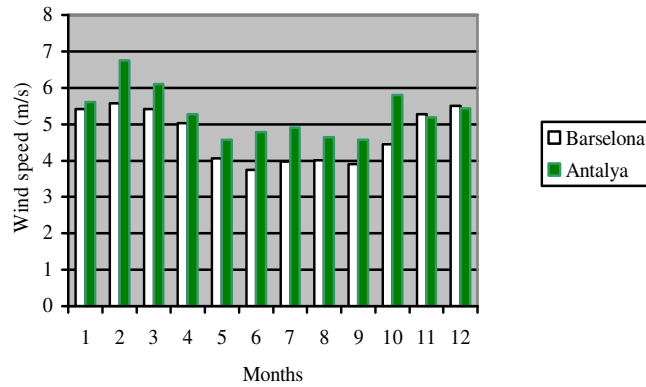


Figure 5.48: Average wind speeds of Barcelona and Antalya [63,76].

Same building under Antalya conditions would give a different energy response. The effect of shading devices on energy use would be more obvious. Table 5.21 is the building annual load distribution for base case and present case in Antalya conditions.

Table 5.21: Comparison of base case with present case in Antalya conditions.

Case Type	Description	Solar Gains from windows kWh/m ²	General Lighting kWh/m ²	Sensible Heating kWh/m ²	Sensible Cooling kWh/m ²
no	Base case (no shading)	46,59	30,13	17,73	96,67
			Total: 144,53 kWh/m ²		
present	Present case	42,05	30,49	18,27	93,46
			Total: 142,22 kWh/m ²		

Figure 5.49 shows the building annual total load comparison of two cities. Q_{total} is the sum of lighting, heating and cooling loads. Present shading makes a 0,58% decrease of total load in Barcelona when compared with base case, but it makes a 1,59% decrease of total load in Antalya.

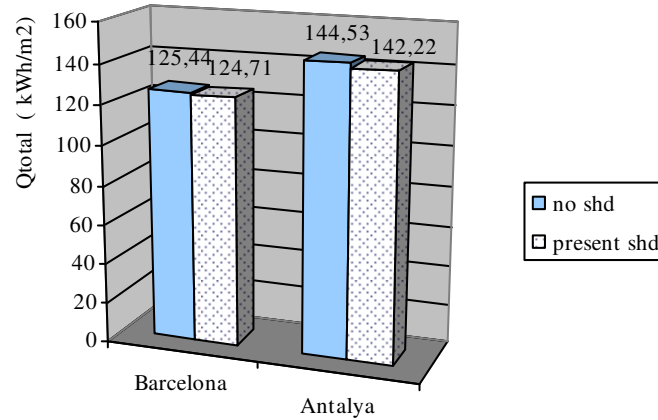


Figure 5.49: Comparison of base case and present case in Barcelona and Antalya conditions.

Also two cases (base case and present case) of building are examined by assuming with the glazing ratio of 60%. The results of the simulation are presented comparison with present glazing ratio of 30% in Table 5.22; (Ql: lighting load, Qh: heating load, Qc: cooling load, Qtotal is the sum of lighting, heating and cooling loads).

Table 5.22: Examination of annual loads with different glazing ratios in Antalya.

Annual Loads	WWR	no facade shading	present shading
Ql (kWh/m2)	30%	30,13	30,49
	60%	29,92	29,95
Qh (kWh/m2)	30%	17,73	18,27
	60%	15,79	16,76
Qc (kWh/m2)	30%	96,67	93,46
	60%	109,57	101,04
Qtotal (kWh/m2)	30%	144,53	142,22
	60%	184,99	143,78

Also this comparison is presented more obviously in Figure 5.50. The figure shows Qtotal differences between window to wall ratio of 30% and 60%. If glazing exceeds, than role of shading on energy savings becomes more important. In this case with present shading Qtotal decreases by 1,59% if WWR is 30%; however Qtotal decreases by 22,27% if WWR is 60%.

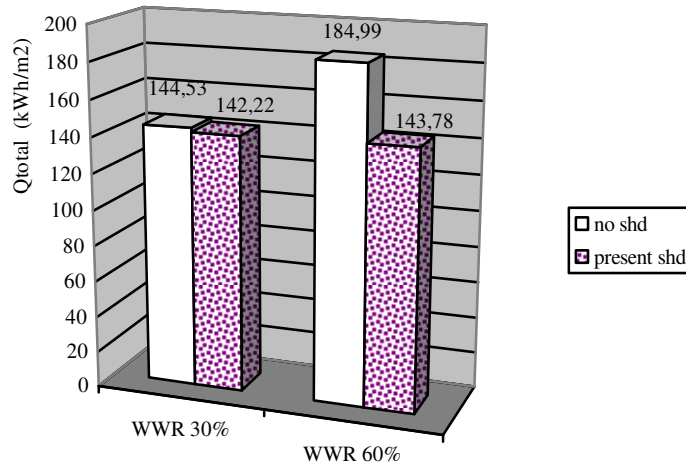


Figure 5.50: Energy comparison of base case and present case with different glazing ratios in Antalya.

