THE EFFECT OF SUN SPACES ON TEMPERATURE PATTERNS WITHIN BUILDINGS: TWO CASE STUDIES ON THE METU CAMPUS

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ABSTRACT

THE EFFECT OF SUN SPACES ON TEMPERATURE PATTERNS WITHIN BUILDINGS: TWO CASE STUDIES ON THE METU CAMPUS

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The aim of this study was to investigate the passive and active parameters affecting energy efficiency of two office buildings with sun spaces, namely the MATPUM Building and the Solar Building on the Middle East Technical University (METU) Campus, Ankara and the effect of sun spaces on temperature patterns within mentioned buildings. Both buildings were oriented in the same direction, namely south. However, the location and the type of the sunspaces differed from each other. The sun space in the MATPUM Building is an atrium which has southerly glazed façade. On the other hand, the sun space in the Solar Building is an enclosed conservatory which has southerly glazed façades and roof.

The effect of sun spaces on temperature patterns within case study buildings was determined by collecting internal temperature and humidity data from different locations within the buildings and external temperature and humidity data on certain days of the week from May to August and October and November. Data loggers were used to collect these data. The collected data was then compared for the two buildings and also for the different months. In conclusion, more heat gain resulting in temperature increase inside the buildings was obtained in conservatories when compared to the atria which have glazed façade instead of glazed roof. This was also proved by the analysis of variance method which was used for the comparison of temperature data of two buildings.

Keywords: Energy efficiency, Sunspace, Passive and Active Parameters, Atria and Conservatories, Thermal Mass, Passive Heating and Cooling,

ÖZ

BİNALARIN İÇİNDEKI SICAKLIK DEĞİŞİMLERİNDE GÜNEŞ MEKANLARININ ETKISI: ODTÜ KAMPÜSÜ'NDE İKİ ÇALIŞMA BİNASI

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Bu çalışmanın amacı, Ankara'da Orta Doğu Teknik Üniversitesi (ODTÜ) Kampüsü içerisinde yer alan iki ofis binası, MATPUM Binası ve Güneş Binası'na ait güneş mekanlarındaki enerji verimliliğini etkileyen aktif ve pasif parametreleri ve bahsedilen bu binalardaki sıcaklık değişimlerinde güneş mekanlarının etkisini incelemektir. Her iki bina da aynı yöne (güney) doğru konumlanmışlardır. Fakat güneş mekanlarının konumları ve tipleri birbirinden farklıdır. MATPUM Binası'na ait güneş mekanı, güneye bakan camlı cephesi olan atriyum tiptir. Öte yandan, Güneş Binası'na ait güneş mekanı, güneye bakan cepheleri ve çatısı camlı olan kapalı kış bahçesidir.

Seçilen çalışma binaları içinde güneş mekanlarının sıcaklık değişimleri üzerindeki etkisi, Mayıs'tan Ağustos'a, Ekim'de ve Kasım'da belirli günlerde, bu binaların değişik yerlerinden iç mekana ait sıcaklık ve nem verileri ve dış mekana ait sıcaklık ve nem verileri toplayarak belirlenmiştir. Bu verileri toplamak için veri toplayıcılar kullanılmıştır. Toplanan verilerle binalar için ve ayrıca değişik aylar için karşılaştırma yapılmıştır. Sonuç olarak, camlı çatı yerine camlı cepheye sahip olan atriyumlarla karşılaştırıldığında, kış bahçelerinde iç mekanda sıcaklık artışına sebep olan ısı artışı daha fazla elde edilmektedir. Bu durum iki binaya ait sıcaklık verilerinin karşılaştırılması için kullanılan değişkenler analizi metodu yardımıyla desteklenmiştir.

Anahtar Sözcükler: Enerji Verimliliği, Güneş Mekanları, Aktif ve Pasif Parametreler, Atriyumlar ve Kış bahçeleri, Pasif Isıtma ve Soğutma

To my family

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ABBREVIATIONS

A/V	Area to building volume
AnoVa	Analysis of variance
CFC	Clorofluorocarbon
DC	Data collector
LP	Lime pozzolana
MATPUM	Mimari Araştırma, Tasarım, Planlama ve Uygulama Merkezi
METU	Middle East Technical University
N	North
ODTÜ	Orta Doğu Teknik Üniversitesi
RH	Relative humidity
SMB	Stabilized mud blocks
TSMS	Turkish State Meteorological Services
U-value	Thermal transmittance coefficient
UV	Ultraviolet
ZODP	Zero ozone depletion potential

CHAPTER 1

INTRODUCTION

In this chapter are presented the argument and primary objectives of the study, together with a survey of relevant literature and a brief overview of the general methodology followed in its conduct. It concludes with a disposition of subject matter that follows in the remaining chapters.

1.1 Argument

The idea of creating energy efficient architecture was born with architecture itself. People create their habitats keeping in mind the climatic conditions so as to obtain good quality environments. Since energy resources have diminished drastically, the building design has also changed. Quality has become more important in terms of energy efficiency and efforts are now being focused on designing buildings with low energy loads.

The energy efficient model of today involves benefits for both the environment and for humankind. The new model involves optimizing the performance of each of the building's components and systems, both individually and in interaction with other energy-consuming systems. Particularly, building systems that integrates with the energy efficiency can provide excellent returns on the initial investment for reducing energy loads. As a result, if the energy consumption of buildings is investigated during the design period, it is possible to provide greater energy savings during the operational one. On the other hand, there are some factors affecting energy efficiency in buildings that are related to the building itself, namely; macroclimate, urban planning, construction materials, form, orientation, insulation, ventilation, infiltration and envelope properties, which include walls, floors and roofs. Once adequate importance is given to these factors, huge energy savings can be obtained.

The aim of a building is chiefly to satisfy the thermal comfort conditions for their healthy and productive environments. Since energy needs increase due to thermal comfort requirements, a significant amount of energy is consumed for both heating and cooling in buildings. However, the need for thermal comfort of the occupants should be fulfilled while reducing the consumption of energy by taking the right precautions. To do this, it is necessary that the effects of the building parameters on energy efficiency should be considered. The most advantageous combination of these parameters can reduce the energy loads in a building.

Besides those parameters, one of the strategies for reducing the heating energy demand is to employ the green house effect which is created by adding glazed spaces on the southern façades of buildings in the northern hemisphere. The heat generated by incident sun rays within a glazed space can be used to heat adjoining spaces.

1.2 Objectives

The objective of this study was to evaluate internal temperatures of sunspaces as well as heat gains in adjoining spaces of a building. While studying the effect of sun spaces on temperature patterns, concurrently the contributions of different types of sun spaces were investigated.

The buildings located on the METU Campus, MATPUM Building and Solar Building, were chosen for the case studies. Both these buildings have sunspaces on their southern façades; hence the objectives of the study were to understand how the sun space contributed to raising in temperature values within there and adjoining space:

- By collecting humidity and temperature data and
- By expressing them in charts and graphs in order to show the energy performance of different locations of the case buildings.

1.3 Procedure

The study was carried out on two offices buildings, namely, the MATPUM Building and the Solar Building. These two office buildings had different architectural and structural properties. Their materials, construction systems, internal layouts, proportions and type of sunspaces also differed from each other. The former incorporates atrium which has a glazed façade and the latter incorporates conservatory which has glazed roof and façades. However, both had a same orientation, namely south.

The effect of sunspaces on temperature patterns within these buildings was assessed by collecting temperature and humidity data with the help of data loggers placed at different locations of the buildings during spring, summer and autumn seasons; that is from May to August and in October and in November.

The measurements were taken with 12 data loggers, such that one constantly measured exterior conditions; five were placed in the Solar Building and the remaining six in the MATPUM Building. Recordings were taken at 15 minute intervals. These were then downloaded, tabulated and converted into graphic form for comparison and evaluation. At the end, the temperature data of two case study buildings were compared by using analysis of variance (AnoVa) method.

1.4 Disposition

The material covered in this study is presented in five chapters:

Chapter 1 presents the argument and objectives of the study. Along with a concise outline of the general procedure which includes how the sources of data captured for the case studies is given. In conclusion, the disposition of the subject matter is presented.

A brief summary of Literature on the subject domain is presented in Chapter 2. It covers active and passive criteria affecting energy efficiency in building with sunspaces. Climate, orientation, site layout, building form, internal layout, infiltration, ventilation, insulation and building envelope as well as the sun spaces are described in the passive factors, whereas selection of appliances, shading devices and solar control are explained as active factors. Finally, the study emphasizes the impact of sun spaces on energy efficiency by describing the performance of the atria and conservatories and their heating and cooling strategies.

The case studies presented in Chapter 3, consist of two office buildings with sunspace located on the METU Campus in Ankara, were examined. Weather data was used for the analysis. The section on method explains how the study was conducted in more detail.

The presentation of results is covered in Chapter 4. The complied data are displayed in figures and tables and the outcome of the study are discussed in this chapter.

The conclusion and recommendations are presented in Chapter 5.

CHAPTER 2

LITERATURE SURVEY

In this chapter, information retrieved from public sources on energy efficiency in buildings as well as the parameters affecting energy efficiency namely, active and passive parameters are presented. Passive parameters were considered to be the climate, building form and internal layout, orientation and site layout, infiltration and ventilation, insulation, building envelope and sun spaces; and active parameters, as selection of appliances, shading devices and solar control. The impact of sunspaces on energy efficiency is presented by way of information on sun space and atria.

2.1 Energy Efficiency of Buildings

According to Oral (2000, p.95), the most crucial aim of a building is to fulfill the need or providing comfort conditions to the occupants. Since the energy requirements of a building depend on its thermal loads, in colder region, huge amount of energy needs to be consumed for heating purposes. Due to the depletion of energy sources in the world, thermal comfort needs should be satisfied while decreasing energy consumption. One way to do this would be to achieve conservation of energy by determining the most advantageous combination of the building parameters which influences the thermal comfort conditions. Bansal (2000, p.350) describes the energy efficiency in buildings regarding heating and cooling loads as follows:

> "Energy efficiency in buildings has been often used in mixed terms. The energy for heating and cooling of buildings, constituting a major part of energy consumption, has been discussed in many details, followed by lighting and ventilation etc. Reduction of heating and cooling energy requirements through improved insulation levels and advance windows is a major thrust in almost all developed countries. In United States, substantial progress has been made towards the goal of cutting the energy consumption by 33 to 50% by incorporating energy efficient building designs, retrofits, equipment and appliances "

Larsen *et al.* (2007, p.987) argue that behavioral changes in life styles and energy consumption patterns in people as well as the utilization of the energy efficient production, processing and distribution technologies minimizes the emissions of greenhouse gasses. The increase in energy efficiency and decrease in gas emissions can be provided by the improvement of the building technologies as an alternative way. In order to decrease the use of fossil fuel based energy, passive solar design, which take the advantage of the orientation, shape, materials, envelope of the building and external landscape, can be utilized in combination with the other energy efficiency strategies.

2.2 Parameters affecting energy efficiency

Chewieduk (2008, p.736) states that climate as well as location and orientation of the building and occupants' demands determines special limits and requirements on the building, its architecture, construction materials, energy systems and its surroundings. The important thing for low energy building is to focus on using renewable energy. The environment is utilized in low energy buildings to promote indoor living conditions and reduce the energy consumption. In addition to application of modern technology, equipment, materials and the structure of the building itself, local conditions may provide energy sources for the building such as solar energy.

The parameters affecting energy efficiency in the buildings can be divided into two groups, namely passive parameters and active parameters which will be explained in detail in the following sections.

2.2.1 Passive Parameters

Macroclimate, orientation, site layout and urban planning, landscaping for shading and wind shelter, building form and internal layout, materials, infiltration and ventilation, thermal insulation, building envelope and sun spaces are defined in the following sections as passive parameters.

2.2.1.1 Macroclimate

McMullan (1998, p. 314-315) claims that the climate of the Earth differs from the climate of the built environment. The former is composed of combined substantial systems regulated by the energy of the Sun. The latter includes smaller systems which are called macroclimate and microclimate. Macroclimate is the term used to define the climate of larger areas, such as a region and a country, whereas microclimate deals with the climate of surrounding and surfaces of the building.

Waterfield (2006, p.13) states that solar gains, wind speed and direction constitute the microclimatic features around a building. The negative effects of the climate on both new and existing buildings may be decreased by numerous implementations which provide increase in positive ones. Orientation is the fundamental factor that generates a microclimate in the surrounding of a building. Lewis & Goulding (1993, p.37) claim that in addition to orientation, site layout and landscaping provide improvements on microclimate of a building. Firstly, the benefits of local winds may be taken and the natural solar protection may be provided by proper site layout of the building. Geographical elements such as mountains, valleys, lakes and sea may also help to increase positive effects of the microclimate. Secondly, landscape has a significant role in creating alterations in microclimate not only for overheated conditions but also for under heated ones. Plants prevent the overheated impacts of the sun and create evaporative cooling effect which saves the energy for air conditioning every year. The comprehensive information about orientation, site layout and landscaping will be given in following sections.

Schittich (2003, p.15) maintains that local climatic conditions and location of buildings have an important effect on the energy requirement of a building as well as its structural characteristics. Air temperatures per season and time of the day, humidity, insulation, wind velocities and directions are influenced by the global climatic zones. Moreover, topography, vegetation and groundcover, location, etc establish the distinctive features of every microclimate. The energy balance of the building is mainly affected by its location on the selected site alone.

2.2.1.2 Orientation

Waterfield (2006, p.16) states that as an ideal strategy, the building should face south in order to utilize heat and light from the sun. Nevertheless, this does not mean that only facing the front entrance to the south is enough. Since getting the available solar gains is dependent on building's layout and the area and location of the glazing, therefore, higher amount of glazing should be placed on the south façade and the most frequently used areas in daytime should be located on the south side of the building. The author points out that since possibility of prevention of solar gains resulting from the surrounding buildings, trees and ground itself can be less; the most ideal site for the building is the one sloping to the south. The building should be located on the north end of the site in order to make best use of quantity of south facing garden; this will decrease the probability of being over shaded by surrounding buildings.

Gonzalo & Haberman (2006, p.34) argue that fulfillment of the need for good orientation and adequate distance between the buildings is provided easily in low density settlements which are located in rural areas or the urban edge. On the other hand, in the urban context, there are some constraints such as access and traffic volumes, noise, density, urban integration, position of adjacent dwellings, etc., which should be considered while designing the building. The authors point out that it is not entirely possible to provide most advantageous orientation of buildings toward always to sun. There is also limited solar incidence in winter, hence and in most cases; the greater density and compact building forms which are the characteristics of urban context provide reduction in energy losses.

Roaf & Hancock (1992, p.197) state that in order to provide maximum utilization of winter solar gains, buildings should be faced to the south on the Northern Hemisphere. However, at places where this is not possible, decrease in energy saving by 2-5% occurs by deviations up to 30º east or west of south and savings can be decreased up to 10% by the deviation up to 45º.

Despite the fact that southerly orientation provides highest incident solar radiation on vertical surfaces, Baker & Steemers (2000, p.23) argue that facing east will bring about a greater reduction in heating energy and less possibility of overheating compared to south or south-west oriented situations in temperate climates. Because, heating requirement of the building will be fulfilled earlier in the day by heat gains. They also claimed that inclined south-facing surfaces are subjected to more sunlight than vertical ones especially in the summer, because of the higher sun angle. This can give away undesired solar gains. These inclined glass surfaces should be preferred in cold climates or in sunspaces such as atria and conservatories with solar control devices.

2.2.1.3 Site layout and urban planning

Ratti *et al*. (2004, p.762) state that the energy performance of the buildings may be developed by studying and simulating their behavior for which many energy models and techniques have been developed recently. Nevertheless, the perception of the building designer is accepted by these models that they ignore the significance of effects taking place at urban scale by regarding the building as an individual object. Particularly, the impact of urban context on energy consumption is still understudied and controversial.

a. Topography

The temperature conditions of the site are affected by the topography. In general, lower average temperatures occur at higher locations of the site. Similarly, there are lower temperatures compared to the nearby site at the lower locations due to cold facades or cold air corridors and ground vapor. Cold-air pressure adjacent to built environment resulting in undesired heat losses can be deflected by good building arrangements and landscaping. Procedures namely burying the building, earth wall, hedges and nearby buildings can reduce the cold-air effects. The differences in ground and air temperatures and in insulation dependent on orientation characterize the slope sites. South oriented slopes are warmest, indeed, southwest ones in winter and south to southeast ones in summer. (Schittich, 2003, p.16)

b. Distances between the Buildings & Over shading

Buildings cannot make use of the favorable south orientation if nearby buildings overshadow the south windows, especially in winter. Local solar data can be used for calculating the minimum required distance between the buildings in order to deflect the over shading. (Figure 2.1) The limitations enforced on site by spacing between the buildings for least amount of overshadow shall be more than enough in order to fulfill the needs for privacy. (Roaf & Hancock, 1992, p.197)

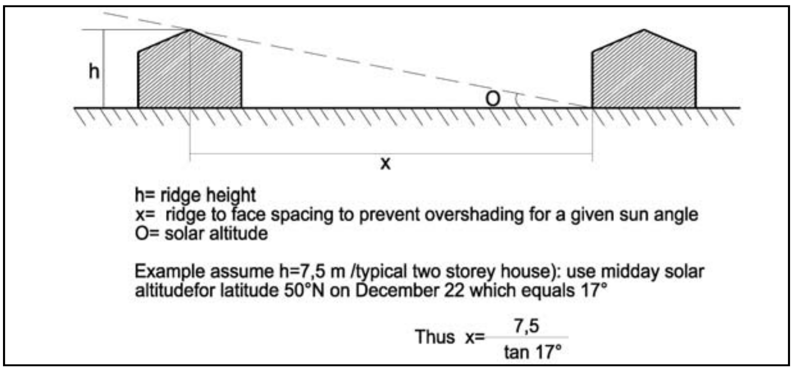


Figure 2.1 Calculations for minimum over shading
(Source: Roaf & Hancock, 1992, p.196)

Similarly, Smith (2005, p.55) states that distance between the buildings is important in order to prevent overshadow in winter times, because the need for solar heat gain becomes maximum. At sloping sites, the level of over shading is influenced by the angle of the slope. To illustrate, the distances between the rows of houses on 10º north facing slope at latitude of 50º N should be more than two times compared to the ones on 10º south facing slope at the same latitude in order to deflect over shading.

Essential distances between the buildings fundamentally affect the feasible density in an urban context. The south oriented units in rows can make use of the same solar radiation, if the required spacing between the rows can be provided especially in winter conditions. For instance, this spacing for a latitude 48º (Munich, Freiburg) is equivalent to three times the building height. According to this condition, the upper limit for sectional density in multi-storey settlements should be 1.0. It is not possible to sustain these distances if there is a need for greater densities. Moreover, the roof shape of the units has an important role in establishing these distances as it is seen in Figure 2.2. (Gonzalo & Haberman, 2006, p.34)

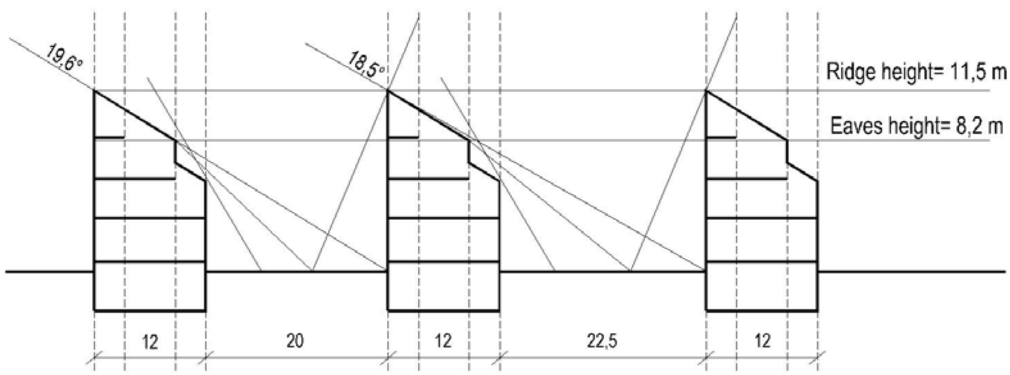


Figure 2.2 South facing rows with optimized distances for solar incidence on building and open areas (Source: Gonzalo & Haberman, 2006, p.35)

2.2.1.4 Landscaping for Shading and Wind shelter

Energy consumed in buildings can be influenced by the shelterbelt trees which also moderate the microclimate. According to Liu & Harris (2007, p.116), the effects of such trees are;

- Shading: conduction and radiation through the building can be decreased by lessening the solar radiation on exterior surfaces of the building.
- Reduction in wind speed: energy consumption of the building can be decreased and better outdoor thermal comfort can be created.
- Reduction in heat losses from the building: shelterbelt trees protect the buildings from low sky temperatures, especially at nights.

Waterfield (2006, p.14) states that shading should be beneficial in some conditions such as in more southerly latitudes and in conservatories in order to deflect overheating in summer. Deciduous trees at the south can have a double function; they provide shade on house and garden areas in summer, whereas they permit solar penetration in winter when the building requires more solar gain. Goulding *et al.* (1992, p.96) grow attention to the fact that the choice and the location of the landscape elements around the buildings is very important in order to prevent structural damage.

Liu & Harris (2007, p. 116-117) point out that there are three ways to reduce in wind velocity in order to decrease energy consumption of buildings. Firstly, the penetration of undesired air into the building can be decreased especially in windy climates. If the wind velocity is lower, the amount of wind flow through gaps in the building skin is lower too, which also reduces the heat losses by infiltration. Secondly, reduction in wind velocity will bring about less convective heat loss from facades of buildings and provides higher surface temperatures. This is mostly important for the buildings which have large glazed facades; because vegetation around the building can save energy which is lost by poorly insulated building elements, such as windows. Thirdly, the local air temperature can be varied by decreased wind speed. When sunlight falls onto the ground in daytime, its surface temperature increases, which is higher than that of air. Therefore, the heat is transmitted from ground to air. Wind velocity has an influence on rate of transmission. When the wind velocity reduces, the air temperature rises.

Schittich (2003, p.16) stresses that wind sheltered locations can be preferred in order to avoid high transmission losses due to higher wind speed reduced by hedges and dense row of trees. Cold air can be prevented and transmitted through appropriate channels by the hedges and group of trees. The author argues that site condition can be developed for building by sheltering the site against wind and active wind fortification tools. Furthermore, the area close to the building can be cooled by vegetation due to evaporation and transformation of carbon dioxide to oxygen.

2.2.1.5 Building Form and Internal Layout

According to Roaf & Hancock (1992, p.198-199), planning rules, site restrictions and requirements and requests of client determine building form. The authors state that there are three main energy considerations related to building form, namely overall surface area influencing fabric heat loss, volume influencing ventilation heat loss and plan-aspect ratio influencing the increase in solar gain. In the internal planning, it is concerned to influence the possibility for penetration of solar gain into the building and significantly affects the utilization of this gain; energy performance of buildings can be improved by variation in the building form and internal planning at little or no extra cost.

a. Building form

Thomas (2006, p.35) states that building form is determined by numerous efficiency concerns such as utilization of Sun’s energy and daylight, provision of views for inhabitants, heat loss at building skin, ventilation requirements and reduction in acoustic conditions. From the environmental point of view, Oral & Yılmaz (2002, p.383) argued that building form is a significant parameter that influences the heat loss through building skin which is determined by thermal transmission coefficient (U-value). Building form depends on shape factor which is the ratio of building length to building depth, height of the building and roof type. Building forms can have different façade areas even if they have the same volume. As a result, the most important aspect defining building form is ratio of total façade area to building volume (A/V) which determines the U-value of building envelope.

Gratia & De Herde (2002, p.477) point out that the ratio of façade area to building volume defines the issue of compactness. Since the heat losses depend on the façade area of building skin, the reduction in heat losses will be more, if the building is made more compact. (Figure 2.3) It should be noted that thermal bridges and losses are brought about from joints between structural sections which belong to non-rectangular layouts and complicated parts. The authors recommend that to avoid this loss, reduction in façade area by changing the building form is preferred instead of providing more insulation or one more layer of glazing, if it is possible. A compact shape generally results in a decrease in cost both by lessening the energy consumption and by diminishing the costs of construction.

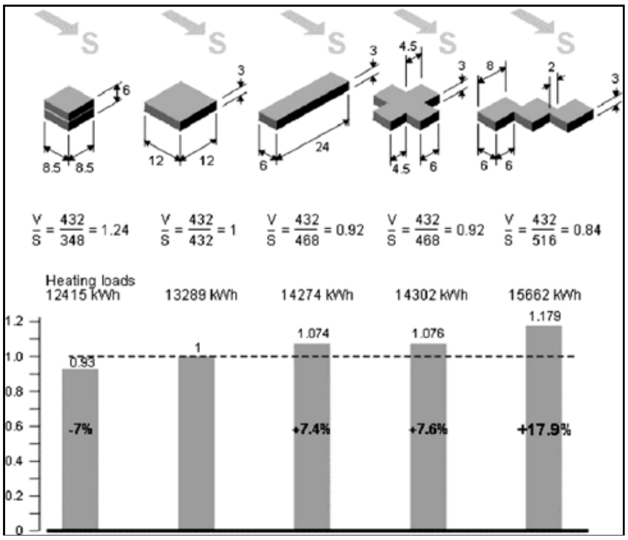


Figure 2.3 Different surface to volume ratios according to different forms (Source; Gratia & De Herde, 2002, p.478)

According to Ward (2004, p. 54-55), buildings which need greater floor area with artificial lighting and mechanical cooling will be those with deep plan forms. The author states that natural lighting and natural ventilation can reach until the distance at about 6 m depth from the window, hence the upper limit of the depth can be considered as 14 m, although the ceiling height may extend this maximum depth for natural ventilation. For instance, the building which has an 8 m high ceiling could be 40 m deep.

b. Internal planning

Waterfield (2006, p.20-21) points out that the most accepted understanding of energy efficient internal layout is to design general use areas on the south. To illustrate, a kitchen may be located on the south-east side; therefore, it will get morning sun, whereas it will not subjected to overheating due to increase in both outside and inside temperatures in the afternoon. As for the living room, it may make use of solar gain later in the day. Consequently, it can be placed on south-west part of the building, on the other hand, the buffer zones namely corridors, storages and garages which does not require special day lighting or heating similar to the living spaces can be situated on the north side of the building. Since the bedrooms are not utilized during daytime, there is no need to locate them to the south. East and south-east parts of buildings are appropriate for bedrooms, because of getting the morning sun which provides brightness in the morning and prevents dampness in the room.

Roaf & Hancock (1992, p.201) are of the opinion that there are two other significant strategies in energy efficient planning; namely, distribution of solar gain through the building and distribution of services. The former can be successful not only with open plan but also with air movement among rooms by designing the internal walls and doors carefully. Furthermore, cross ventilation can be supported by air movement for providing summer cooling. For the latter, there should be an insulated building shell which includes heating and hot water systems consisting of appliances and pipe work. Placing such appliances in the center of the building both lessens the service distribution runs and pipe standing losses and provides obtaining heat gains from the building itself. The services can be eliminated from cold attic which is important for electric cable distribution and cold water storage, by the service distribution strategy.

According to Schittich (2003, p. 18), the principle of zoning is the determining factor in designing internal layout of buildings, especially in housing; e.g. living areas face south and services in the north. While designing the other types of buildings, it is beneficial to use thermal differentiation resulting from the usage such as between work and recreation spaces, office and production areas or exhibition and storage areas. When a building has different requirements, it is helpful to separate it into zones regarding the usages of areas.

2.2.1.6 Materials

The quality standard expected by the occupants should be provided by selecting of those materials and technologies for the construction of the building which do not bring about any undesirable effect on the environment. Since the greenhouse gases such as CO_2 are given out into the atmosphere by production procedures of building materials, consciousness of environmental issues rises in building and construction sector recently (Reddy & Jagadish, 2002, p.129).

Roaf *et al*. (2001, p 38) claim that there are significant factors affecting the choice of materials considering energy efficiency namely, factors determined by the material's inherent qualities and factors affected by the way materials are incorporated into a design. For the former, non-toxic products should be preferred instead of chemically treated materials and materials including toxins. Since the durability of materials will influence the lifespan of the building, it should be considered while choosing construction materials. For the latter, choice of local building materials and minimized processing will help to avoid energy consumption. Similarly, Thomas (2006, p.64) divided criteria for selecting materials into two, namely concerns containing effect on natural environment and effect on human health.. The former comprises ecological degradation because of extraction of raw materials, pollution due to production processes, transportation impacts, and energy inputs into materials which give rise to CO_2, CFC and HCFC emissions. The latter vary from the way that materials are extracted to impacts on workers who manufacture the materials.

Thormark (2005, p.1019) states that the most essential task in sustainable building is reducing the use of energy. The other significant tasks to take into account are decrease in usage of natural resources and making best use of recycling potential. Since the embodied energy constitute an extensive part of the total energy use of the building, the choice of building materials gains importance. As the author points out that being recyclable is not enough; the form of recycling, methods for disassembly and maintenance have to be considered also. Attention must be also paid to the development of new construction regarding both materials and the design of connection details in order to promote considerable reduction of embodied energy and increase the potential for re-use. Reddy & Jagadish (2002, p.129) describe embodied energy as;

> "Embodied energy of buildings can vary over wide limits depending upon the choice of building materials and building techniques. RC frames, RC slabs, burnt clay brick masonry, concrete block masonry, tile roofs represent common conventional systems forming the main structure of buildings in India. Similar building systems can be found in many other developed and developing countries. Alternative building technologies such as stabilised mud blocks (SMB's), prefabricated roofing systems, masonry vaults, filler slab roofs, lime-pozzolana (LP) cements, etc. can be used for minimising the embodied energy of buildings."

2.2.1.7 Infiltration and Ventilation

It should be noted that there is a difference between infiltration and ventilation. Roaf & Hancock (1992, p.202) describe the former as uncontrolled air penetration through cracks and other openings in the building fabric. In contrast, the latter is explained as controlled entrance of fresh air to provide healthy environment against odors and condensation and provide cooling in summer.

a. Infiltration

According to Al-Hamoud (2004, p.254), infiltration increases the energy consumption, especially in residential buildings, due to loose construction. Moreover, it is not sufficient to provide good insulation for the building if it is not airtight. Infiltration cannot be prevented by applying the insulation on the cracks and small openings; conversely, it can only hide them. The tightness of the building construction, exterior shielding, temperature differences, wind velocity and building height have an important role on infiltration. As a result, all openings and cracks should be sealed. To illustrate, electrical sockets and light switches are preliminary sources for uncontrolled air penetration into and out of the conditioned space. The more well-sealed and tight the building is, the more energy efficient it will be and so it will need less insulation in order to accomplish the thermal comfort.

Roaf & Hancock (1992, p.203) argue that there is a strategy consisting of two parts, so as to decrease the infiltration in buildings. Considering the inner part of the insulated envelope as an air barrier constitutes the first part of this strategy. The second part includes minimization of penetrations through insulated building skin and sealing this skin against air leakage which are not prevented. According to Roaf & Hancock (1992, p.203), the strategy will include;

- Not keeping the services in loft spaces, wall cavities and ground floor cavities,
- Separating the building structure from the building envelope,
- Sealing well the leakages around the services, when they are inevitable,
- Sealing well the component of junctions,
- Identifying high performance windows and doors with good quality seals.

b. Ventilation

According to McMullan (1998, p.87), ventilation can be described as the exchange of the air with the fresh one from an internal space. This procedure has to be continuous in order to provide fresh air inside all the time. The quantity and the rate of air removal vary along with the space and person. While breathing, we produce carbon dioxide which is harmful to human health. This carbon dioxide and odors affects the comfort of the occupants. In addition to providing comfort for the occupants, the author indicates the other objectives of the ventilation below;

- "Supply of oxygen
- Removal of carbon dioxide
- Control of humidity for human comfort
- Control of air velocity for human comfort
- Removal of odours
- Removal of miero-organisms, mites, moulds, fungi
- Removal of heat
- Removal of water vapour to help prevent condensation
- Removal of particles such as smoke and dust
- Removal of organic vapours from sources such as cleaning solvents, fumiture, and building products
- Removal of combustion products from heating and cooking
- Removal of ozone gas from photocopiers and laser printers
- Removal of methane gas and decay products from ground conditions."

The latest trend in developed countries is using enough insulation in the buildings, making them air-tight and making use of the waste heat in order to decrease heating energy consumption per year. On the other hand, to reduce the cooling loads of the buildings during the summer time and transition periods, the ventilation of the building gains importance. This ventilation has been attempted to be succeeded in a natural way. (Bansal, 2000, p.350)

Baker & Steemers (2000, p.55-56) state that natural ventilation can be a result of the wind pressure or thermal buoyancy (stack effect). Both have an effect on a building in different amounts along with the existing wind strength and thermal conditions. According to the authors, the former is resulted from the wind blowing through a building. Since the momentum is changed when the air is prevented or there a decrease in its speed, pressure is occurred on the building surface. The latter is defined by Smith (2005, p. 145);

> "The stack effect or Gravity displacement is dependent on the difference in temperature between the outside and inside air and the height of the air column. There is considerable variation in the relative temperatures over the diurnal and seasonal cycle. During the summer, night-time cooling can be achieved by passing large quantities of fresh air over the structure. Night-time cooling works when the external temperature is lower than the internal one and gravity drives the cooler air down into the building. In the daytime in summer when the internal temperature has become lower than the outside temperature, it is necessary to cool the incoming air, perhaps by evaporative cooling or a heat pump. If heat is transferred from the input duct to the exhaust duct, this further assists buoyancy."

The design issues, which affect the feasibility of natural ventilation system and decided at the early design stages, are the form, orientation and depth of the building; the internal layout; assurance of flow paths for the air such as atrium spaces, stacks and windows. The depth of 6m is the threshold for a room which will be ventilated naturally. Nevertheless, this depends on the overall plan form. Since open plan spaces resist to air flows at minimum, whereas highly partitioned spaces decrease the ability of air movement, internal layout of the building should be designed as simple as possible. The main source of the natural ventilation is window. The opening type, location and size of the window affect the natural ventilation. The best type is considered as tilting windows. Ventilation is more effective if the windows are larger. Furthermore, locating the openings at both low and high levels within the building promotes the natural ventilation. (Ward, 2004, pp.67, 69,107)

Natural ventilation is inadequate individually particularly in commercial and institutional buildings. Enough air movement around the building is obtained with the help of the mechanical assistance which should not be perceived as air conditioning. Air conditioning is more complex than the mechanical ventilation. Mechanical ventilation is defined as the provision of air flow and movement by fans and supply/extract ducts. Since it has no integrated cooling system, the temperature of the supplied air is limited to the existing temperature conditions. On the contrary, a refrigeration system is utilized for cooling the in an air conditioning system. This system provides more accurate control of air temperature and humidity only within air-tight buildings (Smith, 2005, p.146).

Roaf & Hancock (1992, p.206) state that an accurately controlled ventilation rate can be obtained by full mechanical ventilation of which improvement of the air quality is the main advantage as well as the improvement of the condensation control. In addition, energy used in buildings may be reduced due to integration of heat recovery to the ventilation system. However, the benefits of the system should be assessed carefully considering the installation cost, maintenance costs and running costs of the fans.

2.2.1.8 Thermal Insulation

Al-Hamoud (2004, p.254) describes the thermal insulation as a material or combination of materials which slows down the rate of heat flow resulting from conduction, convection and radiation as a result of its high thermal resistivity. The author also states below that the way thermal insulation works;

> "Thermal insulating materials resist heat flow as a result of the countless microscopic dead air-cells, which suppress convective heat transfer. It is the air entrapped within the insulation, which provides the thermal resistance, not the insulation material. Creating small cells within thermal insulation across which the temperature difference is not large also reduces radiation effects. It causes radiation 'paths' to be broken into small distances where the long-wave infrared radiation is absorbed and/or scattered by the insulation material. However, conduction usually increases as the cell size decreases."

According to Smith (2005, p. 68-69), the main criterion for identifying the insulation material is to avoid using the materials which are hazardous to the environment such as the materials including chlorofluorocarbon (CFC); and to select the materials which has zero ozone depletion potential (ZODP). The author categorizes the insulation materials into three;

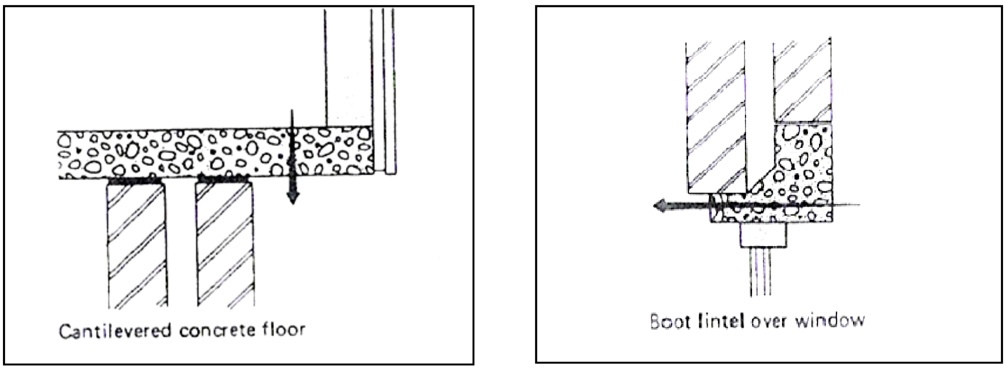
- *Inorganic/mineral:* these are the calcium and silicon based products such as glass fiber and rock wool.
- *Synthetic organic:* these are the materials obtained from the feedstock.
- *Natural/organic:* these are including lamb's wool and vegetation based materials such as hemp.

The insulation features of the building envelope chiefly specify the energy efficiency of the building. It provides two benefits both for buildings and the occupant. Firstly, the energy consumption of the buildings decreases. This also reduces the costs. Secondly, comfort conditions such as indoor air quality, thermal comfort and protection against external noise are enhanced. These benefits are promoted by the appropriately sealed; moisture protected and well insulated walls. (Uçar & Balo, 2008, p.731)

Since thermal insulation brings about decrease in heat loss from the buildings in winter time, sufficient insulation should be used at early design stage of the building as well as added existing buildings. It also lessens the heat flow into a building in summer time when the outside temperature is higher than the inside one. In other words, thermal insulation provides cooler indoor environments in the summer compared to ones in poorly insulated buildings. In large buildings, especially in office buildings, huge energy savings is obtained by reducing the cooling loads. (McMullan, 1998, p.31)

The good insulation quality of building envelope is necessary for passive utilization of the solar energy, for the reason that the captured solar radiation should be efficiently stored in the interior with the help of good quality insulation materials. The building components with a high insulating capability generate the effective insulation for the building envelope. Insulating materials and insulating components are used in the opaque façade areas as a high insulation capacity building component. Those of which used in the transparent areas are high grade glazing, transparent insulating materials and multilayered facades. While planning these components, thermal bridges have to be prevented. (Schittich, 2003, p.19)

According to Smith (2005, p. 78), thermal bridges occur when there are differences between the thermal properties of the materials which constitute the building fabric. This differentiation creates heat flow. It is possible to have condensation on the inner surfaces of thermal bridges. In case the continuity of insulation is provided, the problem is solved. Thermal bridges chiefly occur at the junction points of the structural components such as at the junction of roof and wall or wall and floor; around windows and doors, especially frames and lintels; around apertures of building services. (Figure 2.4)



(a) **(b)**

Figure 2.4 Thermal bridges **a.** At cantilevered concrete floor **b.** At boot lintel over window (Source; McMullan, 1998, p. 46)

2.2.1.9 Building envelope

Buildings generate constant comfortable and healthy indoor environments against the differential external climatic conditions with the help of energy performances of building envelopes as well as a supplementary use of energy inputs for heating and cooling. The careful design of the building envelope which can provide high thermal efficiency constitutes the characteristic of the sustainable design. Furthermore, since the thermal energy is exchanged with the external environment by the building envelope, the layers and components of the envelope should be considered while designing a building. Building is in integration with the outdoor climate conditions with the help of the building envelope. (Pulselli *et al*, 2008, p. 920-921)

Oral *et al.* (2003, p.281) define the building envelope as “the totality of (building) elements made up of components which separate the indoor environment of the building from the outdoor environment.” The authors also state that the design of the building envelope is dependent on the various factors such as environmental, technological, socio-cultural or aesthetic factors. In terms of energy aspect, in order to achieve reduction in energy consumption, the design of the building envelope is accepted as a part of the passive system which can reduce the load of active systems.

According to Oral *et al.* (2003, p.282), it is possible to design the building envelope with the help of the design parameters which aims providing comfort conditions and energy conservation. These parameters can be divided in two groups which are given below:

- Parameters associated to external environment namely, solar radiation; external temperature, humidity, wind velocity, illumination level and sound level
- Parameters associated to built environment which can be considered on the basis of settlement scale, building scale and room scale

Roberts (2008, p.4553) states that the passive way to reduce the requirements for heating and cooling is considered as a well insulated building envelope without thermal bridges. There are two significant elements for the well insulated building skin namely, high levels of insulation with lowest thermal bridges which is mentioned in the previous section and air tight construction.

The components of the building envelope may be separated into three groups namely roof, wall and fenestration such as windows and doors.

a. Roofs

Suehrcke *et al.* (2008, p.2224) argue that the heat flow from the roof through inside of building can be decreased by utilization of roof color, reflective foil and insulation. Although the use of roof insulation and reflective foil are indicated in building regulations in most countries, the selection of the appropriate roof color is not admitted as a strategy to contribute the insulation. Nevertheles, the solar absorbance of the roof affects the thermal performance of the building. About 1 kW/m^2 of solar radiation is captured by the roof surface at the clear sky conditions. At the range of 20% to 95% of solar radiation is absorbed. Hence, the color of the roof surface affects this absorbed solar radiation, for instance a black surface proposes a higher solar absorbance.

In terms of the insulation aspect, Levis & Goulding (1993, p. 80) state that the most economical surface for the thick levels of insulation is supplied by the roofs when compared to the insulation levels of the rest of the building envelope. Insulation layer is generally put on top of the ceiling or structural part of the roof. Another point is the hygrothermal problem which is seen in the flat or almost flat roofs, because they have strict solutions for snow and rain penetration such as tight cover and vapor barrier, the interstitial moisture can be trapped inside. Using an internal vapor barrier as tight as possible is obligatory.

b. Exterior Walls

Ichinose *et al*. (2008, p.1) introduce the high reflectivity materials which are applied on exterior walls and have an important effect in storing the solar radiation and, hence, increasing the energy conservation. They decrease the absorption of the heat; consequently, lessen the cooling loads of the buildings. Most of the high reflectivity paints are utilized on existing exterior surfaces. However, since the paint is subjected to environmental conditions and contamination of the particles on the surface, it starts to deteriorate and age.

Table 2.1 Solar gain factors for external walls
(Source; Pfeifer *et al.,* 2001, p.172)

ORIENTATION	LIGHT COLOR	DARK COLOR
South	0,04	0,12
East-West	0,03	0,07
North	0,02	0,06

According to the study conducted by Eskin & Türkmen (2007, p.770) to analyze the annual cooling and heating energy requirements of office buildings in different climates in Turkey, the energy requirement for cooling is interrelated to the solar absorption of the external wall surfaces. The greater energy savings can be achieved by the lower solar absorptance. The results of the study given below:

> "A 30% reduction in solar absorptance can result an 11.6% saving in annual required cooling energy in hot and humid climates (Antalya) and 10.5% saving in hot climates (Izmir), while 6% saving in cold climates like Ankara. When annual required energy has been considered, in cold climates maximum 2% saving can be achieved due to the positive effect on the heating loads, while this amount reaches 10% in Antalya since the heating period is short and required heating energy is low compared to cold and mild climates."

In the low energy buildings, the structural parts of the walls should be designed on the warm side of the insulation material, otherwise they bring about thermal bridges to be occurred in the junction points. In such cases, insulation materials can be used as a cladding material for new buildings and also as a retrofitting material for existing ones. The hard surfaced high density mineral wools are utilized as cladding which can also meet the fire and durability needs of the buildings (Lewis & Goulding, 1993, p. 80).

c. Fenestration

The openings of a building not only provide greatest opportunities but also pose the greatest risks in terms of passive solar use. A significant input is obtained in energy supply of the building and thermal comfort of the occupants with the help of the openings of the buildings. On the other hand, they cause the heat loss and overheating which reduces the indoor comfort level. According to the calculations of the EnEV, the ratio of window to wall area should not be too great in case the quality of glazing is average. If this percentage is exceeded, the quality of the glazing should be increased in order to reduce heat loss in winter (Schittich, 2003, p.20).

Ward (2004, p.58) agrees that the glazing ratio affects the design of the building facades. 30-50% glazing ratio is acceptable for the building which does not have mechanical cooling. There is an optimum design of glazing systems which balances the energy flows both in winter and summer conditions. This balanced design is dependent on orientation, location, obstructions and occupant needs. Particularly, the orientation has an important role in designing the glazing of the buildings. The solar radiation penetrates in the morning from the east facing windows which warms the space, whereas west facing windows are effective in terms of heating in the afternoon when the space is already warm because of the occupant's thermal comfort, hence this causes overheating. South facing windows let in solar radiation around midday which makes solar control easier.

Roberts (2008, p.4553) states that the windows are the poor insulators of the building envelope. While comparing to the other parts of the building envelope, they have a heat loss coefficient four to ten times higher. In the past, very small windows were used due to this higher heat loss coefficient. Nowadays, depending on the improvement of the glazing types, window areas are increased. Bansal (2000, p.350) explains these improvements in the glazing products in three basic approaches:

- Change in the chemical composition of the glazing itself hence, change in the physical characteristics of the glazing,
- Application of a coating onto the glazing such as reflective coatings and films,
- Assembly of different layers of glazing and control of the properties of spaces between layers.

Poorly insulated doors, which open to the outside or through an unheated room, give away heat loss from the building and are damaged due to the differentiations in temperatures to which two sides of the door is subjected. Since the mechanical problems occur, they no longer close appropriately. The solution for this problem is locating a windscreen in front of the external doors if there is an available space. (Schittich, 2003, p.21)

2.2.1.10 Shading

Thomas (2006, p.41) argues that fixed shading devices such as roof overhangs have disadvantages, since they prevent passive solar gain permanently. (Figure 2.5) It can be accepted to make an arrangement dependent on the direct solar gain according to the variable seasons such as blocking the sun rays in summer and letting them enter in winter. These fixed shading devices also bring about loss in daylight permanently. Apart from utilization of the architectural components, there are other systems for providing shade and solar control which will explain in section 2.2.2.2.

2.2.1.11 Sun spaces

The solar energy can be obtained directly or indirectly by heating a sunspace which can be a glazed area in front of the building facing south or with the building itself. The former is called a conservatory and the latter as atrium. These two types of the sunspaces are explained in detail in Section 2.3.

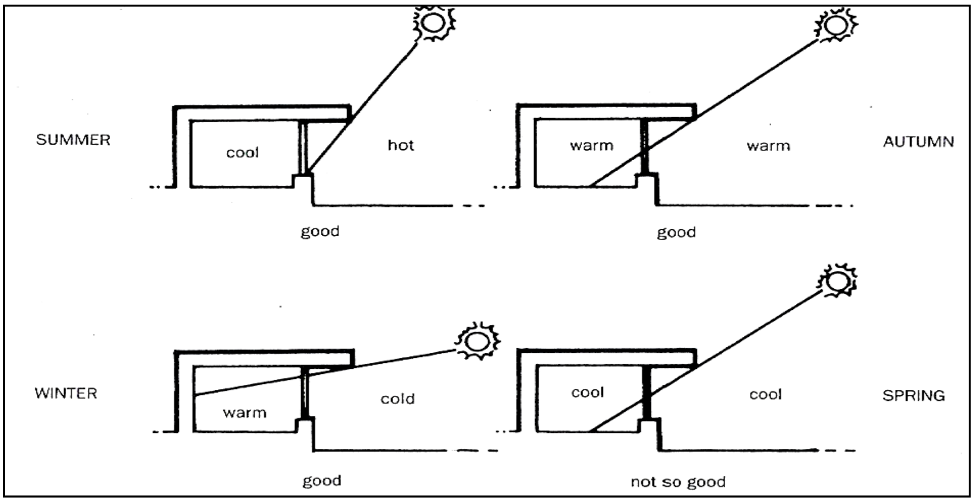


Figure 2.5 The effects of roof overhang on solar radiation in different seasons (Source; Waterfield, 2006, p. 26)

2.2.2 Active Parameters

Selection of appliances and shading devices for solar control are explained in the following sections as active parameters.