5.7 Analysis of Simulation Results

In this section, the case study building is simulated in DesignBuilder simulation program and its energy behaviour is determined. The results showed that only one façade of building needs to be shaded. Therefore, in following parts of the section several shading device types having different features (materials, dimension, distance from glazing...etc.) are examined in Southwest façade of building.

Making comparisons between the best of each shading device type the most efficient shading device type is found as 1,5m overhang or a movable shade which cause a 4,17% decrease in total load.

One of the outcomes from this section is the impact of atrium shading. The building without atrium shading is also simulated and compared with present (shaded) case. When the atrium is shaded; lighting load increases by 4,8%, heating load increases by 4,5%, cooling load decreases by 6,8%. This makes an 0,5% contribution in total energy savings.

All simulations in building are continued with lighting control which causes a 46,32% decrease in lighting load.

Overhangs obstruct low radiation from west with a long projection and allow diffuse radiation but louvres obstruct both direct and diffuse radiation. As compared with base case, there is 34,5% decrease in solar gains from windows when present case is

applied. There would be 48,8% decrease in solar gains if shading device type is chosen as overhang.

It is also underlined that the effect of shading on energy is not very clear in this building having small windows; but if the building had more glazing ratio, the effect of shading would be more obvious. With 30% WWR, Q_{total} decreases by 0,58% when present shading is applied but with 60% WWR, Q_{total} decreases by 2,97% when present shading is applied as compared to base case.

Changing the site also showed that how the external conditions effect the building. Same building simulated in Antalya conditions had a higher energy demand and savings with shading devices were more clear. Present shading makes a 0,58% decrease of total load in Barcelona when compared with base case, but it makes a 1,59% decrease of total load in Antalya. Moreover; if glazing exceeds in Antalya, (if WWR is 60% instead of 30%); then Q_{total} decreases to 22,27% with present shading when compared with base case. The simulation results confirmed that shading it is more essential in this climate.

6. CONCLUSION

With climate change, global air temperatures has a tendency of increase. In Europe, Mediterranean basin and surrounding countries will be affected most from climate change impacts. The predicted effects of climate change scenario present a number of primary challenges for buildings. Future heating loads will decrease and the cooling loads will increase.

Buildings are responsible for nearly half share of the total energy use in the world, a little less in Europe. Energy use of buildings vary with environmental conditions, building's thermophysical properties, and internal loads. As building envelope is the barrier between inside and outside conditions and regulator of the energy flows, façade design is one of the crucial determiners of building energy use. So; building façade design is a significant subject.

The intelligence of a facade is not necessarily determined by the complexity of its control systems or materials, but also by the ability of the facade to be compatible with its environment and use natural energy sources and doing this with minimum need of technical equipment.

If during design period, façade is designed with only considering the building functions and site data (direction, solar position, etc.) is ignored, subsequently the user requirements can only be regulated by methods which may not correspond the needs or/and thermal comfort may be provided only with mechanical cooling systems. Because of many reasons, dependence on mechanical cooling should be decreased where possible and environmental friendly low energy techniques should be preferred. Shading design should carefully considered especially in hot and temperate regions and where cooling season is long and cooling loads are high.

Shading can be guaranteed either with simple methods like a part of the building element (structural shading) or by integration of comprehensive appliances to the façade (shading devices).

Fixed shading devices decrease cooling demand in summer, on the other hand limit passive solar gains in heating period and obstruct sunlight even when the solar radiation is low; so heating and lighting demand may increase. So; it can be stated that movable devices are more successful as they are adaptable to changes. Wind loads in high-rise buildings shouldn't be omitted when designing external shading devices. Also fixed overhangs face snow load.

Because they are placed in front of the glazing, louvres obstruct diffuse radiation too. So they increase lighting and heating demand, also restrict view. Also; when the blade-window distance decreases, it partially blocks air movements near the device, so cooling demand increases. Lightshelves; if not regularly cleaned may not fulfil their task.

Weather has a dynamic nature, movable devices respond better to it. Movable devices offer significantly higher performance for east and west orientations due to variable low sun angles but durability, maintenance and operation factors should be considered. The shading control system is an important issue; otherwise it may give users feeling of discomfort or adaptation problems or be distracting. An optimum shading control system would be daylight linked, simple and user integrated. Integration allows the user to make a decision between, solar control, glare protection and view.

For ensuring both thermal and lighting comfort; an effective shading combination, including fixed exterior devices to manage solar heat gain, and operable interior systems to manage daylighting can be used together.

Especially in facility buildings, installation, operation and maintenance costs of movable devices are a disadvantage in determination period of device selection. For economical reasons fixed devices can be more advantageous in service buildings like the case study building, and operable facades are more common in commercial buildings.

This work is an approach to solar control systems over a case study. The office type building has fixed shading devices and PV panels on the façade, also atrium shading and it is located in Barcelona-in temperate climate zone.

Numerical simulations were performed to find appropriate façade shading approach. The results of several shading devices are given with comparisons. The results of

several shading devices are compared with the present shading. Then, same building is simulated at a different location; in Antalya to observe the efficiency of shading devices in a different climate. This showed the impact of external conditions on building energy use.