2.2.2.1 Selection of Appliances

Since the total energy of the Universe is always steady, some of the energy is lost during the conversion process in which energy is converted from one form to another. To illustrate, while converting chemical energy stored in a fuel into heat energy with the help of a boiler, hot gasses resulting from this conversion process is built up and is allowed to ascend the chimney. Another example is that around 90% of the electrical energy consumed by the traditional light bulb is lost as heat rather than the light. However, with the help of the new technologies, these disadvantages are attempted to be overcome such as utilizing the efficient forms of electric lamps and using heat pumps to making use of low temperature heat sources. (McMullan, 1998, p. 322)

Roaf & Hancock (1992, p. 216-217) state that while designing a building, lessening the energy costs for heating and hot water production is focused on more. On the other hand, costs for electricity utilized in lights and appliances are nearly same as those for heating, cooking and hot water. There is a huge potential for reducing the costs although the designers insist on not to decrease energy used in the appliances. Furthermore, by using low energy fluorescent lamps instead of tungsten lamps, the considerable savings is obtained for electrical lighting. Additionally, Ward (2004, p.129) concentrates on luminaire design which has an effect on light distribution. A great amount of light can be absorbed by the poorly designed fittings. 1 % of light losses can be reduced by the proper design of luminaires.

In terms of using more daylight to reduce the requirement for the artificial lighting, Schittich (2003, p.65) emphasizes on light directing elements which guide the daylight to reach through the deep sides of the room. Reflecting louvers or light shelves, light scattering panes, light deflecting prisms or holographic-optical elements are the examples of such light directing elements. The aim of these elements is to optimize the provision of the daylight without any increase in heat loads due to incident sun.

According to Goulding *et al.* (1992, p.84), the heating system in the buildings is composed of four parts namely, production units, distribution system, heat emitters and controls. Each part of the heating system has an important effect on energy efficiency either by nominal in full operating conditions or seasonal. The factors related to the parts of the heating system affect its performance, hence affect final energy consumption. The author explains these factors as:

- "The production unit or boiler's conversion efficiency of fuel to useful heat: This depends on design of the production unit, chimney losses and unutilized losses of the boiler to the room
- The efficiency of distribution: this relates to the length of the distribution system, the temperature of transported fluids and insulation employed to reduce pipe losses.
- The efficiency of heat emitters: this related to way heat is to be emitted (by radiation or by convection) and any possible obstructions to efficient emission.

- The efficiency of control of the distributed heat in rooms, either occupied or unoccupied."

The same arrangement is made for obtaining energy used for hot water heating as that used for space heating in well insulated houses, even if it is significantly higher particularly in super insulated buildings. Therefore, central heating system is mainly used for heating the water rather than heating the building. This situation becomes more important than before, especially for making the provision of hot water in low energy dwellings. (Roaf & Hancock, 1992, p.215)

2.2.2.2 Shading Devices and Solar Control

The main aim of the shading is to diminish the amount of radiant energy passing into the room. Since the room surfaces absorb this radiation, the heat gain to the room is also diminished. It is also important to avoid solar radiation to fall directly onto the occupants. The efficient temperature felt by the occupant increases about 6ºC with the help of this direct heat gain. Another purpose of the shading which is a fundamental part of passive building design is to reduce the glare occurring on work spaces of occupants. (Baker & Steemers, 2000, p.31-32)

It should be considered carefully to decide on the design and specification of proper shading devices at the early stages of design process. It is clearly understood from the Table 2.2 and Figure 2.6, external shading has an important effect on diminishing overheating while comparing to internal shading which is effective to lessen the glare. The solar reflecting glass is not also as efficient as external shading in preventing undesired heat although it causes decrease in solar gain up to50%. The reason for this is that 70% of the incident solar radiation is absorbed by the glass itself. Moreover, the degree of tint in the glass affects the internal light level. (Lewis & Goulding, 1993, p. 49)

Table 2.2 A percentage of external solar radiation reaching the inside dependent on the shading devices (Source; Ward, 2004, p.60)

Shading	Type of Shade	Single Glazing	Double Glazing
None	None	76	64
	Lightly heat absorbing	51	88
	Densely heat absorbing	39	25
	Coated glass	56	25
	Heat Reflecting	28	25
Internal	Dark plastic blind	63	56
	White venetian blind	48	46
	White cutton blind	41	40
	Linen blind	30	33
Mid pane	White venetian blind	-	28
External	Dark plastic blind	22	17
	Canvas roller blind	14	11
	Louvred sun breaker blades at 45°	14	11
	Dark miniature louvred blind	13	10

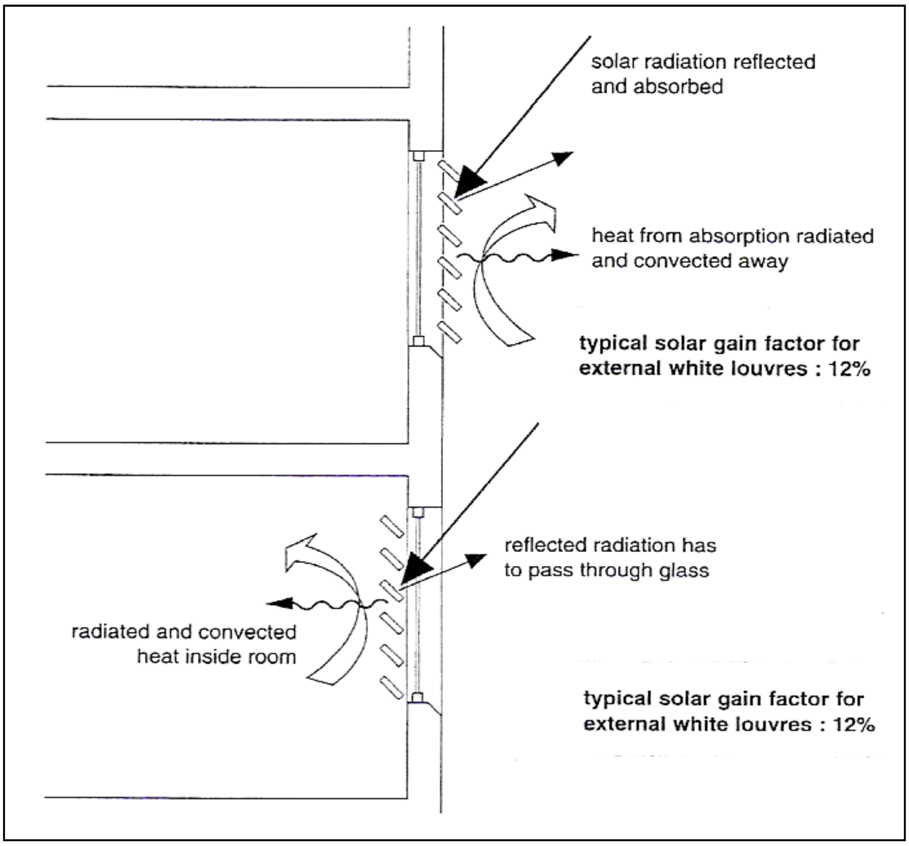


Figure 2.6 The performance of internal and external louvers (Source; Baker & Steemers, 2000, p. 32)

Thomas (2006, p.41-42) divides the external shading devices into two namely, fixed shading devices and movable shading devices. Firstly, fixed shading devices have disadvantages, since they prevent passive solar gain permanently. It can be accepted to make an arrangement dependent on the direct solar gain according to the variable seasons such as blocking the sun rays in summer and letting them enter in winter. These fixed shading devices also bring about loss in daylight permanently. Secondly, the movable shading devices like blinds located between the layers of glazing allow more heat into the space compared to the fixed ones. On the other hand, they are more trustworthy than the fixed ones and more efficient than the internal blinds. Since the movable external devices are subjected to outdoor weather conditions, hence require maintenance, their costs are higher.

Curtains, blinds with wooden, metal or plastic slats and shutters comprise the main internal shading devices. Thermal insulation may be integrated in the layers of these shading devices such as mineral fiber built into shutters and aluminum and polyester layers in blinds. Ventilation is also considered while designing the internal shading devices. (Thomas, 2006, p. 42)

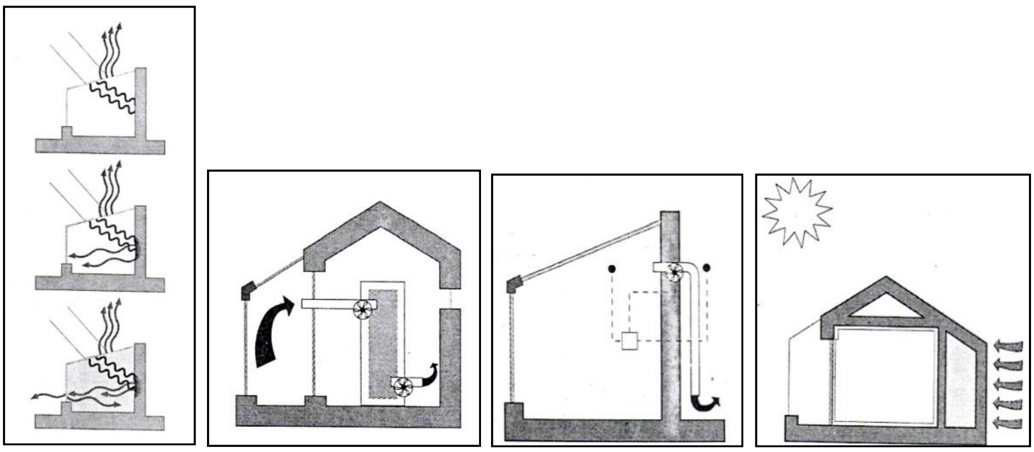
Since the tinted and reflective glass brings about decrease in daylight by a similar or higher factor than their thermal coefficient, the utilization of these materials is not suggested as a shading strategy. Although they have improved high-performance types in order to reduce the thermal gain, they do not prevent their heat loss in winter time which is higher than the insulated solid wall. (Baker & Steemers, 2000, p.33)

2.3 Sunspaces for Energy Efficiency

Lewis & Goulding (1993, p. 27-28) argue that the one of the important strategy to fulfill the heating needs of the buildings during the cold days is solar energy. The author divides the heating strategy dependent on the solar energy into four parts:

- Solar collection: the collection of the solar energy and its conversion into heat.
- Heat storage: storage of the heat resulting from the collection of solar energy.
- Heat distribution: distribution of the stored heat to the parts of the building which need heat.
- Heat conservation: keeping the heat in the building as long as possible.

Solar energy is collected at sunspaces by greenhouse effect which consists of three stages which are shown in Figure 2.7a. Firstly solar energy is collected in the building skin, then absorbed by the solid components of the building and finally, released as radiation. This radiation is stored in the sunspace itself which is called indirect storage which is the storage of heat obtained by convection and radiation. (Figure 2.7b) This accumulated heat can be transferred by fans and ducts to make use of it in another part of the house. Heat can also be distributed in a natural way if there is no boundary between the sunspace and attached building. (Figure 2.7c) An unheated sunspace located on the south side of the building serves as a protective buffer zone which reduces the heat losses from the building envelope. (Figure 2.7d) (Steemers *et al,* 1992, pp. 54-72)



(a) **(b)** **(c)** **(d)**

Figure 2.7 Passive heating strategy of a sunspace **a.** Solar collection **b.** Heat storage **c.** Heat distribution **d.** Heat conservation
(Source; Steemers *et al,* 1992, p.54)

Passive cooling is defined as application for heat reduction without using any mechanical components and energy inputs. One of the measures for cooling design strategy is to reduce the amount of solar energy by using fixed or movable shading devices, vegetation or special glazing types. Ventilation is another measure for cooling design strategy either by using cooler external fresh air or by using natural cooling methods. (Lewis & Goulding, 1993, p. 28-30)

According to Waterfield (2006, p. 27), movable internal shading device can be utilized for controlling the solar radiation in a sunspace as it is shown in Figure 2.8. Despite of requirement for manual intervention and maintenance, this type of shading is accepted as efficient since it provides shading during daytime in summer and also provides insulation during nighttime in winter. Steemers *et al.* (1992, p.90) emphasize on the effect of ventilation that:

> "The chimney or stack effect can also be put to effective use to release unwanted heat from a building via a sunspace or atrium. The air movement in the sunspace can give rise to an intake of air from the building into the sunspace this may in turn be dissipated to the outside. The same effect can be used to create cross ventilation. Here, air enters the building form cool pockets created in outside spaces on the building's shady side and flows through the building towards the sunny side where it rises as it is exposed to the sun."

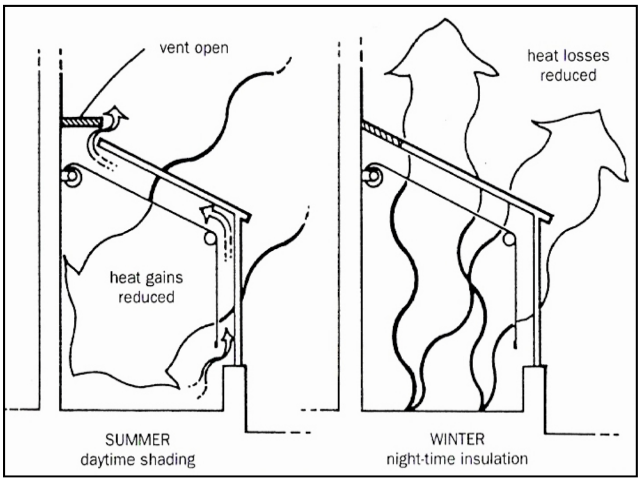


Figure 2.8 A movable shading device used in conservatory
(Source; Waterfield, 2006, p. 28)

The two types of sun spaces, namely, conservatories and atria, are explained in detail under the following two sections.

2.3.1 Conservatories

Waterfield (2006, p.75-76) defines the conservatory in a technical point of view as a space having 75% glazed roof area and 50% glazed walls. Since the sun is mostly effective at the south, the conservatory should be located on the south part of the house or even one façade of it should make use of the south sun. There are two types of conservatory namely, free-standing and lean-to. The former is a self supporting structure which is more expensive to be built. On the other hand, it is flexible in proportions and in roof design. The latter makes use of the structure of the existing building to support itself. (Figure 2.9) The main advantage of this type is reduced wall area, hence reduced heat loss, as some sides of the conservatory are buffered by the existing structure.

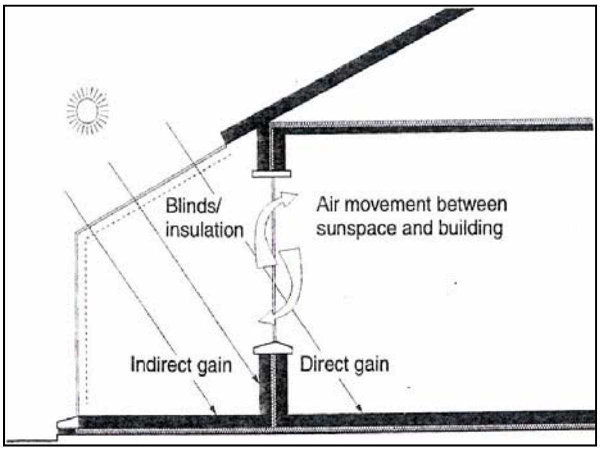


Figure 2.9 A lean-to type conservatory (Source; Smith, 2005, p. 60)

Thomas (2005, p.47) defines the conservatories as buffer zones which is a second skin around the main building envelope. Heat loss can be reduced with the help of this additional envelope, at the same time as the benefits of the solar gain in buildings are maintained. The beneficial solar heat gain is also trapped between the skins. Besides its advantages, a second envelope has disadvantages which are cost, obstruction in provision of natural ventilation and the threat for spread of smoke and fire due to creation of large enclosed space associated with the building floors.

There are various geometrical configurations of conservatories attached to the south wall. They can be also semi-projecting or completely recessed into the building which is surrounded on three sides by existing building. They can occupy part or the whole facade of the building and can have the height of one, one and a half, two or more storey. There are also detached ones which may supply warm air to buildings with the help of the fans and ducts. (Goulding *et al,* 1992, p.70)

The main aim of the conservatories is to promote thermal performance of the building as well as provide amenity and extra space when they are carefully designed. Otherwise the conservatory can bring about an increase in heating costs. Therefore, it should be effective to know the way a conservatory works. The author explains the four main functions of the conservatories as (Figure 2.10):

- The buffer effect: since the temperature in the conservatory is higher than the outside temperature, heat loss from the wall which conservatory is attached reduces as well as air leakage from the house reduces.
- Heat gains: the temperature in conservatory becomes higher than that in the house during sunny days. This creates heat gain to the building.
- Ventilation preheat: the conservatory provides preheated ventilation air for the house compared to the outside air.
- Summer cooling: in order to decrease the heat gain in the summer, shading should be used in the conservatory. The hot air in the conservatory should be vented by top vents of it. This also contributes to house ventilation.

According to Schittich (2003, p.21), particularly when poorly designed, the conservatories have also disadvantages such as cooling quickly at night and overheating during the daytime in summer. The advantages in terms of the energy issues are invalidated by the large glazed surfaces with low quality glazing. On the other hand, Goulding *et al.* (1992, p.70) state that the overheating can be controlled by using the shading devices in summer as well as using vents for exchange of the heated air. Furthermore, the requirement for shading reduced with the help of vertical glazing rather than inclined one. The heat loss during the night time in winter can be reduced by using the movable insulation.

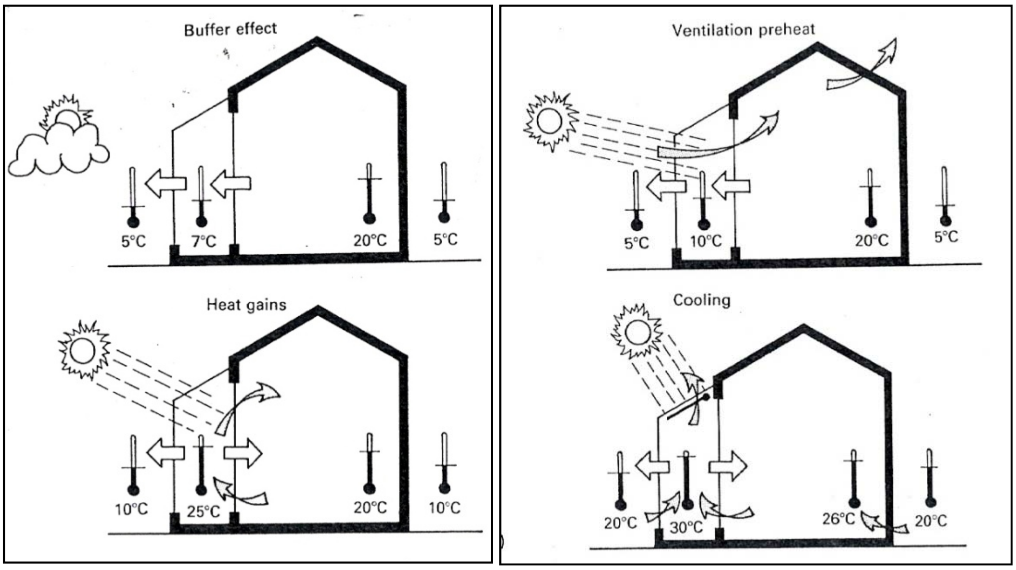


Figure 2.10 The functions of conservatories (Source; Roaf & Hancock, 1992, p. 212)

2.3.2 Atria

Atria are buffer spaces which had various forms having different range of complexity. In the simplest form of the atria, they are the enclosed spaces which have functions of preventing the rain to enter, letting the light and solar radiation to penetrate. There is no heating system used in the simple forms. It can be possible in these forms that the smoke and heat are dispelled by the high level openings or an extraction system. On the other hand, the heating system and ventilating system are incorporated in complex atria forms. The solar and light control systems are also installed in these forms. (Thomas, 2006, p. 47)

The amount of daylight falling onto the floor of the atria is dependent on their proportions. If the atrium space is wider and shallower, the amount of direct daylight in atrium space increases. The form of the atrium envelope gains importance in case it is not wider and shallower. Nevertheless, internal reflections contribute to the distribution of the daylight, even the height of the building increase. The effect of atrium height on direct daylight reaching to atrium space is shown in Figure 2.11. (Goulding *et al.,* 1992, p.147)

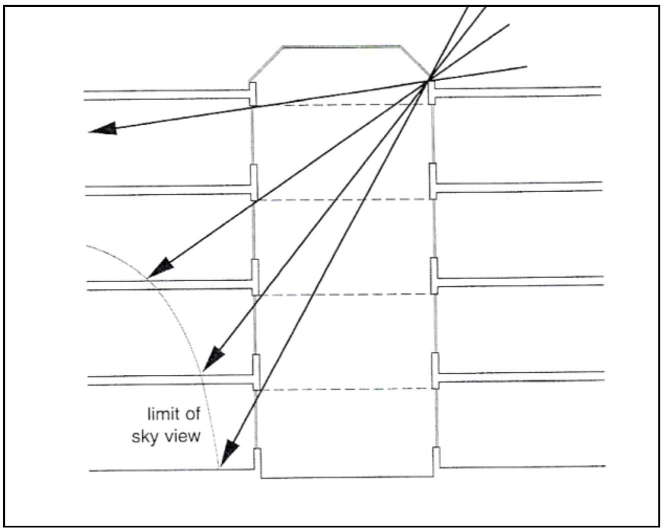


Figure 2.11 The effects of atrium height (Source; Baker & Steemers, 2000, p. 69)

Atria are chiefly used in designs for architectural purposes rather than for the aim of energy saving nowadays. Large public and commercial buildings are incorporated the atria as a common feature of architectural design. However, this does not mean that the atria give away high energy consumption constantly in the building that they are used. When the mechanical ventilation, artificial lighting and air conditioning system are used in atria, the energy consumption of a building can enhance compared to the similar one without an atrium. (Baker & Steemers, 2000, p.66)

Goulding *et al.* (1992, p.139) state that one of the advantages of the atria is creating a useful space by converting an open space to an atrium which can be used for circulation, restaurants or recreation areas. They can also be used for preheating of the ventilation air. Since the atria prevent the building facades to be subjected to external weather conditions, the heat loss from the building facades in winter time reduces. They also reduce the maintenance costs of the facades. Another advantage of the atria is to make use of the day lighting during the daytime instead of artificial lighting. (Figure 2.12) They also provide connection areas within one building and between streets. On the contrary, the author claims on disadvantages of the atria which are given below:

- "Added fire and smoke risks,
- The provision of ventilation to spaces which would otherwise be open to ambient air,
- The loss of daylight to rooms adjacent to courtyards caused by the roof structure,
- The risk of cross contamination in hospital atria and the spread of odors in glazed malls,
- The cost of glazing,
- The risk of overheating."

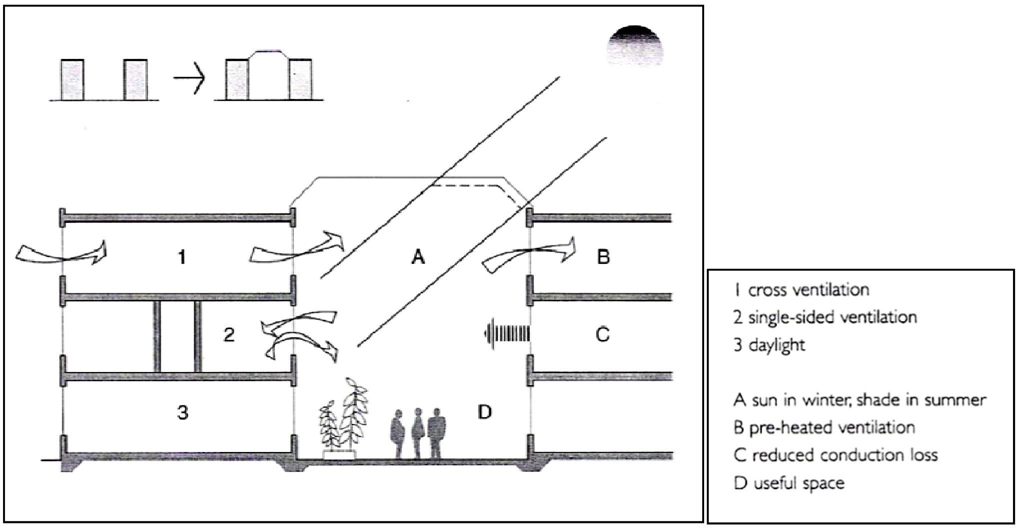


Figure 2.12 The benefits of an atrium (Source; Baker & Steemers, 2000, p. 67)

Baker & Steemers (2000, p. 71-76) states the winter and summer performances of the atria. protectivity, which is the ratio of the separating wall area to atrium external skin area, and solarity, which is the ratio of south facing glazing area to total area of glazing of atrium skin, are the main factors affecting the winter performance of the atrium. Preventing the overheating is the main purpose in terms of summer performance. This can be achieved with the help of some passive measures namely, shading which is preferred to be provided by movable devices; ventilation which can be provided by naturally and mechanically; and incorporation of the thermal mass.

CHAPTER 3

MATERIAL AND METHOD

This chapter consist of two subsections; namely, material and method. The section on material includes weather data for Ankara, the two case-study buildings with sun spaces, data loggers and data which is collected from these buildings. The section on method includes data collection, presentation and evalution.