When projection of overhangs are increased, it blocks more direct radiation but penetrates diffuse radiation in Southwest direction where the sun is not high in the sky. So; overhang with 1,5m projection is found as the best overhang type. Also; simulation of different overhang materials didn't make big difference in total loads. If 0,8m projection is preferred instead of 0,5m projection (present case) for sidefin and overhangs, there would be 3,8% decrease instead of 3,2% decrease in total load when compared with base case.

All shading device types made approximately 3-4% decrease in building total load besides its contribution to thermal and lighting comfort.

Solar load control is a main topic of architecture, but is often not considered during the early design phase of the building. External shading devices, dominate the façade appearance of the buildings with large glazing areas in hot climates or hot periods of the year. To reach a certain level of shading, transparency of glazing may be sacrificed over several months of the year.

Especially in temperate climates, different seasons and temperature fluctuations are observed year round. If heating load is also high then it is not logic to neglect solar gains. So; there must be a good balance between passive solar gains and solar control. Shading design is a complicated subject as it is the combination of many factors. Otherwise just avoiding from overheating is not a complex matter.

Solar control should be considered not only by designers in the initial stages of design but also with a team comprising specialists in this field. First approaches can be made in the light of experiences, but for certain decisionmaking and dimensioning, building energy calculations are essential. Thus, it is necessary to use simulation programs. Design process requires calculations, several simulations, study and time. It shouldn't be delayed to the end of design. Because of many variables mentioned in previous chapters, a unique solution is necessary for each case.

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APPENDICES

APPENDIX A: Architectural plans of Primary Health Care Building

APPENDIX B: Lighting plans of Primary Health Care Building

APPENDIX B

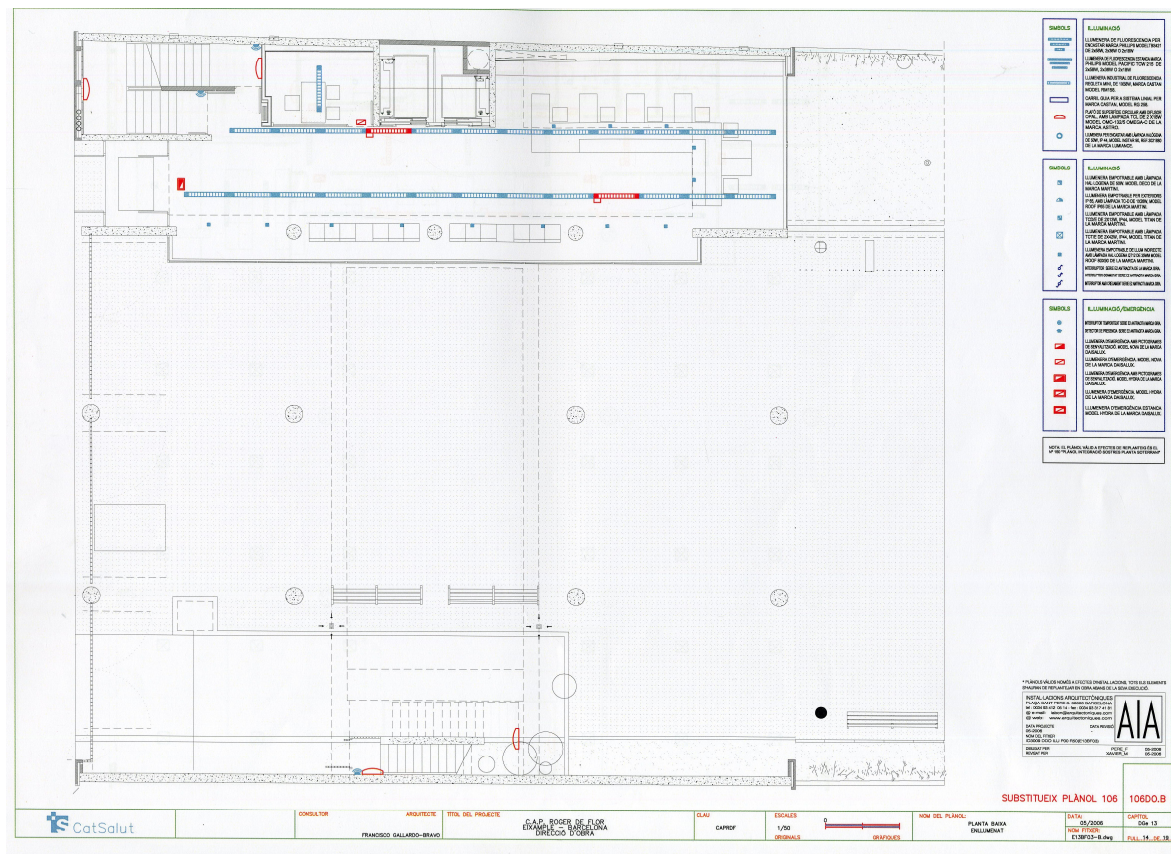


Figure B.1: Lighting plan of entrance floor.

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