3.1 Material

The role of sunspaces in reducing the heating loads in buildings was assessed by collecting temperature and humidity data inside the buildings with the help of Tiny Tag data loggers. The weather data of Ankara, the two case-study buildings; namely, the MATPUM Building and the Solar Building located on the METU Campus in Ankara, the data loggers and the data collected are defined under the following sections.

3.1.1 Weather data for Ankara

Thermal conditions within a building are influenced by the outside weather conditions. Hence, the weather data is required in order to compare and evaluate the internal performance of the building with regard to the weather conditions.

Weather data was obtained in three ways:

- Outside temperature and humidity data was collected with a data logger during the summer and winter seasons *i.e.* from May to August and from October to November, concurrently in the case study buildings. The data was recorded at 15 minute intervals.
- Weather data were taken from Turkish State Meteorological Services (TSMS) for the period when data was being collected with the data loggers in order obtain daily means and sky conditions as well as wind speed.
- Daily weather conditions were also noted by the author, whether it was cloudy, rainy, windy, snowy or sunny in the area where the buildings are located.

3.1.2 Case study buildings

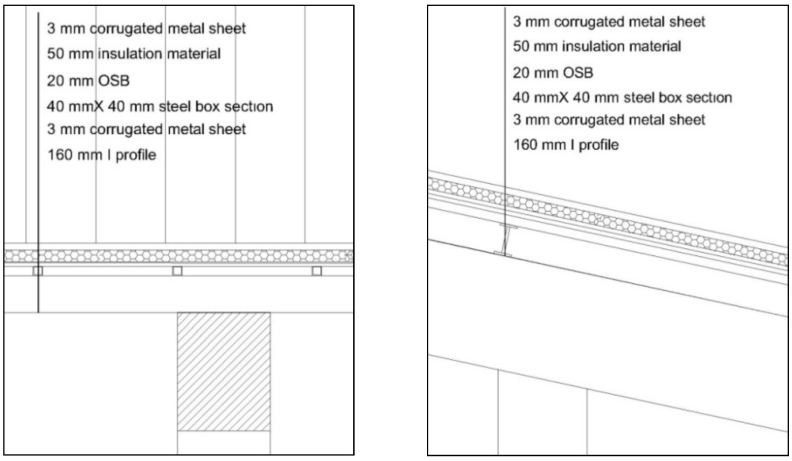
Two buildings having sunspaces were studied to explain the role of such spaces in reducing heating loads of the buildings. Both of these buildings, namely, the MATPUM Building and the Solar Building are located in Ankara on the campus of Middle East Technical University.

3.1.2.1 The MATPUM Building

The MATPUM Building is situated on a sloping site in the western part of the campus between the Faculty of Architecture and the Technopark. Its construction was finished in October 2005.

The MATPUM Building is a reinforced concrete framed building with a double layered corrugated metal sheeting roof supported by I-beams which are located on the main concrete beams. (Figure 3.1) Both interior and exterior walls of the building are made of hollow concrete block. The exterior walls are insulated from the outside.

Addition to this insulated wall, there is a double layered corrugated metal sheeting which covers the north wall of the building from the outside.



(a) **(b)**

Figure 3.1 System detail from the roof of the MATPUM Building
a. Longitudinal section **b.** Cross section
(Drawn by; Ensari & Kabal, 2004)

The building has a linear form lying on the east-west axis. The long facades of the building are facing north and south. There is a glazed area facing the south which provides light and heat to the open office area which. The sunlight coming from south façade is controlled by the fixed sun breakers which are shown in Figure 3.2 below. In contrast to public areas, the private offices and services are situated along the north façade.

Figure 3.2 South façade of the MATPUM Building showing the fixed sun breakers

The total building area is approximately 2350 m². The building with a south facing atrium like space has three storeys; lower ground floor, upper ground floor and mezzanine floor. Service rooms such as storages, generator room, technical rooms and restrooms are located on the lower ground floor, along with two meeting room and five offices. Main entrance is from the upper ground floor in which offices and studios are arranged. The mezzanine floor has rooms allocated on offices. (Technical drawings of floor plans, sections and elevations are given in Appendix A.)

3.1.2.2 The Solar Building

The METU Solar Building was designed as a result of the collaboration between the Departments of Architecture and Physics on the METU Campus in Ankara. The construction of the building was started as a summer practice for 2^{nd} year students of architecture in 1975 and finished after five years at the end of 1980.

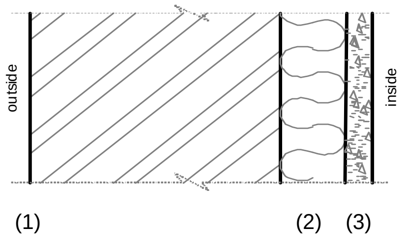
The solar house building is composed of two floors; ground floor and mezzanine floor. Total area of the building is 85 m². The building has a kitchenette and a restroom at the northern part of ground floor, besides large meeting room occupies the whole southern façade. At the mezzanine floor, there is a private office which has no barrier between ground floor and itself. (Technical drawings of floor plans, sections and elevations are given in Appendix B.)

Figure 3.3 External view of the Solar Building

The major passive element, conservatory, provides contributions for heat gain both to the meeting room and private office from the southern part. (Figure 3.4) It is composed of double glazed façades and inclined roof. The roof is carried by steel trusses which are supported by the reinforced concrete columns. There is a glazed boundary between the conservatory and the main building which provides controlling the penetration of the heat resulted from the solar radiation.

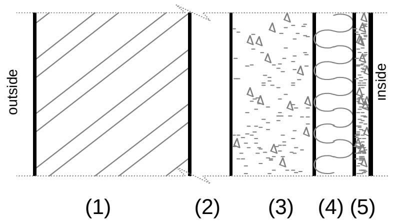
Figure 3.4 View of conservatory in the Solar Building

The construction materials of the Solar Building are presented in Figure 3.5. As it can be seen from the figure, the external wall of the building is made of brick masonry which is insulated from the outside and covered with the cement plaster. In addition to this, the AAC is used in the construction of north wall of the building. The inclined roof of the building covered with the double glazing from the outside. There are eighteen heat collectors was incorporated onto the roof, but they do not perform any more. The ceiling is covered by the timber tiles.



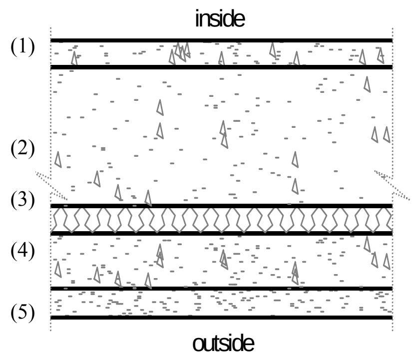
Building Material		Thickness (mm)
(1)	Brick Masonry	190
(2)	Shape Mate IB	50
(3)	Cement Plaster	20
	Total	270

1. East-west wall



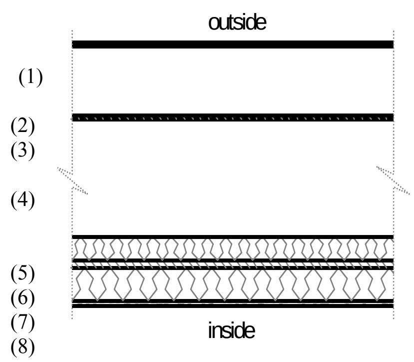
Building Material		Thickness (mm)
(1)	Brick Masonry	190
(2)	Air Gap	50
(3)	AAC	100
(4)	Shape Mate IB	50
(5)	Cement Plaster	20
	Total	410

2. North wall



Building Material		Thickness (mm)
(1)	Leveling Concrete	50
(2)	R. Concrete	250
(3)	Floor Mate 200	50
(4)	Blockage Concrete	100
(5)	Compacted Earth	50
	Total	500

3. Floor



Building Material		Thickness (mm)
(1)	Double Glazing	24
(2)	Air Gap	150
(3)	Selective Surface	6
(4)	Air Gap	250
(5)	Roof Mate PS	50
(6)	Aluminum Decking	15
(7)	Glass Wool	70
(8)	Timber Ceiling	15
	Total	580

4. Roof

Figure 3.5 Building materials of the Solar Building (Source; Karagüzel, 2004)

3.1.3 Data loggers

Tinytag data loggers (Figure 3.6) were used for taking the measurement from the MATPUM Building and the Solar Building. These data loggers is a device for recording temperature and humidity data at predetermined intervals over set periods of time inside and outside of the building. Since data loggers are sensitive devices, they could not be subjected to direct sunlight or located near heat producing apparatus or exposed to rainfall.

Figure 3.6 Tinytag data logger

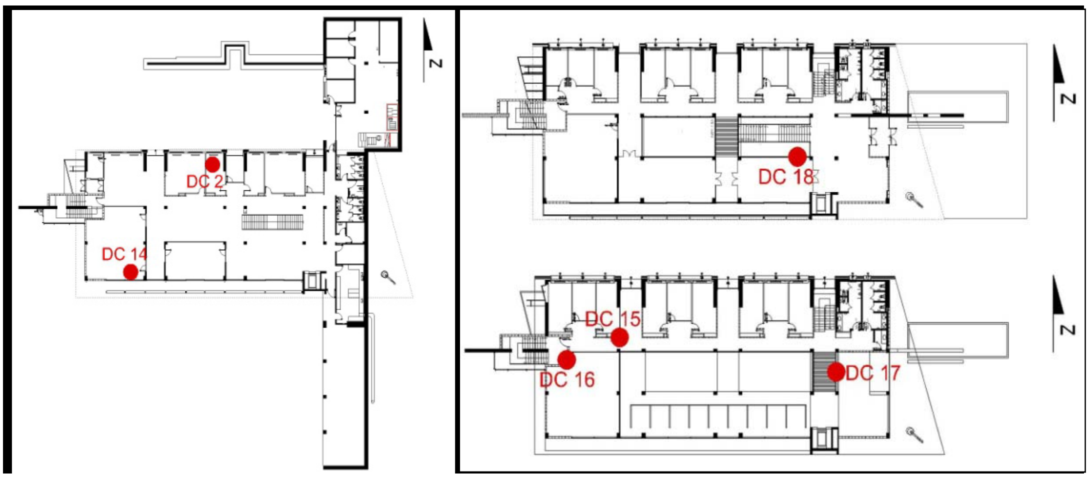
3.2 Method

In order to make appropriate comparison and evolution for reducing the heating loads with the help of the sun spaces, data was collected during three seasons namely, spring, summer and autumn. Winter data was not collected, because the heating system starts to open in the buildings and readings would not reflect the actual performance of the sun spaces.

The technical drawings of the two buildings were obtained and photographs were taken, especially the locations of the data loggers. The plans and the photos showing the locations of the data loggers are presented below.

In this study, twelve Tinytag data loggers were recorded temperature and humidity data at 15 minute intervals during the spring, summer and autumn seasons; from May to August and from October to November. Six data loggers were located in the MATPUM Building and five data loggers were placed in Solar Building. The remaining one data logger measured the external temperature and relative humidity for observations and comparisons.

The six data loggers were located in different parts of the MATPUM Building. DC-2 was at the lower ground floor of the building in room number 5 which is a closed room located on the north side of the building (Figure 3.8a). DC-14 was hung behind a radiator at the lower ground floor in the meeting room facing the south (Figure 3.8b). DC-15 was put behind a radiator at the mezzanine floor at the fire exit which is located on the north (Figure 3.9a). DC-16 was placed on the north wall at mezzanine floor. (Figure 3.9b) DC-17 was on the steel beam at mezzanine floor. (Figure 3.10a) Finally, DC-18 was located on a hand rail at the upper ground floor (Figure 3.10b). The drawing showing the location of the data loggers in the MATPUM Building (Figure 3.7) is presented below.



(a) **(b)**

Figure 3.7 The locations of the data loggers on the plans of the MATPUM Building
a. At the lower ground floor
b. At the upper ground floor and at the mezzanine floor

(a) (b)

Figure 3.8 a. DC-2 in room 5 on the lower ground floor of the MATPUM Building
b. DC-14 in the meeting room on the lower ground floor of the MATPUM Building

(a) (b)

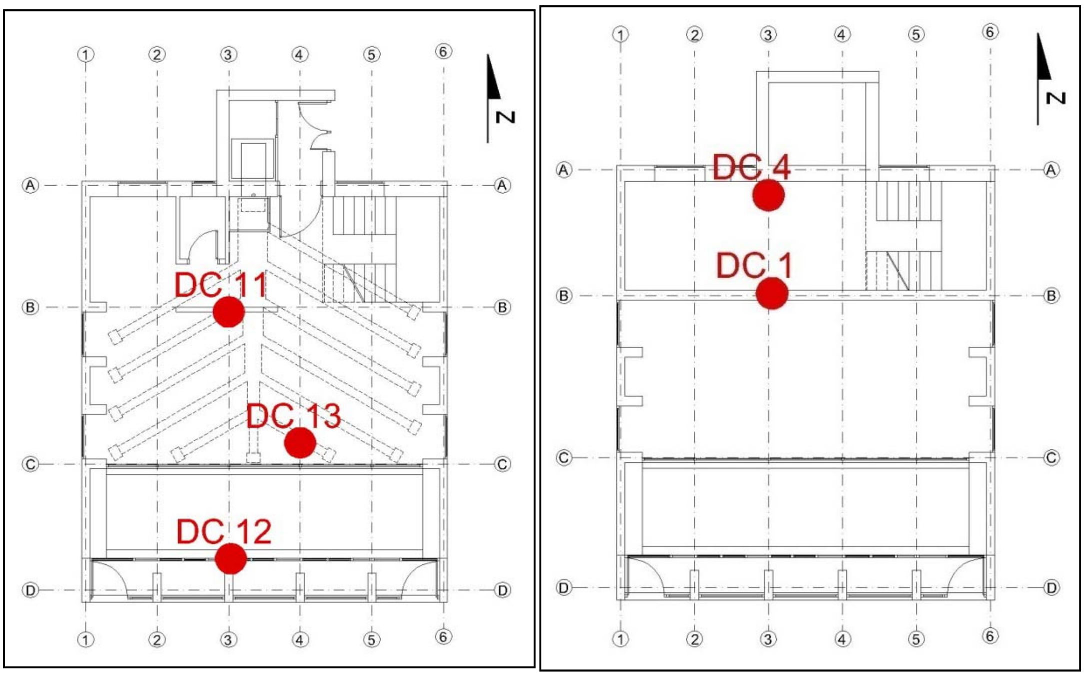
Figure 3.9 a. DC-15 at fire exit on the mezzanine floor of the MATPUM Building
b. DC-16 on partition wall on the mezzanine floor of the MATPUM Building

(a) (b)

Figure 3.10 a. DC-17 on the roof structural element of the MATPUM Building
b. DC-18 on handrail at upper ground floor of the MATPUM Building

There are five data loggers which are located different parts of the Solar Building. DC-1 was on the parapet wall of the mezzanine floor at 1.20 m height. (Figure 3.12) DC-4 was hung closely from the ceiling at north side wall at mezzanine floor. (Figure 3.13a) DC-11 was hung from a pipe under the floor slab of the mezzanine floor. (Figure 3.13b) DC-12 was located in the conservatory hung from the steel truss. (Figure 3.14a) DC-13 was hung from coat hanger which was located just in front of the glazed façade to which conservatory is attached. (Figure 3.14b) The drawing showing the location of the data loggers in the Solar Building (Figure 3.11) is presented below.

The five data loggers were located in the building in a way that they constitute a line both horizontally and vertically. Therefore, the assessment of the temperature values according to the distance from the conservatory and height provides information for comparison and evaluation.



(a) **(b)**

Figure 3.11 Locations of data loggers shown on floor plans of the Solar Building

a. On the ground floor
b. On the mezzanine floor

Figure 3.12 DC-1 on the parapet of the mezzanine floor of the Solar Building

(a) **(b)**

Figure 3.13 a. DC-4 hung from the ceiling of the Solar Building
b. DC-11 hung from a pipe under the floor slab of the mezzanine floor of the Solar Building

(a) **(b)**

Figure 3.14 a. DC-12 in the conservatory of the Solar Building
b. DC-11 hung on a coat hanger near the glazing on the ground floor of the Solar Building

The first set of data was collected for seventy-five days from 23 May to 6 August, 2009. Second set of data was collected from the buildings for forty-three days from 14 October to 21 November, 2009. The recorded data both sets were downloaded from the data loggers with the software (Gemini) and tabulated and converted into charts and graphs in order to evaluate and compare. The temperature data was also compared by using analysis of variance method (AnoVa).

CHAPTER 4

RESULTS AND DISCUSSION

This chapter presents the results, analyses and the discussion on the outcomes of the data collected from the case study buildings at METU during three seasons; spring, summer, autumn. The following sections include the graphs and charts which are constructed from the results of the temperature and humidity data collected from selected buildings in predetermined periods for comparison and assessment. Temperature and humidity data collected from May to August and October and November are presented in Appendix C.

4.1 Comparison of Temperature and Humidity Data

The first set of data was collected for seventy-five days from 23 May to 6 August, 2009 and the second set of data was collected for thirty-nine days from 14 October to 21November, 2009. The temperature and humidity data for eight days in May for spring season, the data for eight days in July for summer season and data for eight days in October for autumn season for the MATPUM Building and the Solar Building are given here for comparison and clarity. Winter data was not collected, because the heating system starts to open in the buildings and readings would not reflect the actual performance of the sun spaces.

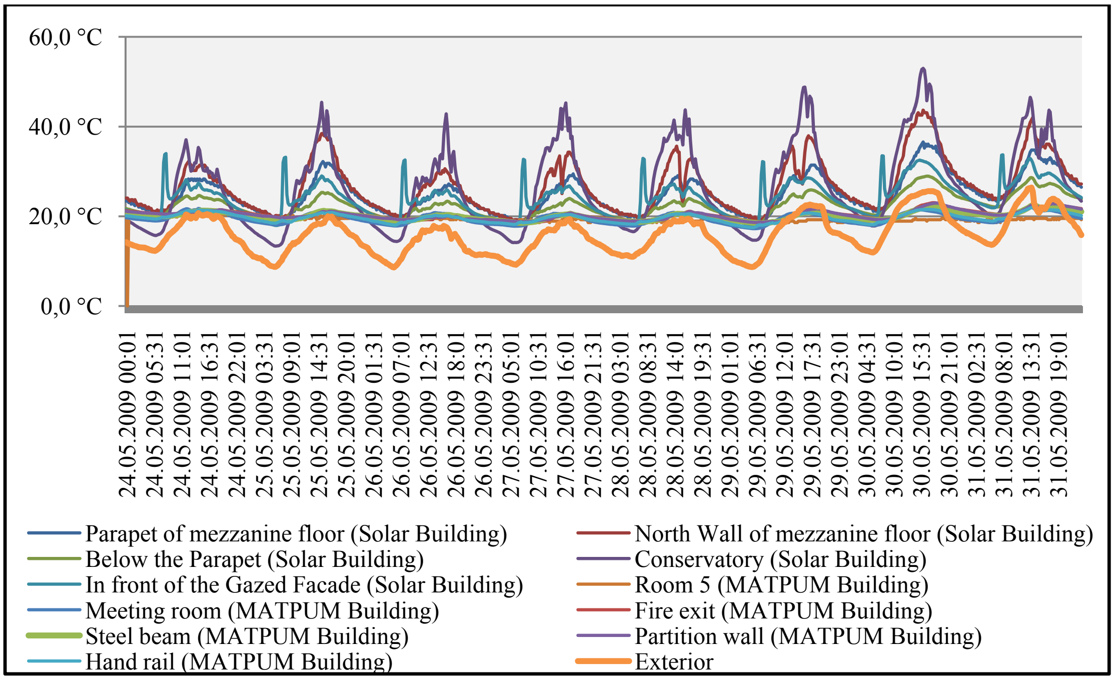


Figure 4.1 Temperature chart of the MATPUM Building and the Solar Building (24-31 May 2009)

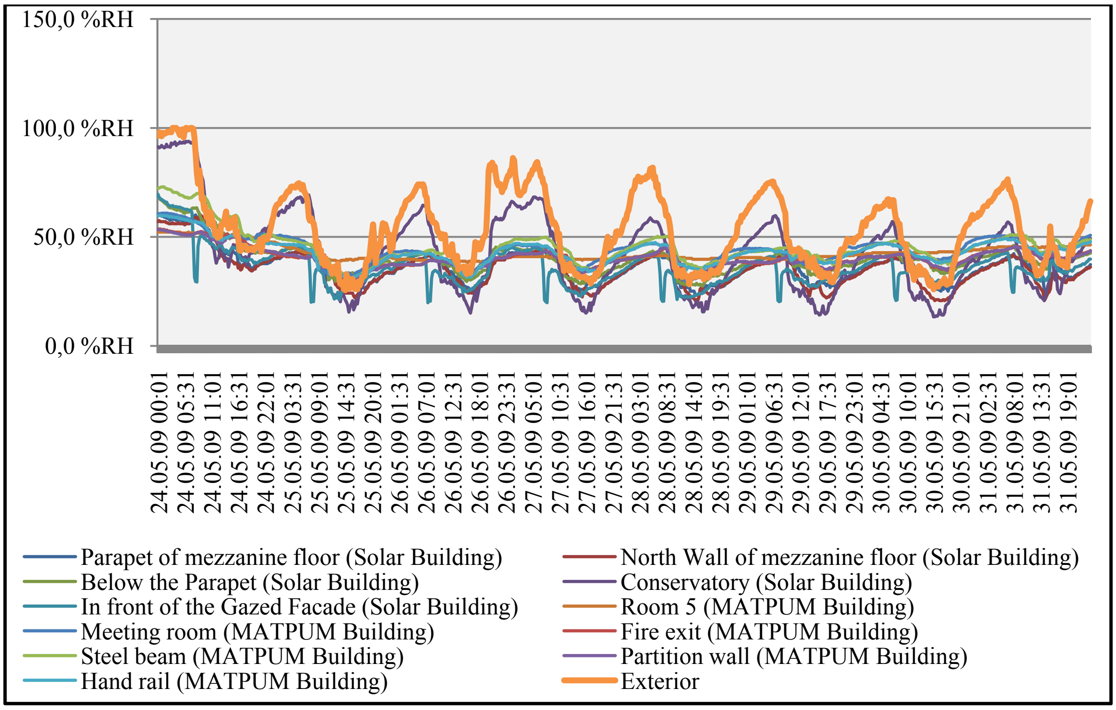


Figure 4.2 Humidity chart of the MATPUM Building and the Solar Building (24-31 May 2009)

Table 4.1 Temperature & Humidity values of the MATPUM Building and Solar Building (24-31 May 2009)

LOCATION	DATA LOGGER	FIGURE	MIN TEMPERATURE	MAX TEMPERATURE	FLUCTIATIONS	MIN HUMIDITY	MAX HUMIDITY	EXPLANATİONS
Room 5 (MATPUM Building)	DC 2	Figure 3.8a	19°C	20°C	0.5°C	39%	52%	Room was unoccupied and close
Meeting Room (MATPUM Building)	DC 14	Figure 3.8b	17°C	22°C	3.5°C	31%	61%	Room is facing to south
Fire-exit (MATPUM Building)	DC 15	Figure 3.9a	19°C	23°C	1°C-week days 3.5°C-weekend days	31%	53%	-
Partition Wall (MATPUM Building)	DC 16	Figure 3.9b	19°C	23°C	1°C-week days 3.5°C-weekend days	30%	53%	The location was in the atrium close to north
Steel Beam (MATPUM Building)	DC 17	Figure 3.10a	18.5°C	22°C	2.5°C	31%	73%	The location was in the atrium in the middle
Hand Rail (MATPUM Building)	DC 18	Figure 3.10b	17.5°C	22°C	3.5°C	31%	61%	The location was in the atrium close to the south
Parapet (Solar Building)	DC 1	Figure 3.12	19°C	36°C	7°C-week days 15°C-weekend days	25%	60%	The space was mostly occupied areas
North wall (Solar Building)	DC 04	Figure 3.13a	19°C	43°C	7°C-week days 21°C-weekend days	21%	59%	The space was mostly occupied areas
Below the Parapet (Solar Building)	DC 11	Figure 3.13b	19°C	29°C	4°C-week days 7°C-weekend days	28%	69%	The location was under the slab of mezzanine floor
Conservatory (Solar Building)	DC 12	Figure 3.14a	13°C	52°C	26°C	14%	93%	It is a glazed sunspace facing south
In front of the glazed facade (Solar Building)	DC 13	Figure 3.14b	18°C	33°C	10°C	21%	69%	The location was between main building and conservatory

Figure 4.1 shows the temperature chart for six interior spaces in the MATPUM Building and five interior spaces in the Solar Building and for the exterior from 24th to 31st May, 2009. It can be seen from the chart that the exterior temperature fluctuated between 8 °C and 27 °C during mentioned days.

Table 4.1 shows the maximum and minimum temperature and humidity values in the MATPUM Building and in the Solar Building from 24th to 31st May, 2009. In the first column of the table, the locations of the data loggers in two buildings are indicated. The code of the data loggers are specified in the second column. The third column includes the number of figures which shows the location of the data loggers. The maximum and minimum temperature values for the selected days are indicated in forth and fifth columns respectively. The sixth column shows daily temperature fluctuations. The maximum and minimum humidity values for the selected days are shown in seventh and eighth columns. In the last column, brief explanations about the locations of the data loggers are indicated. (Table 4.2 and Table 4.3 present the same information for different months)

According to the chart, the interior temperatures in MATPUM Building did not vary in the same way when compared to the exterior ones, especially in room 5. This unoccupied room is located on the north façade of the building and was kept closed. Therefore, no heat gain from the incident sun, occupants, equipments or convectional air currents took place in this room. On the other hand, the interior temperatures in the Solar Building, especially in the conservatory, were higher compared to the exterior ones. Since it is a sun space which is composed of glazed south facing surfaces of facades and roof in order to transfer the direct sunlight into considerable heat gain, the temperatures in the conservatory fluctuated more than the ones in other spaces. Particularly, the green house effect caused an increase in temperature of the conservatory. The temperature of the conservatory reached its peak point at nearly 2.00 pm and its temperature decreased until around 6.00 am. According to Table 4.1, the temperature in front of the glazing in Solar Building, which is a boundary between the conservatory and the main building, had lower daily fluctuations when compared to the one in the conservatory.

Since meeting room in MATPUM Building is facing to the south, the interior temperature increased due to direct sunlight during day time, whereas there was considerable decrease in temperature during night time due to heat loss from the adjacent glazing. The day time temperature around the hand rail was similar to ones measured in meeting room due to southerly glazed facade. On the other hand, the nighttime temperatures around hand rail were rather higher than the ones measured in the meeting room. The reason for this is that the rail is located approximately 4 m away from the glazing. When the temperature values obtained in these two locations were compared to the ones in the conservatory in Solar Building, it can be seen that more heat gain resulted from solar radiation was obtained in the conservatory.

The temperatures around the parapet and north wall of the mezzanine floor in Solar Building were lower than the the ones in the conservatory. Although both of these spaces were very close to each other, temperatures near the north wall were much higher than those around the parapet. The reason for this is that the heated air rises up to highest point through the north wall with the help of the slope of the roof. The other reason is the wooden ceiling material which mostly affects the temperature of the mezzanine floor, because it traps the heat inside space. The temperature values, especially upper temperature values and daily flactuations, below the parapet differed from the ones around parapet of mezzanine floor, although the one was just below the other.

In MATPUM Building, solar radiation penetrated through glazed façade from the south and provided heat gain for the inside. This increased the interior temperature and resulted in higher fluctuations, especially in the fire-exit and around the partition wall at mezzanine floor. Since both of these spaces were not subjected to direct sunlight in daytime, temperature increase resulted from heat gain from the south façade due to convection especially at around 12 noon. Temperature started to increase at around 8.00 am and reached its peak point at nearly 18.30 pm. As it can be seen from the Table 4.1, although the data loggers at partition wall and around steel beam which supports the roof measured the temperature of the same space, the temperatures measured around steel beam were a bit lower than the one measured around partition wall. The reason for this is heat loss from the roof. However, the time period for increase and decrease in temperature was also similar with the one for Partition wall.

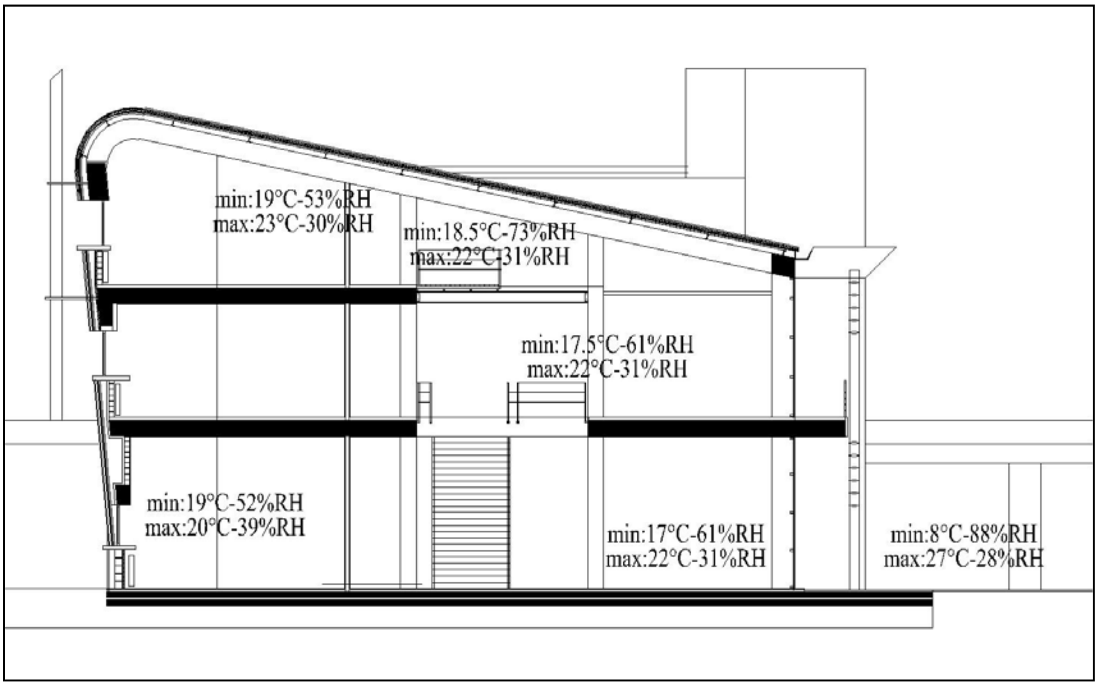


Figure 4.3 Section showing the minimum and maximum temperature and humidity values at different locations of the MATPUM Building (24-31 May 2009)

According to Figure 4.3, the exterior relative humidity varied from 28% to 88%. In the MATPUM Building, the interior humidity values showed smaller fluctuations compared to the exterior ones. The humidity in room 5 mostly stayed stable, because the room was kept closed and unoccupied. On the other hand, the humidity in meeting room, around the hand rail and steel beam had higher daily fluctuations in keeping with the temperature fluctuations. As it is seen from the graph, humidity at these spaces fluctuated in parallel to exterior humidity. The reason for this is air infiltration through building envelope from the roof and glazed south façade. When compared to these three locations, the humidity in fire exit and around partition wall had smaller fluctuations.

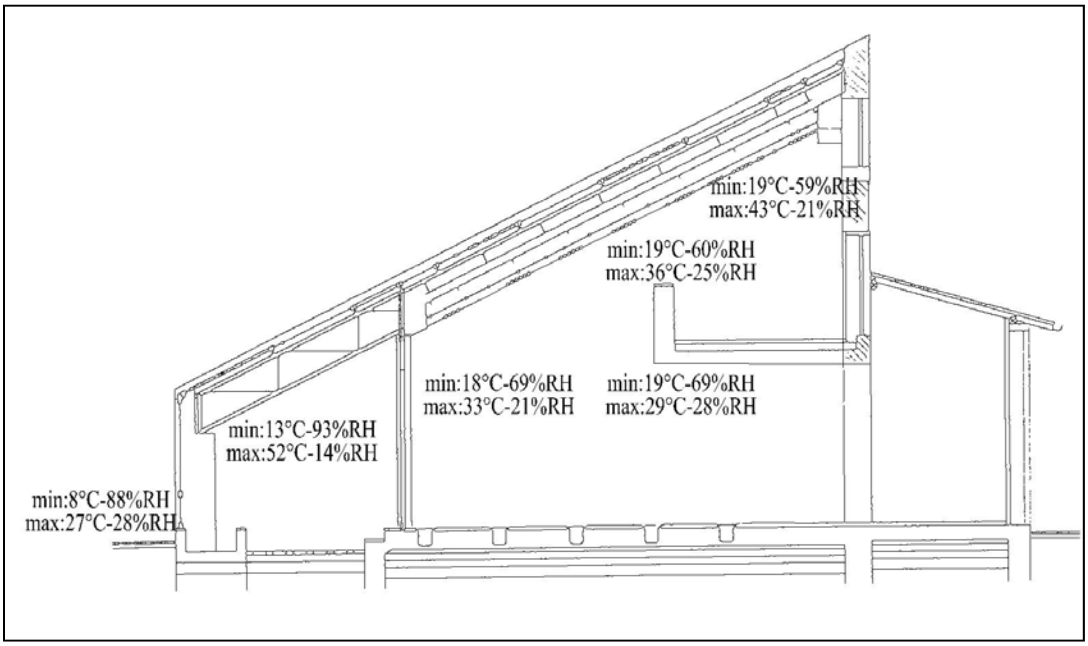


Figure 4.4 Section showing the minimum and maximum temperature and humidity values at different locations of the Solar Building (24-31 May 2009)

According to Figure 4.4, in Solar Building, the interior humidity values were lower except the ones in conservatory when compared to the exterior ones. The reason for this is the higher internal temperatures, because when the temperature increased, humidity decreased accordingly. Therefore, the humidity in the conservatory had higher daily fluctiations in keeping with the temperature fluctuations. The higher the temperature, the lower the humidity was. The reason for this increase is that there was huge heat gain due to solar radiation during the daytime and this heat gain was subjected to colder glazed conservatory surfaces during the nighttime. Therefore, condensation occured and then, this caused increse in humidity at nighttime. The humidity at ground floor was higher than the one in mezzanine floor with reference to temperature values at these locations.

When the humidity values were compared between two buildings, since the internal temperatures in Solar Building were higher, the minimum humidity values were lower than the ones in MATPUM Building. Even these values in Solar Building are lower than the exterior humidity values.

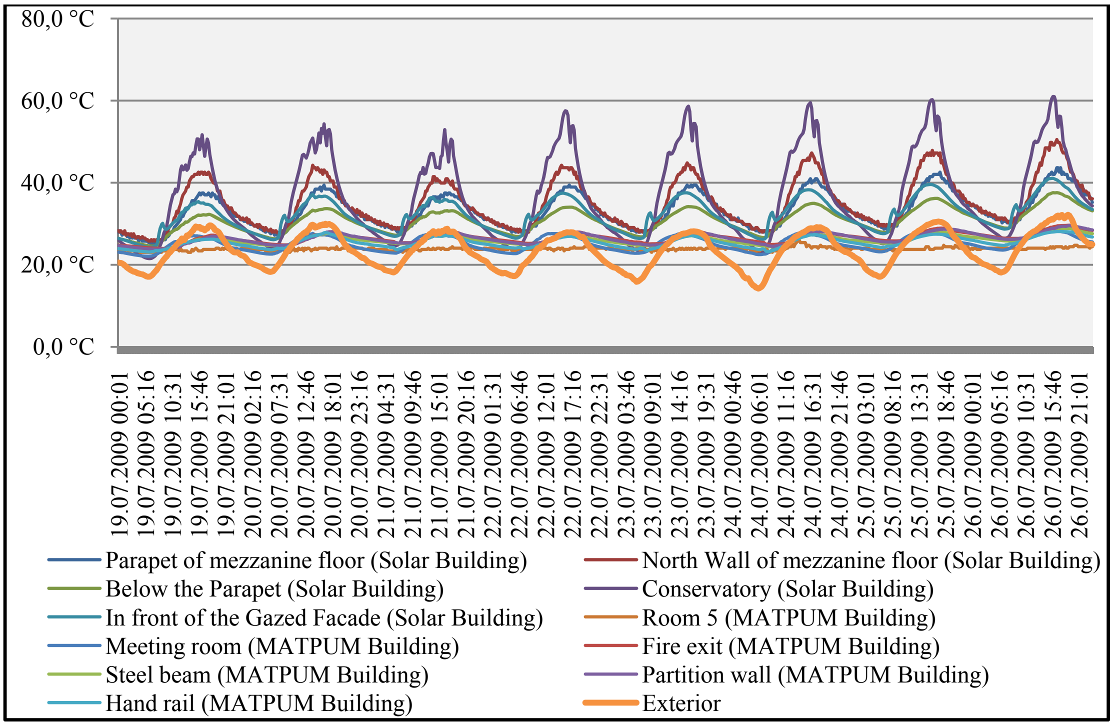


Figure 4.5 Temperature chart of the MATPUM Building & Solar Building (19-26 July 2009)

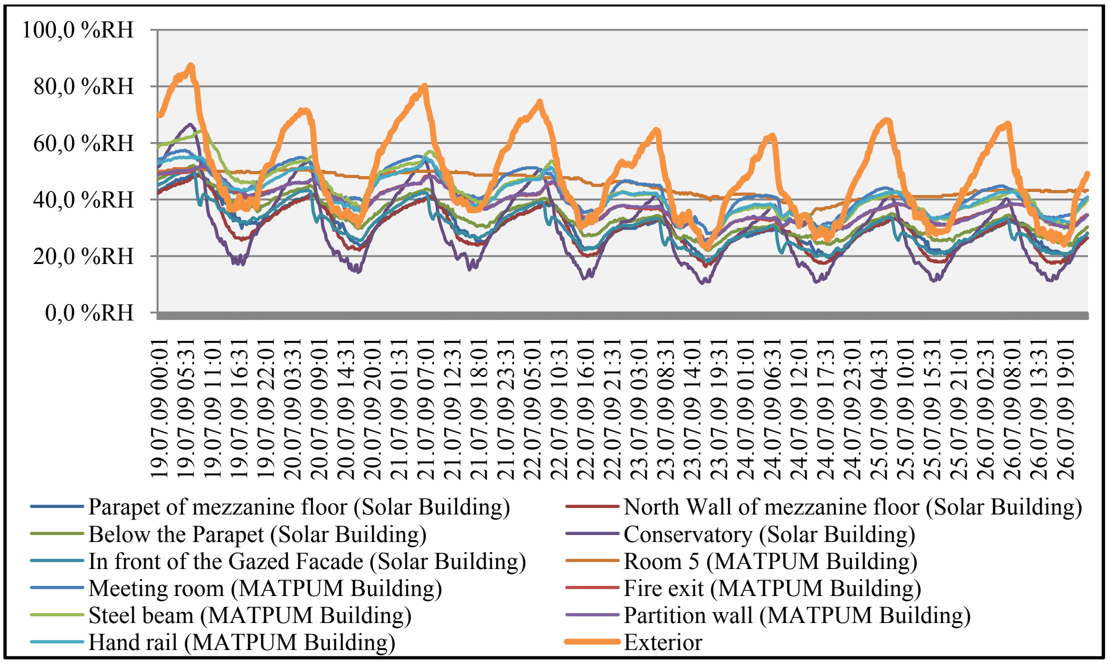


Figure 4.6 Humidity chart of the MATPUM Building & Solar Building (19-26 July 2009)

Table 4.2 Temperature & Humidity values of the MATPUM Building & Solar Building (19-26 July 2009)

LOCATION	DATA LOGGER	FIGURE	MIN TEMPERATURE	MAX TEMPERATURE	FLUCTIATIONS	MIN HUMIDITY	MAX HUMIDITY	EXPLANATİONS
Room 5 (MATPUM Building)	DC 2	Figure 3.8a	19°C	20°C	0.7°C	32%	51%	Room was unoccupied and close
Meeting Room (MATPUM Building)	DC 14	Figure 3.8b	22°C	29°C	3.5°C	28%	57%	Room is facing to south
Fire-exit (MATPUM Building)	DC 15	Figure 3.9a	24°C	29°C	2.5°C-week days 3.5°C-weekend days	26%	52%	-
Partition Wall (MATPUM Building)	DC 16	Figure 3.9b	24°C	29°C	2.5°C-week days 3.5°C-weekend days	26%	52%	The location was in the atrium close to north
Steel Beam (MATPUM Building)	DC 17	Figure 3.10a	23.5°C	29°C	2.5°C	24%	64%	The location was in the atrium in the middle
Hand Rail (MATPUM Building)	DC 18	Figure 3.10b	23°C	28°C	2.5°C	25%	55%	The location was in the atrium close to the south
Parapet (Solar Building)	DC 1	Figure 3.12	25°C	43°C	13°C	19%	49%	The space was mostly occupied areas
North wall (Solar Building)	DC 04	Figure 3.13a	26°C	50°C	20°C	18%	48%	The space was mostly occupied areas
Below the Parapet (Solar Building)	DC 11	Figure 3.13b	24°C	37°C	8°C	22%	52%	The location was under the slab of mezzanine floor
Conservatory (Solar Building)	DC 12	Figure 3.14a	23°C	61°C	35°C	11%	66%	It is a glazed sunspace facing south
In front of the glazed facade (Solar Building)	DC 13	Figure 3.14b	25°C	41°C	11°C	19%	50%	The location was between main building and conservatory

Figure 4.5 shows the temperature chart for six interior spaces in the MATPUM Building and five interior spaces in the Solar Building and for the exterior from 19th to 26th July, 2009. It can be seen from the chart that the exterior temperature fluctuated between 14 °C and 32 °C during mentioned days. It should be noted that the temperature values during the summer season were lower in 2009 when compared to previous summer seasons. It was mostly raining so that the temperatures were lower. Although the days between 19th and 26th July 2009 had highest temperatures according to monthly temperature chars which are presented in Appendix C, the maximum temperature could not be more than 32°.

According to Figure 4.5, the interior temperatures in two buildings were different from each other. The fluctuations of interior temperatures in MATPUM Building were lower than the ones in the Solar Building. Particularly, room 5 in the MATPUM Building had temperatures which were mostly stayed stable as it was seen in May. The reason for this is that no heat gain from the incident sun, occupants, equipments or convectional air currents took place in this room, because it is an unoccupied room on the north side of the building. On the contrary, the conservatory in Solar Building had higher daily fluctuations. According to the Table 4.2, it had 61°C as maximum temperature and 24°C as minimum temperature during selected days. Since it is a sun space which is composed of glazed south facing surfaces of facades and roof in order to transfer the direct sunlight into considerable heat gain, the temperatures in the conservatory fluctuated more than the ones in other spaces. The temperature values were also higher in front of the glazing in Solar Building, but it had lower daily fluctuations when compared to the ones in the conservatory.

Since meeting room in MATPUM Building is facing to the south, the interior temperature increased due to direct sunlight during day time, whereas there was considerable decrease in temperature during night time due to heat loss from the adjacent glazing. The day time temperature around the hand rail was similar to ones measured in meeting room due to southerly glazed facade. On the other hand, the nighttime temperatures around hand rail were rather higher than the ones measured in the meeting room. The reason for this is that the rail is located approximately 4 m away from the glazing.

The temperatures around the parapet and north wall of the mezzanine floor in Solar Building were affected by the slope of the roof. Since the heat gain resulted from solar radiation were mostly accumulated in these locations, they had higher temperatures in daytime. Although both of these spaces were very close to each other, temperatures near the north wall were much higher than those around the parapet due to slope of the roof. The temperature values, especially upper temperature values and daily flactuations, below the parapet differed from the ones around parapet of mezzanine floor, although the one was just below the other.

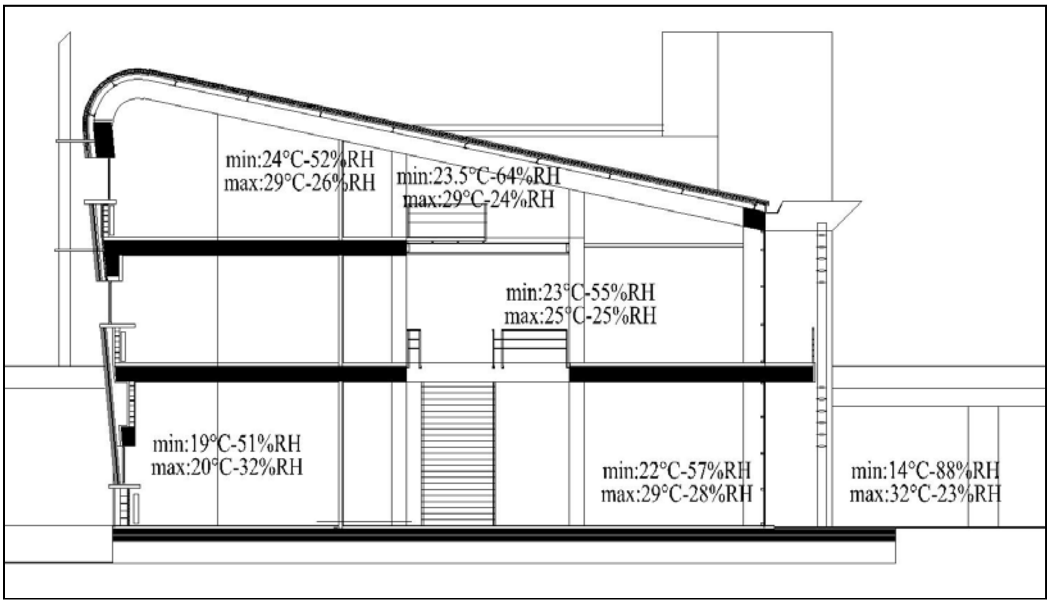


Figure 4.7 Section showing the maximum and minimum temperature and humidity values at different locations of the MATPUM Building (19-26 July 2009)

The temperature values assessed in fire exit and around partition wall in MATPUM Building were higher when compared to other locations of the building, but lower than the ones assessed in the similar locations in Solar Building. Since both of these spaces were not subjected to direct sunlight in daytime, temperature increase resulted from heat gain from the south façade due to convection. As it can be seen from the Table 4.2, although the data loggers at partition wall and steel beam which supports the roof measured the temperature of the same space, the temperatures measured around steel beam were a bit lower than the one measured around partition wall. The reason for this is heat loss from the roof. However, the time period for increase and decrease in temperature was also similar with the one for Partition wall.

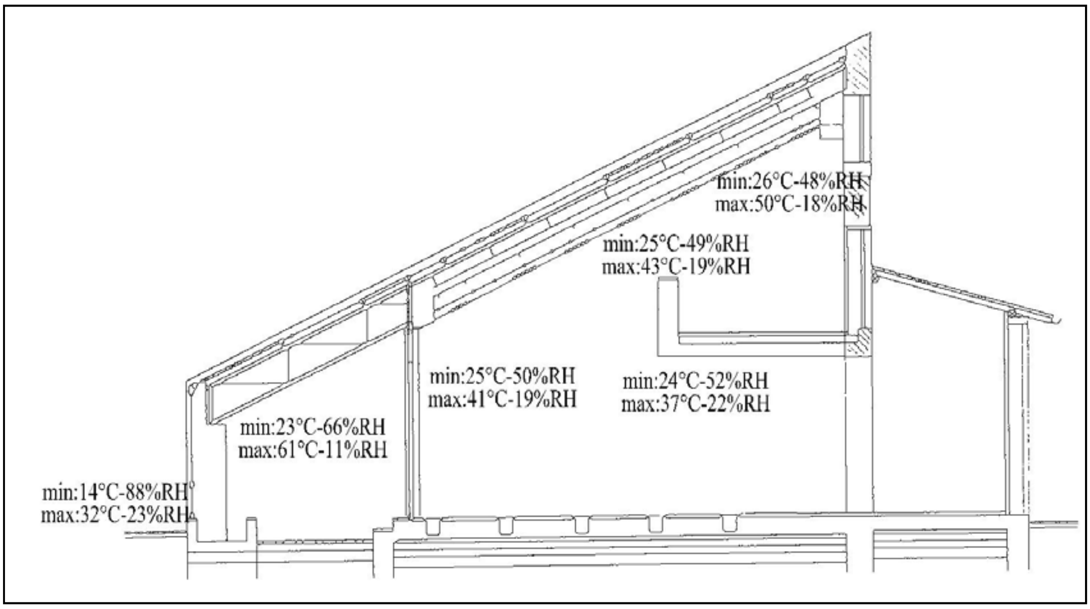


Figure 4.8 Section showing the maximum and minimum temperature and humidity values at different locations of the Solar Building (19-26 July 2009)

According to Figure 4.7 and Figure 4.8, the exterior relative humidity varied from 23% to 88%. Figure 4.6 shows that the interior humidity values had smaller fluctuations compared to the exterior ones for both buildings. The fluctuations in humidity values were similar at all locations except room 5 in MATPUM Building which had stable humidity during the selected days. As it is seen from the graph, humidity at all locations except room 5 fluctuated in parallel to exterior humidity. The minimum humidity values in Solar Building, especially in conservatory, were lower than the ones in MATPUM Building keeping with the temperature fluctuations.

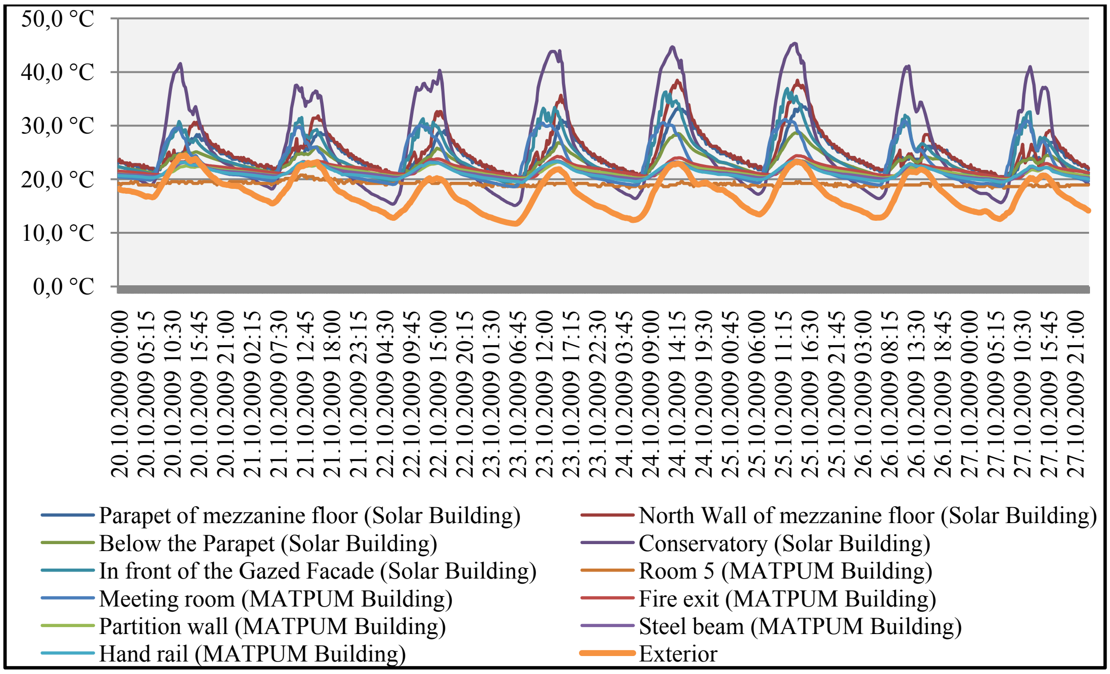


Figure 4.9 Temperature chart of the MATPUM Building & Solar Building (20-27 July 2009)

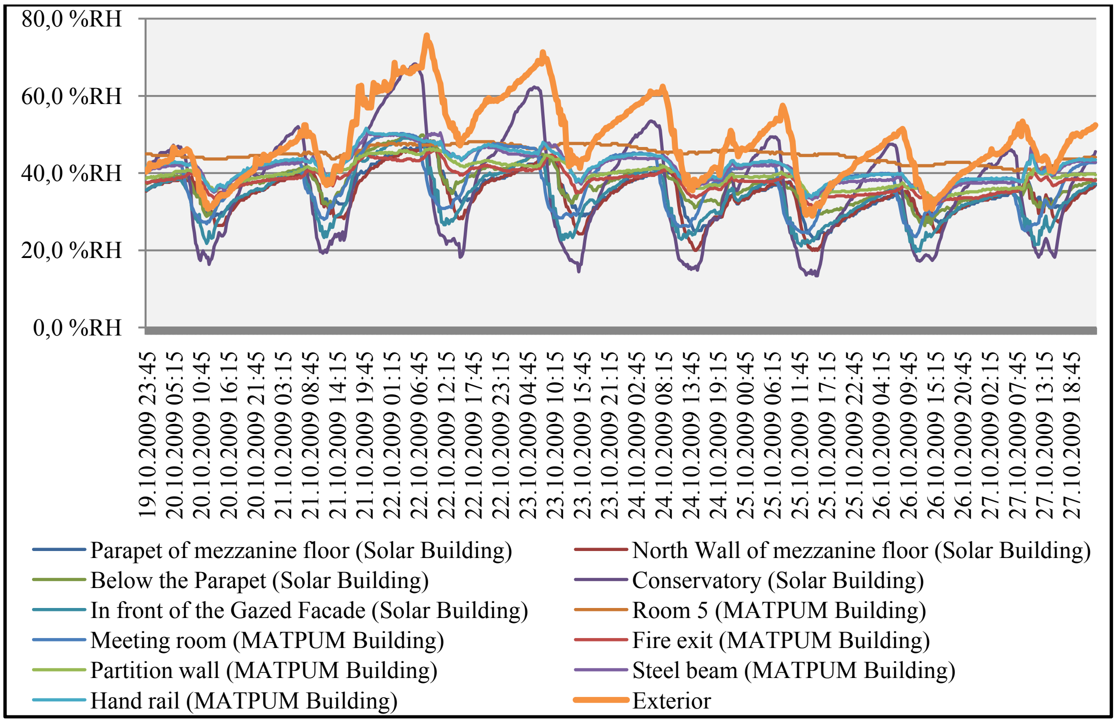


Figure 4.10 Humidity chart of the MATPUM Building & Solar Building (20-27 July 2009)

Table 4.3 Temperature & Humidity values of the MATPUM Building & the Solar Building (20-27 October 2009)

LOCATION	DATA LOGGER	FIGURE	MIN TEMPERATURE	MAX TEMPERATURE	FLUCTIATIONS	MIN HUMIDITY	MAX HUMIDITY	EXPLANATİONS
Room 5 (MATPUM Building)	DC 2	Figure 3.8a	19°C	20°C	0.5°C	41%	48%	Room was unoccupied and close
Meeting Room (MATPUM Building)	DC 14	Figure 3.8b	19°C	31°C	11°C	25%	50%	Room is facing to south
Fire-exit (MATPUM Building)	DC 15	Figure 3.9a	20°C	24°C	3.5°C	31%	45%	-
Partition Wall (MATPUM Building)	DC 16	Figure 3.9b	20°C	23°C	2°C	33%	46%	The location was in the atrium close to north
Steel Beam (MATPUM Building)	DC 17	Figure 3.10a	20°C	23°C	2.5°C	34%	50%	The location was in the atrium in the middle
Hand Rail (MATPUM Building)	DC 18	Figure 3.10b	20°C	24°C	3.5°C	33%	51%	The location was in the atrium close to the south
Parapet (Solar Building)	DC 1	Figure 3.12	20°C	34°C	8°C	23%	48%	The space was mostly occupied areas
North wall (Solar Building)	DC 04	Figure 3.13a	21°C	38°C	VARİABLE	20%	48%	The space was mostly occupied areas
Below the Parapet (Solar Building)	DC 11	Figure 3.13b	20°C	29°C	6°C	27%	50%	The location was under the slab of mezzanine floor
Conservatory (Solar Building)	DC 12	Figure 3.14a	15°C	45°C	VARİABLE	14%	68%	It is a glazed sunspace facing south
In front of the glazed facade (Solar Building)	DC 13	Figure 3.14b	19°C	36°C	VARİABLE	21%	49%	The location was between main building and conservatory

Figure 4.9 shows the temperature chart for six interior spaces in the MATPUM Building and five interior spaces in the Solar Building and for the exterior from 20th to 27th October, 2009. It can be seen from the chart that the exterior temperature fluctuated between 12 °C and 24 °C during mentioned days.

The interior temperatures in MATPUM Building did not vary in the same way when compared to the exterior ones, except for the meeting room. It can be seen from the chart that the temperatures in this location were very higher and had higher daily fluctuations than the ones in other five locations. Since meeting room is facing to the south, the interior temperature increased due to direct sunlight during day time, whereas there was considerable decrease in temperature during night time due to heat loss from the adjacent glazing. On the other hand, the interior temperatures in the Solar Building, especially in the conservatory, were higher compared to the exterior ones. Since it is a sun space which is composed of glazed south facing surfaces of facades and roof, the temperatures in the conservatory fluctuated more than the ones in other spaces.

On the other hand, since the room 5 was an unoccupied room which is located on the north façade of the building and was kept closed, no heat gain from the incident sun, occupants, equipments or convectional air currents took place in this room. Therefore, the temperature in this room mostly stayed stable.

According to Table 4.3, the temperature in front of the glazing, which is a boundary between conservatory and the main building, had lower daily fluctuations when compared to the ones in conservatory. The temperatures around the parapet and north wall of the mezzanine floor were also lower than the the ones in conservatory. However these two locations had higher daily fluctuations when compared to other locations except conservatory due to slope of the roof which caused collection of heat in these locations. The temperature, especially upper temperature values and daily fluctuations, below the parapet differed from the ones around parapet of mezzanine floor, although the one was just below the other.

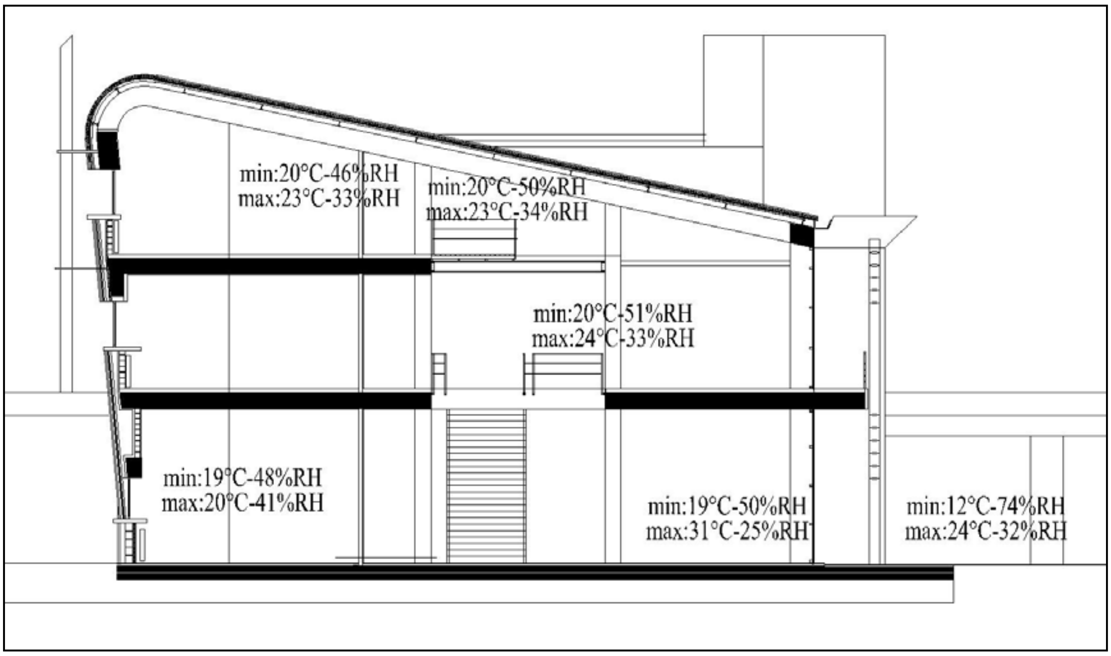


Figure 4.11 Section showing the minimum and maximum temperature and humidity values at different locations of the MATPUM Building (20-27 October 2009)

As it can be seen from the Figure 4.11, temperature values and daily fluctuations in fire-exit, around hand rail, steel beam and partition wall were very similar to each others. Solar radiation penetrated through glazed façade from the south and provided heat gain for the inside. Although these spaces were not subjected to direct sunlight in daytime, temperature increase resulted from heat gain from the south façade due to convection.

According to Figure 4.10, the exterior relative humidity varied from 32% to 74%. The interior humidity values in MATPUM Building had smaller fluctuations compared to the exterior ones except for the Meeting room. As it is seen from the graph, humidity at this location fluctuated in parallel to exterior humidity. The reason for this is air infiltration through building envelope from the glazed south façade. The humidity in Room 5 mostly stayed stable, because the room was kept closed and unoccupied. On the other hand, the humidity in remaining four locations had smaller fluctuation in keeping with the temperature fluctuations.

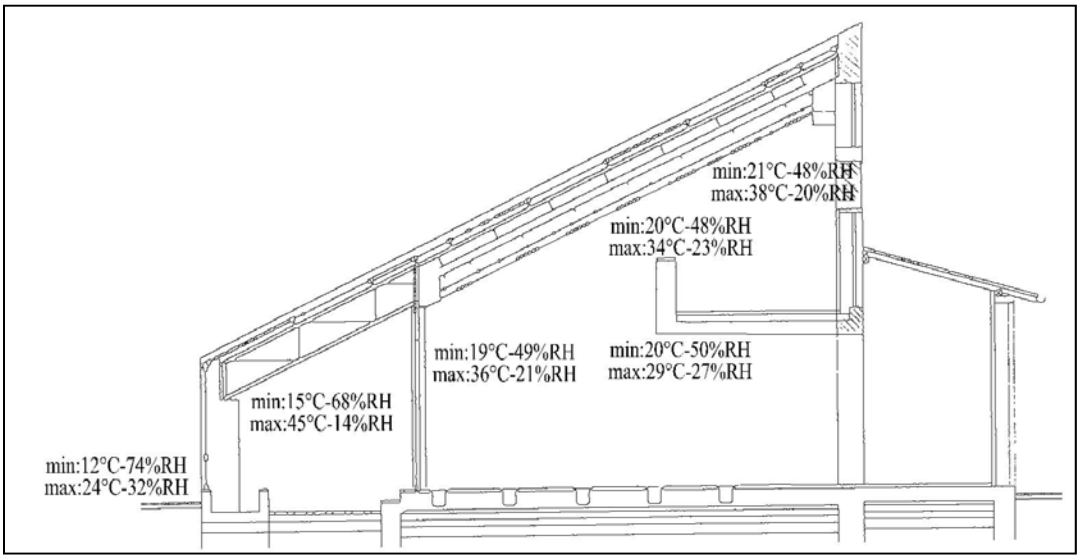


Figure 4.12 Section showing the maximum and minimum temperature and humidity values at different locations of the Solar Building (20-27 October 2009)

The interior humidity values in Solar Building had smaller daily fluctuations except the onesin conservatory. The humidity in the conservatory had higher daily fluctiations in keeping with the temperature fluctuations. The higher the temperature, the lower the humidity was. The reason for this increase is that there was huge heat gain due to solar radiation during the daytime and this heat gain was subjected to colder glazed conservatory surfaces during the nighttime. Therefore, condensation occured and then, this caused increase in humidity at nighttime. The humidity at ground floor was higher than the one in mezzanine floor with reference to tremperature values at these locations.

4.2 Analysis of Variance (AnoVa) Method

In this part of the study, the temperature data collected from two locations of case study buildings, namely partition wall in the MATPUM Building and north wall in the Solar Building, 19^{th} to 26^{th} July, 2009 were compared bu using AnoVa method. The aim is to show variance of heat gain which was obtained from these buildings which have different types of sun spaces.

Table 4.4 Summary of the temperature data collected from case study buildings (19-26 July 2009)

Groups	*Count*	*Mean*	*Variance*
DC-16 Partition wall in the MATPUM Building	768	26,42	1,66
DC-4 North wall in the Solar Building	768	34,99	34,77

Mean and variance values of the number of 768 temperature data collected from two different locations, namely partition wall in the MATPUM Building and north wall in the Solar Building, is presented in Table 4.4. As it can be seen from the table, mean value of temperature data collected from around the partition wall in the MATPUM Building was lower than the mean value of temperature data collected from around the north wall in the Solar Building. The reason is that the temperature values obtained from the Solar Building were higher due to effect of heat gain resulted from solar radiation in conservatory.

Table 4.5 AnoVa table for the temperature data collected from case study buildings (19-26 July 2009)

Source of Variation	*df*	*SS*	*MS*	*F*	*P-value*
Among Groups	1	28198,41	28198,41	1547,79	1,19E-234
Within Groups	1534	27947,14	18,22		
Total	1535	56145,55			

The variance between two sets of data is presented in AnoVa Table (Table 4.5). In the first column of the the table, the sources of variation, namely among groups and within groups, are presented. In the second column, degrees of freedom (df) is shown. Sum of squared deviations (SS) and mean squares (MS) of the collected temperature data are indicated in third and forth columns respectively. F-value and P-value (level of significance) are presented in fifth and sixth columns respectively. As it can be infered from this table, there are significant difference between two groups which are composed of the two sets of temperature data collected from two different locations.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

Together with the increase in energy prices, air pollution and decrease in fossil fuels buildings that are responsive to environmental issues and that have low energy consumption became important in the building industry. Within the framework of this study, the role of sun spaces for achieving energy efficiency in buildings was investigated by recording the temperature and humidity data from two case study buildings with sun spaces, namely MATPUM Building and the Solar Building during two periods; from May to August and from October to November. This chapter presents the conclusion derived from the study and offers some suggestions for further studies.

Sun spaces are incorpareted to the buildings in order to help to buildings' energy demand. They provide solar heat for the buildings during winter time as well as appropriate daylighting. This results in reducing the heating loads and energy demand for the buildings. In this study, the effect of sunspaces on energy efficiency were investigated by collecting temperature and humidity data from two case study buildings. According to this data, the results are revealed below:

- Temperatures in/around the sunspaces were the highest when compared to the other locations. Temperature fluctuations of the outside air affected the interior temperatures of the sun spaces due to solar radiation during daytime and air infiltration during night time.
- The locations at mezzanine floor had higher temperatures when compared to the ones at ground floor in both buildings.
- The temperature and humidity measurements mostly stayed stable in an unoccupied and closed room (Room 5 in MATPUM Buiding)
- Being very close to the building envelope affected the temperature and humidity values at those locations. To illustrate, the nighttime temperature around the roof structural element decreased due to heat loos from the roof. Similarly, the nighttime temperature in meeting room decreased due to heat loss from the adjacent glazing.

The two case study buildings have different kind of sun spaces which are facing to the south. The MATPUM Building have the atria with south facing glazing and the Solar Building have the conservatory which is attached to main building and composed of glazed facade and roof. When the temperature and humidity data, which was taken from both buildings, was analyzed, it was seen that sun spaces belonging to both buildings revealed different results when compared to each other. The results of the comparison are explained below:

- The temperature values which were gathered from the conservatory in the Solar Building were much higher than the ones in the atrium in MATPUM Building within the same time period. Since the sun spaces distrubuted the collected heat through the indoor environments, the temperatures in the sun spaces also affacted the interior temperatures. The interior temperatures in the Solar Building were higher when compared to the ones in the MATPUM Building.
- In keeping with the temperature values, humidity in both sun spaces and interior spaces revealed different results in range. The humidity values were

higher in the Solar Building than the ones in the MATPUM Building within the same time period.

The temperature data collected from two different locations of two case study buildings, namely partition wall in the MATPUM Building and north wall in the Solar Building, were compared by using the analysis of variance method. This method proved that there was a significant temperature difference between these two buildings. This means that temperature values in the Solar Building higher than the ones in the MATPUM Building. the reason for this is that conservatory in the Solar Building collects more heat gain which is resulted from solar radiation when compared to atria in the MATPUM Building.

Although it is important to obtain heat gain from the sun spaces during the winter periods in order to reduce the heating loads, the heat gain from the sun spaces, especially from the conservatory caused overheating during especially the summer season. This problem can be solved by taking some precautions and making necessary interventions which are listed below:

- The effects of the heat gain resulted from the solar radiation can be reduced by making maintenance on ventilation system of the conservatory during summer periods. Therefore, the stored heat can be allowed to go out.
- External movable shading devices can be used to control the solar energy penetrating through the glazing.

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APPENDICES

APPENDIX A

TECHNICAL DRAWINGS OF THE MATPUM BUILDINGS

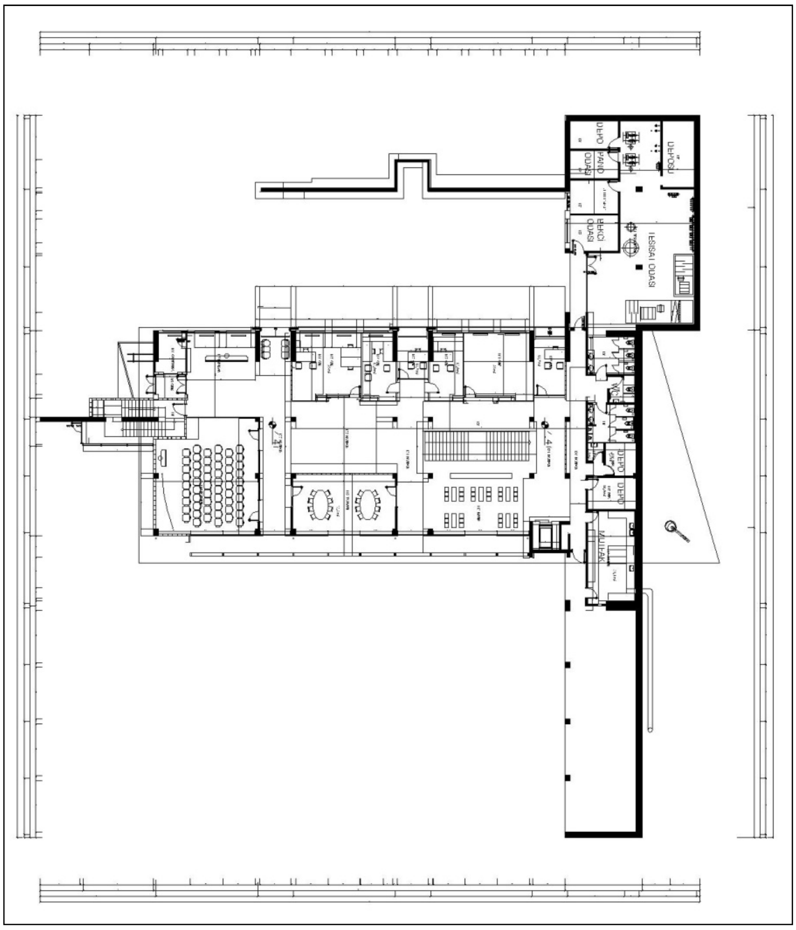

Figure A.1 Lower Ground Floor of MATPUM Building

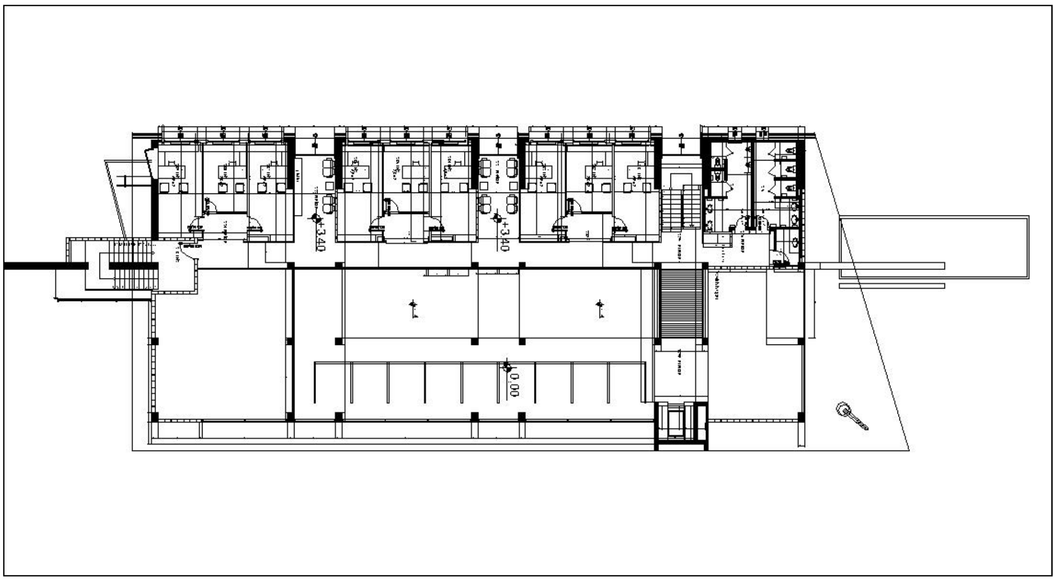

Figure A.2 Upper Ground Floor of MATPUM Building

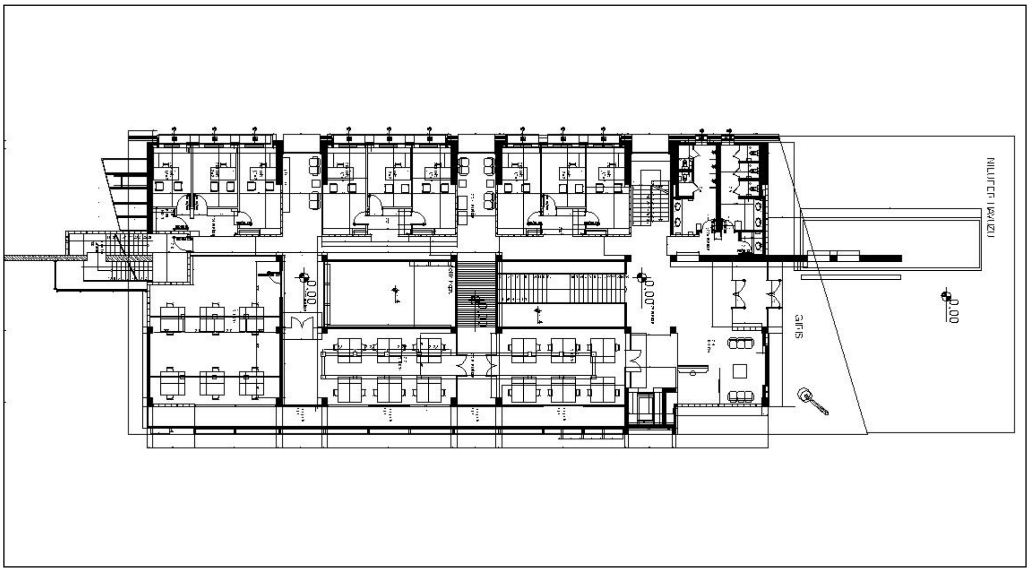

Figure A.3 Mezzanine Floor of MATPUM Building

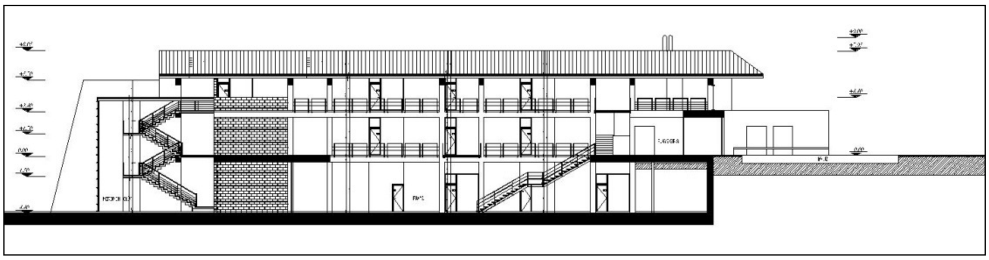

Figure A.4 Longitudinal Section of MATPUM Building

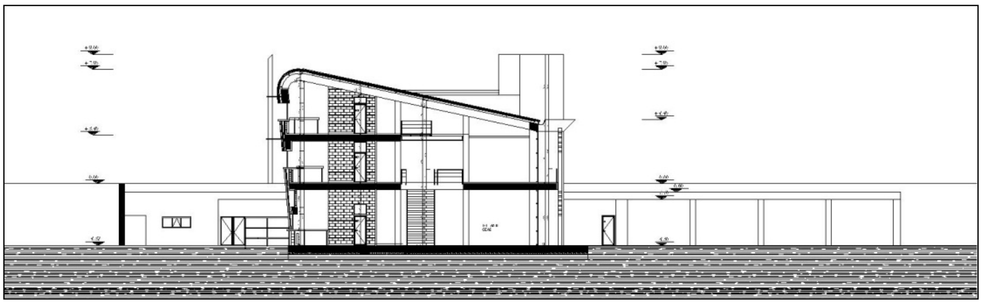

Figure A.5 Cross Section of MATPUM Building

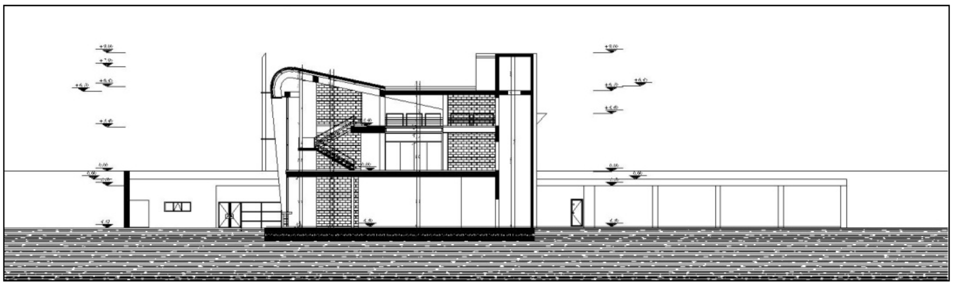

Figure A.6 Cross Section of MATPUM Building

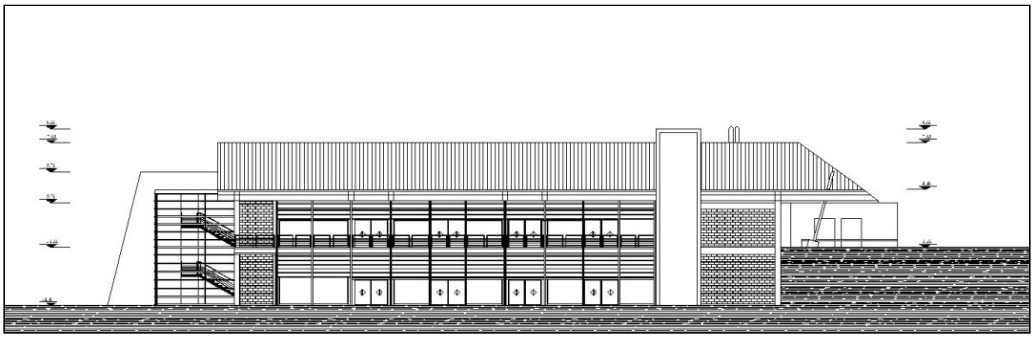

Figure A.7 South Elevation of MATPUM Building

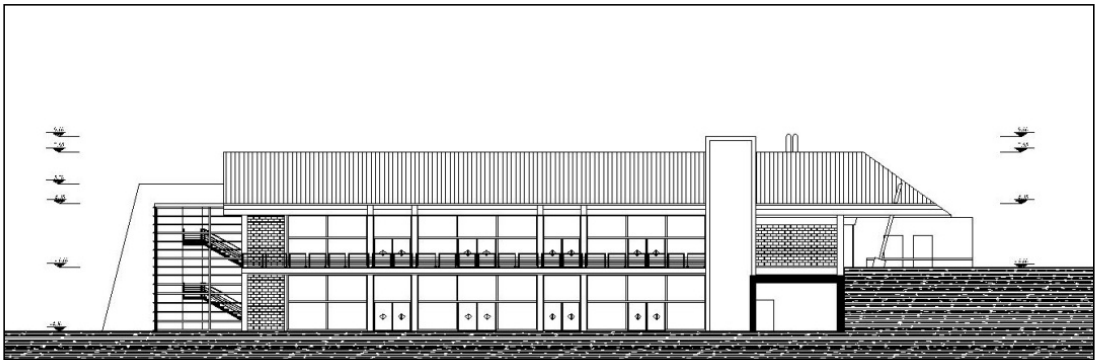

Figure A.8 Inner South Elevation of MATPUM Building

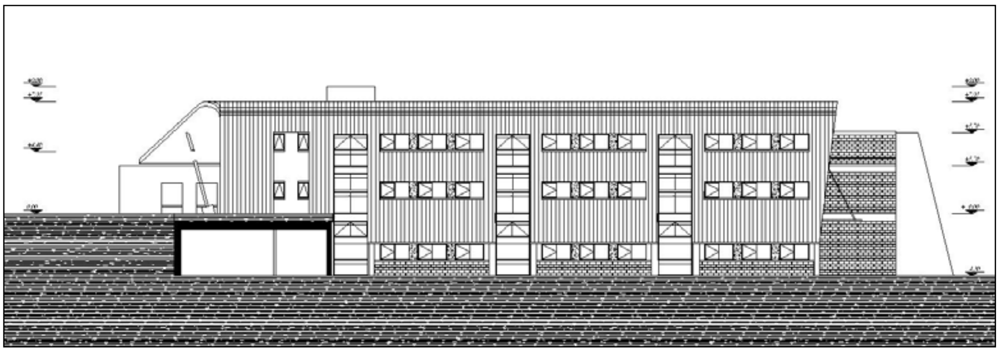

Figure A.9 North Elevation of MATPUM Building

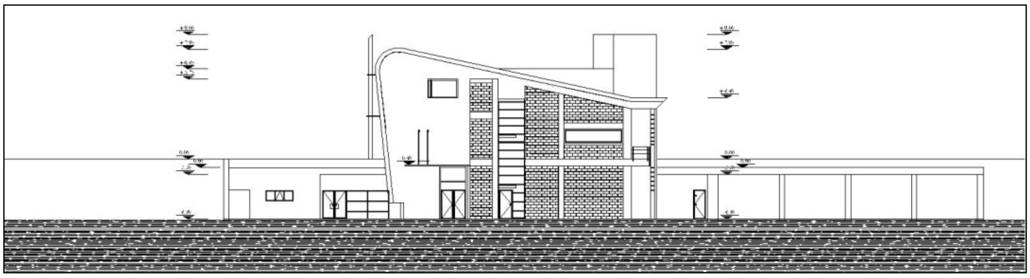

Figure A.10 West Elevation of MATPUM Building

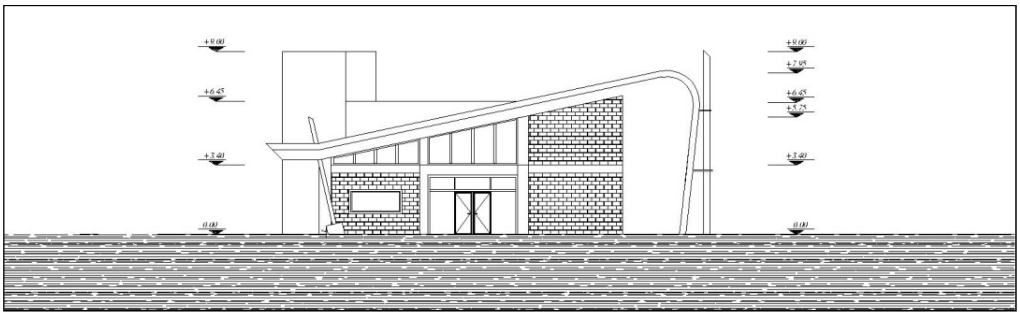

Figure A.11 East Elevation of MATPUM Building

Figure A.12 Site plan of MATPUM Building

APPENDIX B

TECHNICAL DRAWINGS OF THE SOLAR BUILDING

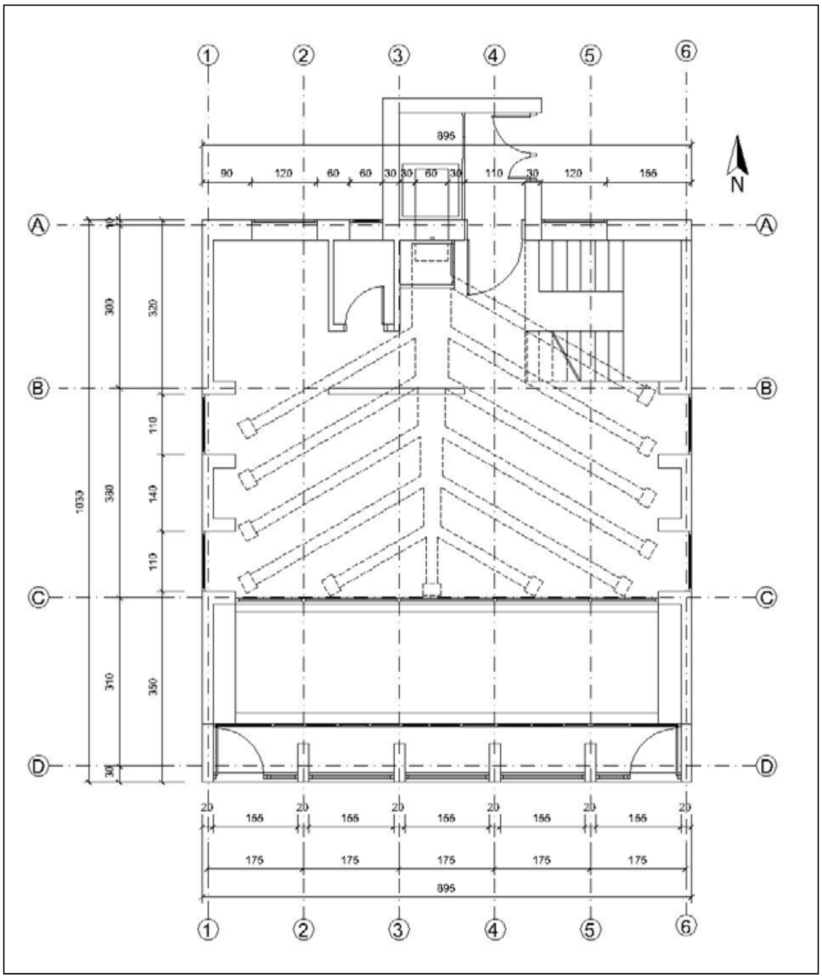

Figure B.1 Plan of Solar Building

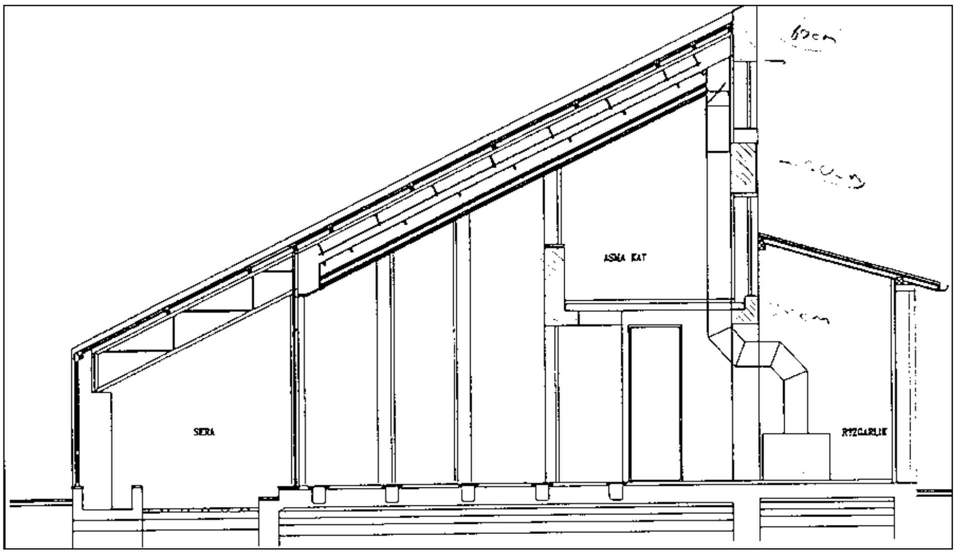

Figure B.2 Section of Solar Building

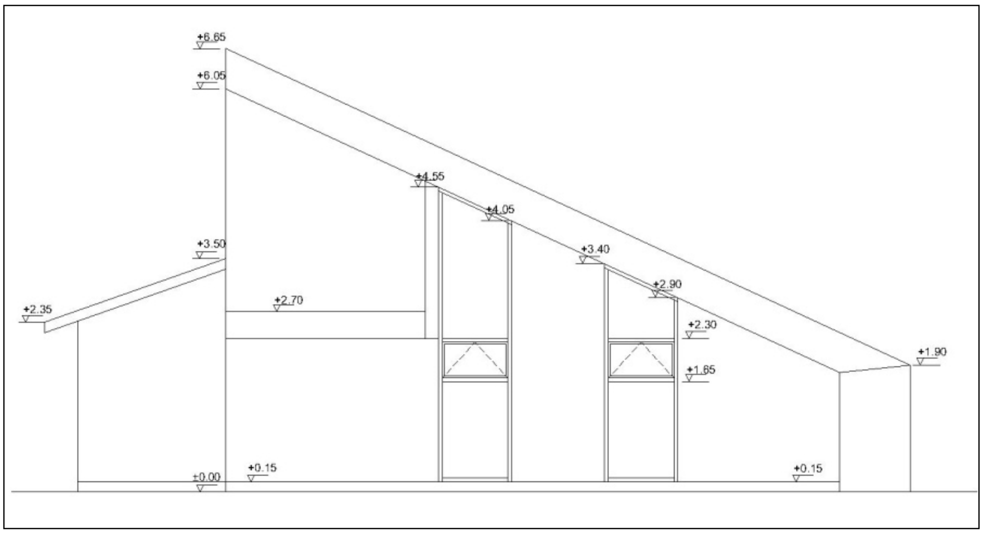

Figure B.3 West Elevation of Solar Building

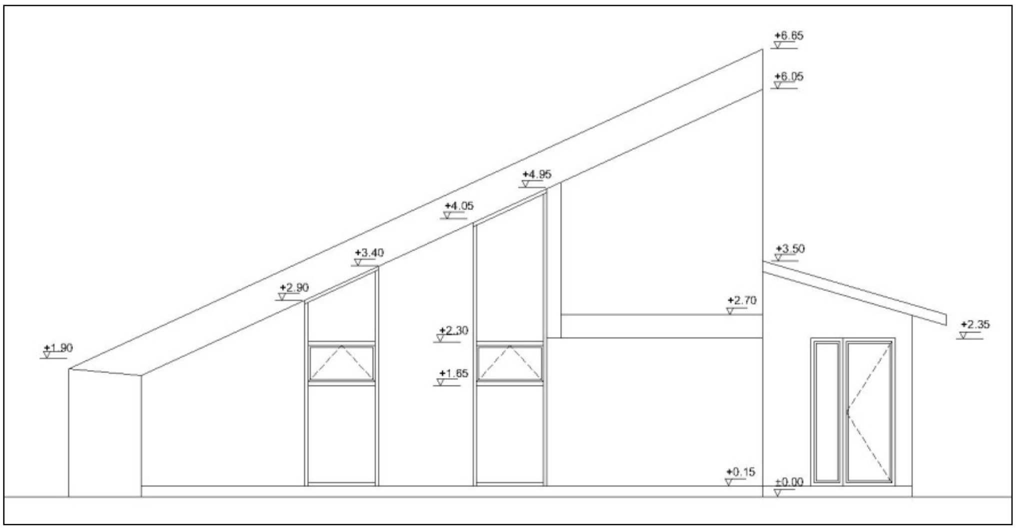

Figure B.4 East Elevation of Solar Building

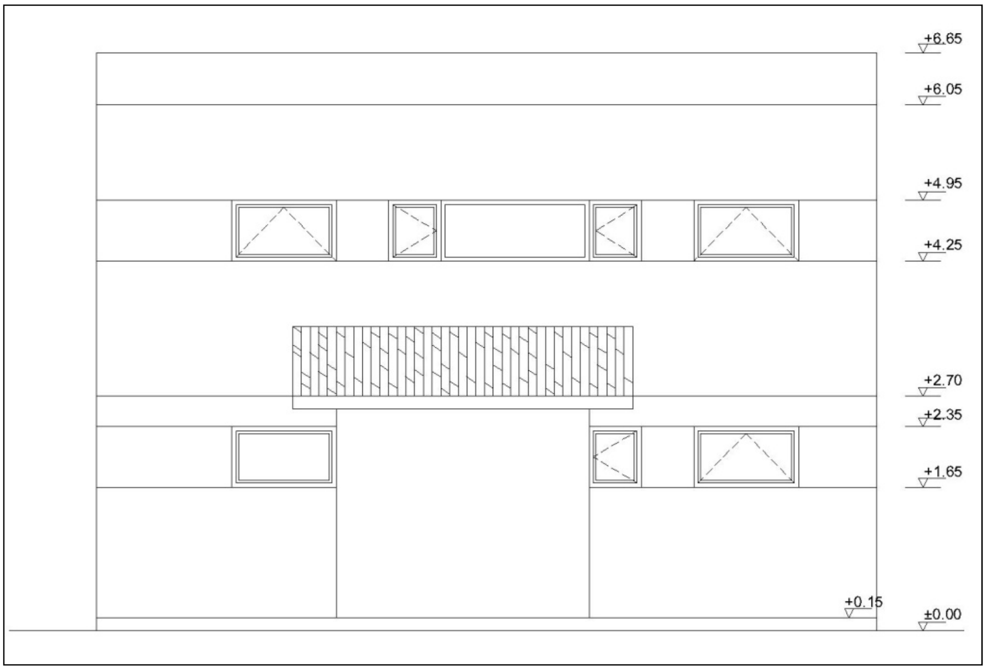

Figure B.5 North Elevation of Solar Building

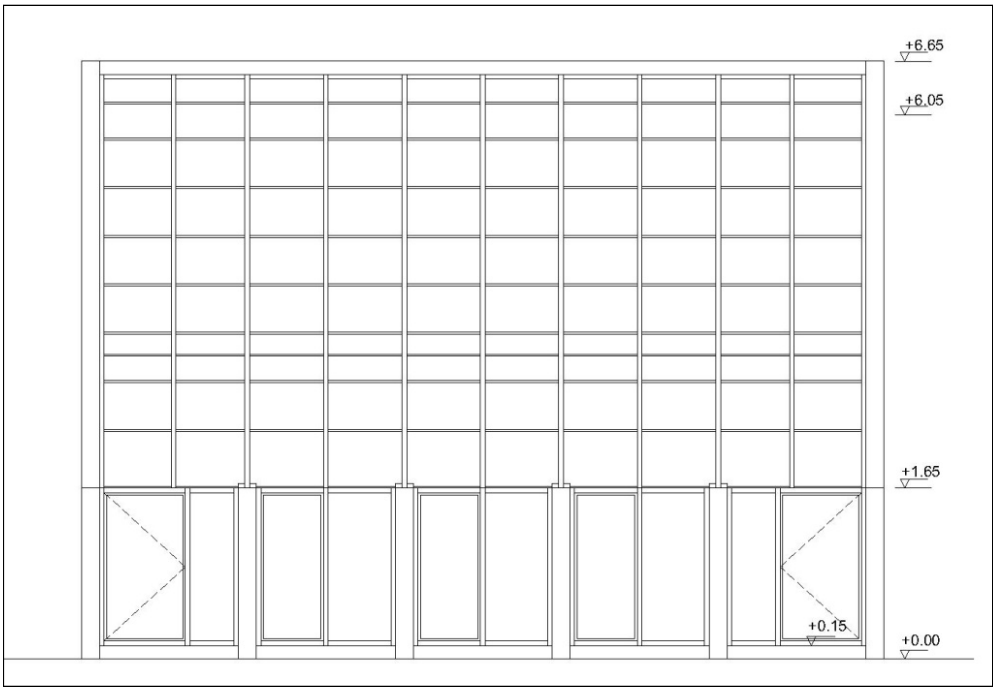

Figure B.6 South Elevation

APPENDIX C

TEMPERATURE AND HUMIDITY CHARTS FOR FIRST SET OF DATA AND SECOND SET OF DATA

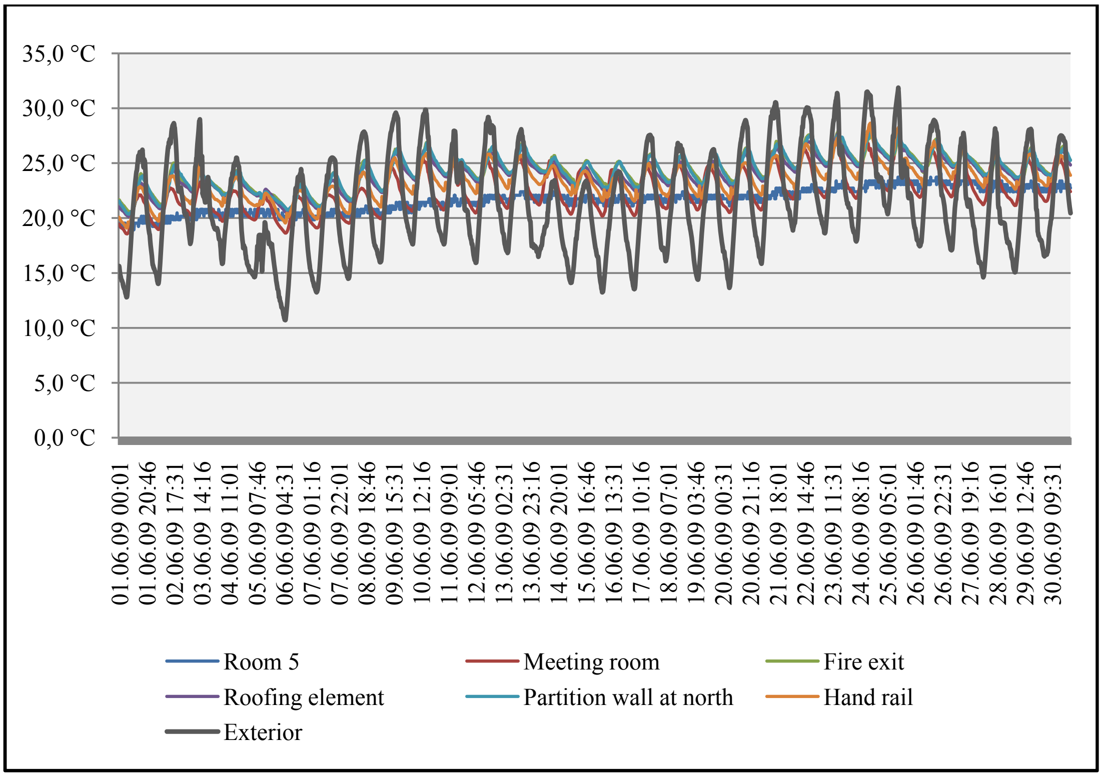

Figure C.1 Temperature chart of the MATPUM Building (01-30 June 2009)

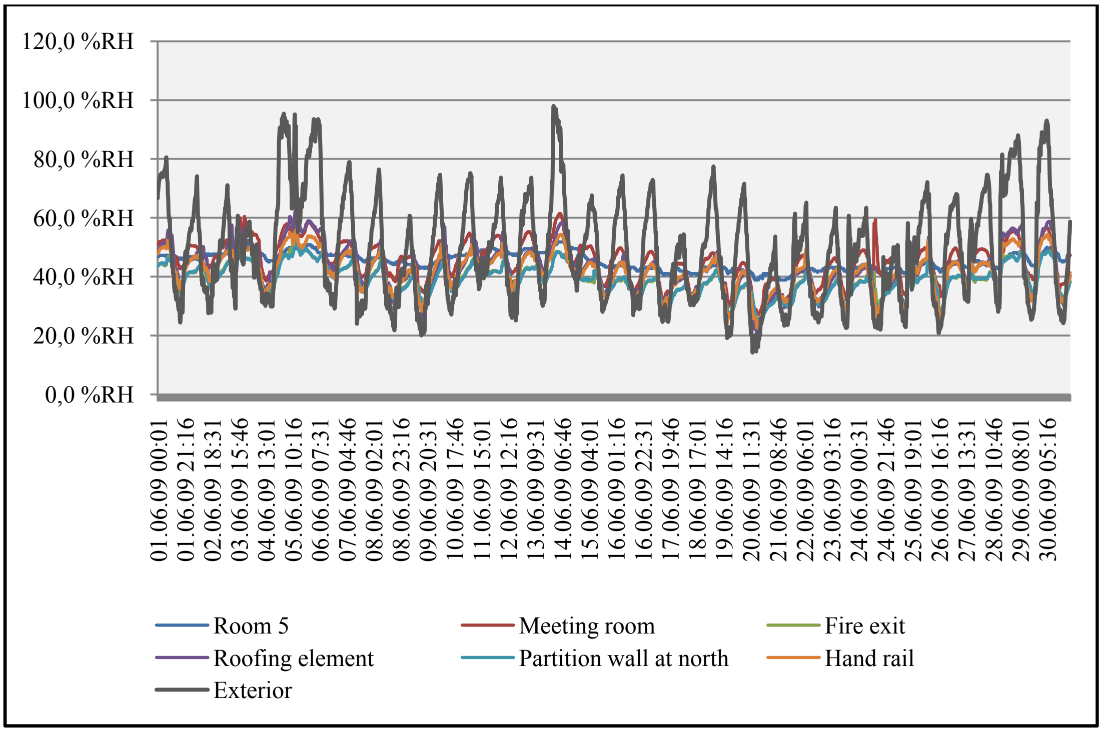

Figure C.2 Humidity chart of the MATPUM Building (01-30 June 2009)

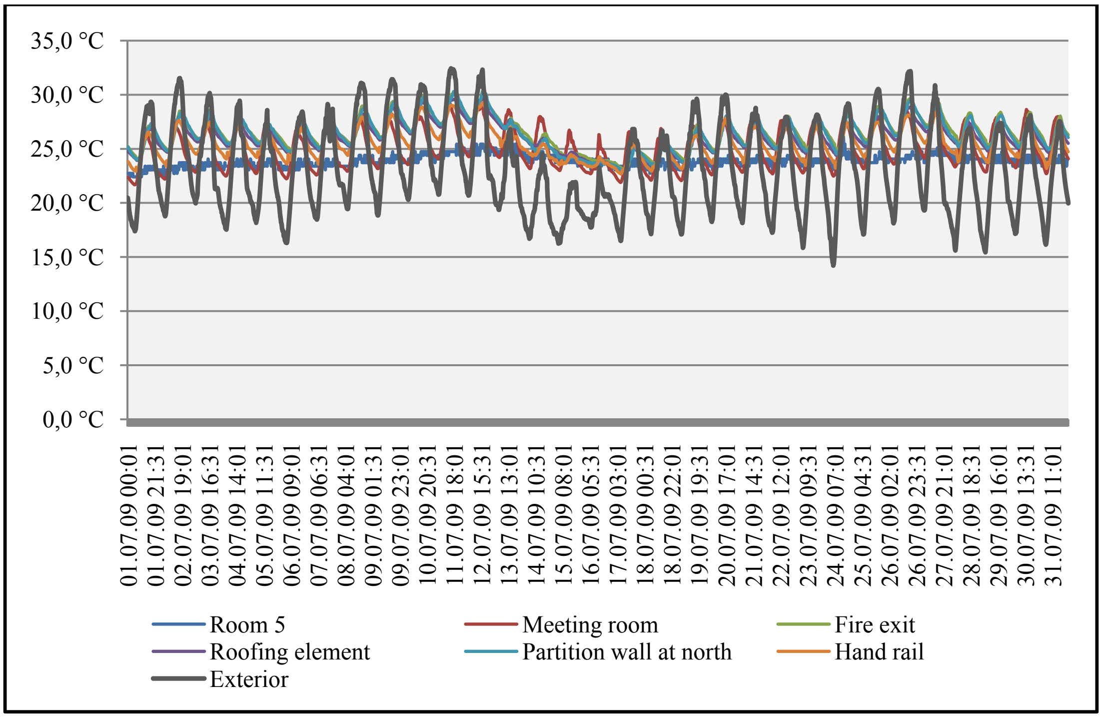

Figure C.3 Temperature chart of the MATPUM Building (01-31 July 2009)

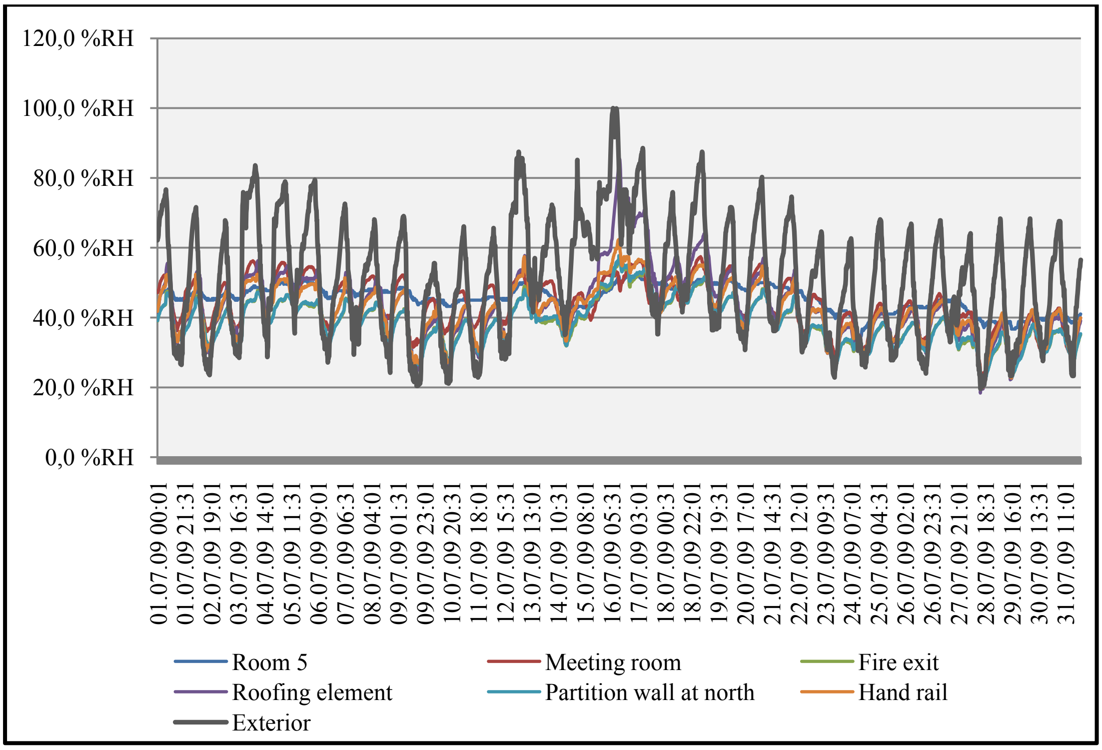

Figure C.4 Humidity chart of the MATPUM Building (01-31 July 2009)

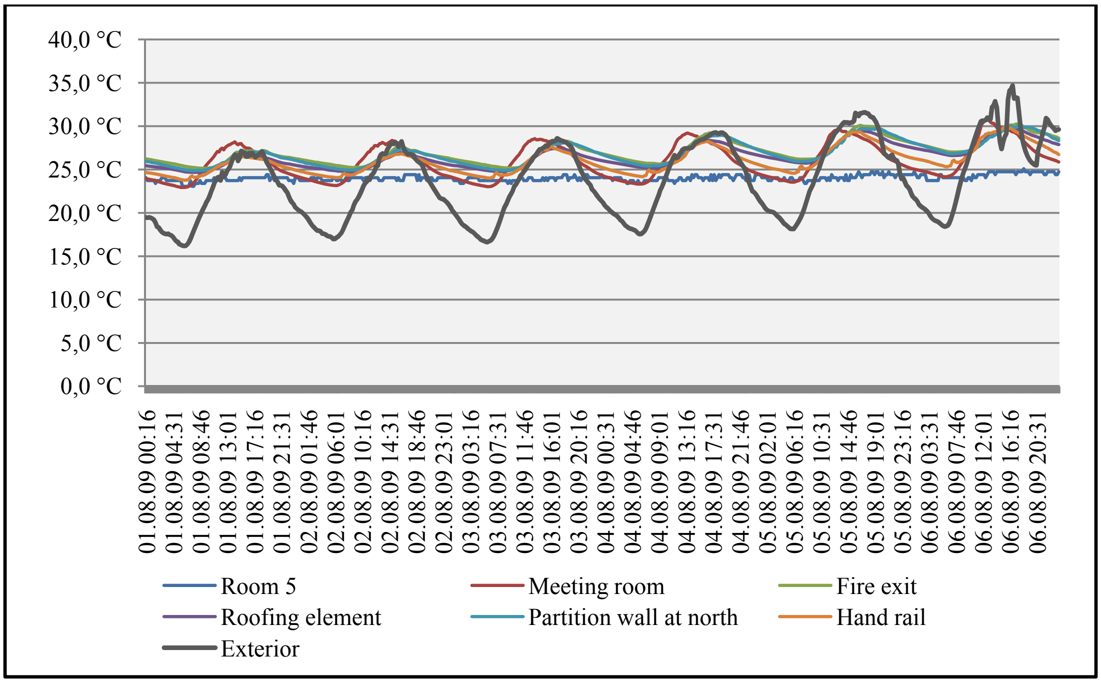

Figure C.5 Temperature chart of the MATPUM Building (01-08 August 2009)

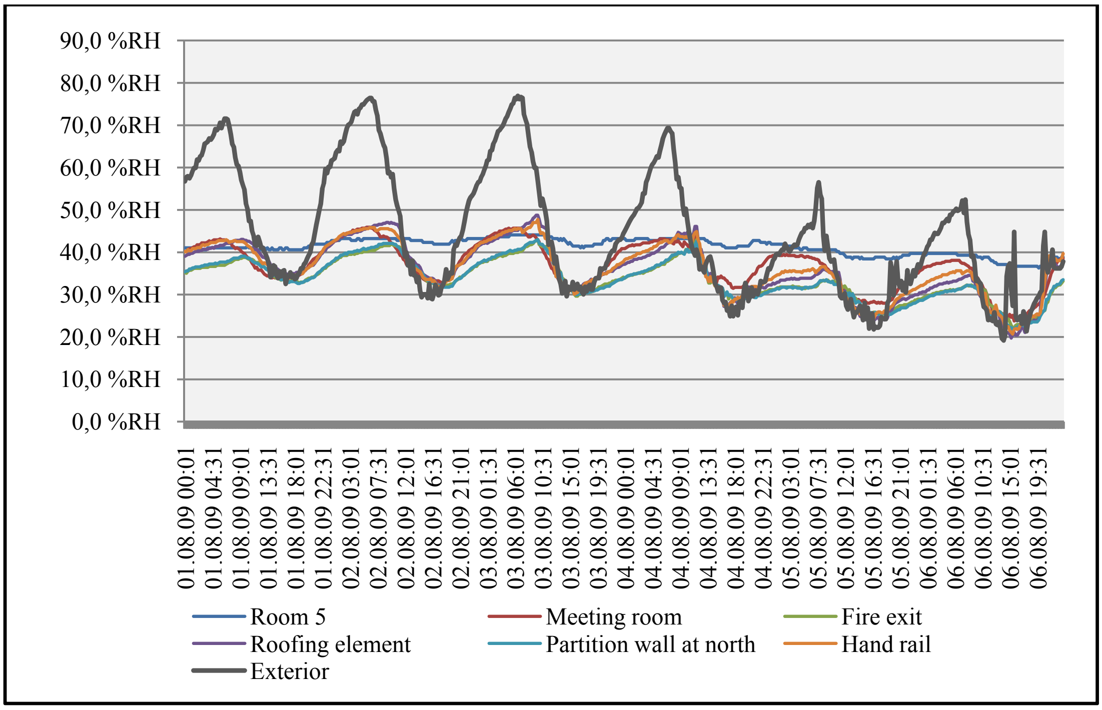

Figure C.6 Humidity chart of the MATPUM Building (01-08 August 2009)

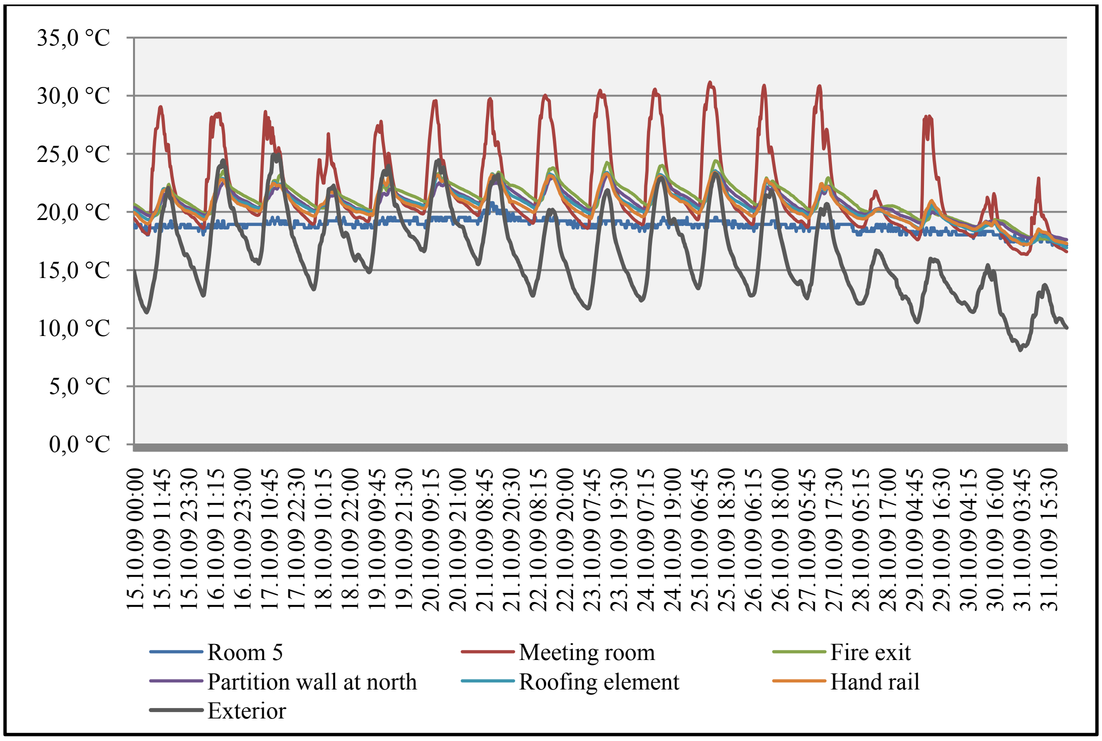

Figure C.7 Temperature chart of the MATPUM Building (14-31 October 2009)

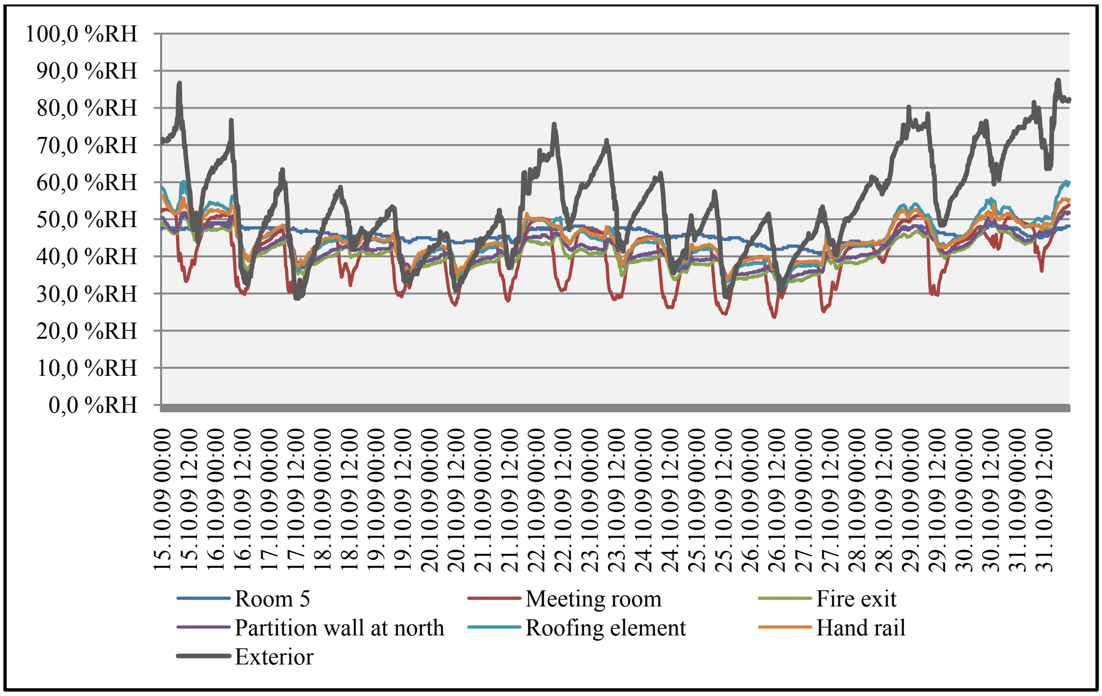

Figure C.8 Humidity chart of the MATPUM Building (14-31 October 2009)

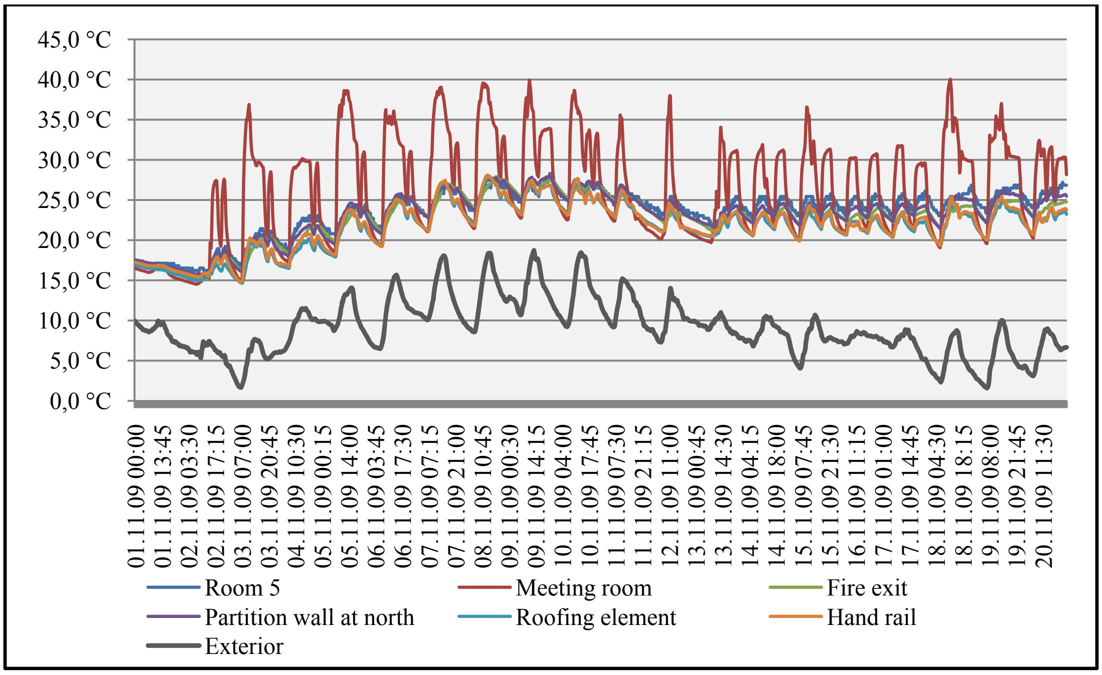

Figure C.9 Temperature chart of the MATPUM Building (01-20 November 2009)

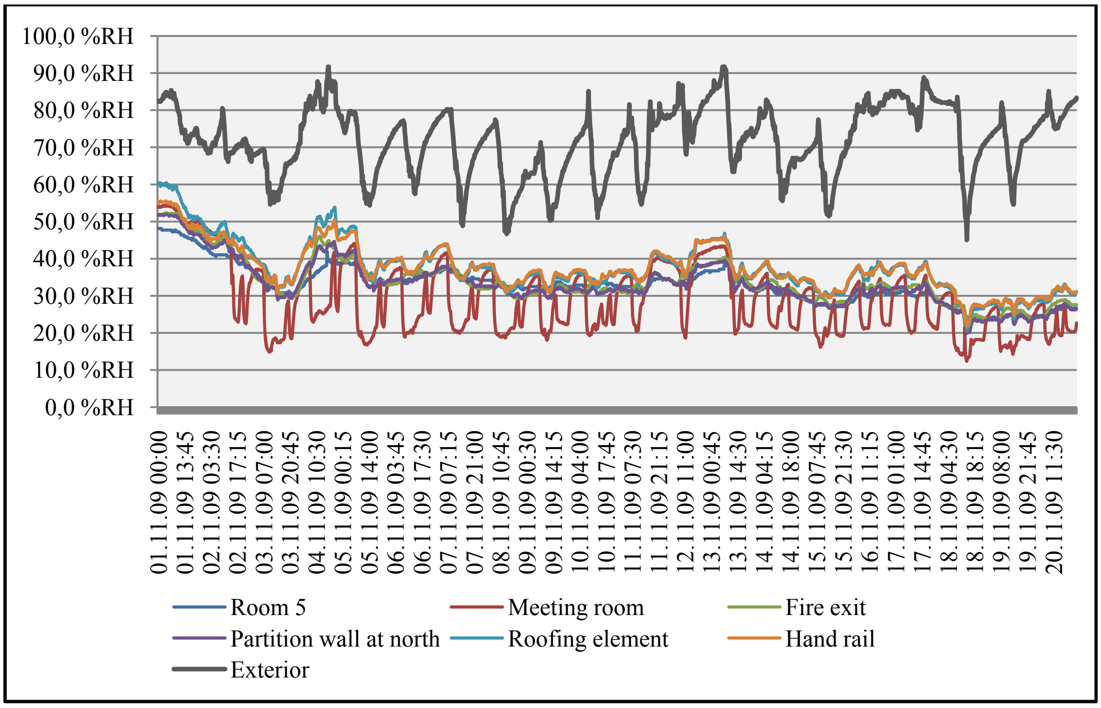

Figure C.10 Humidity chart of the MATPUM Building (01-20 November 2009)

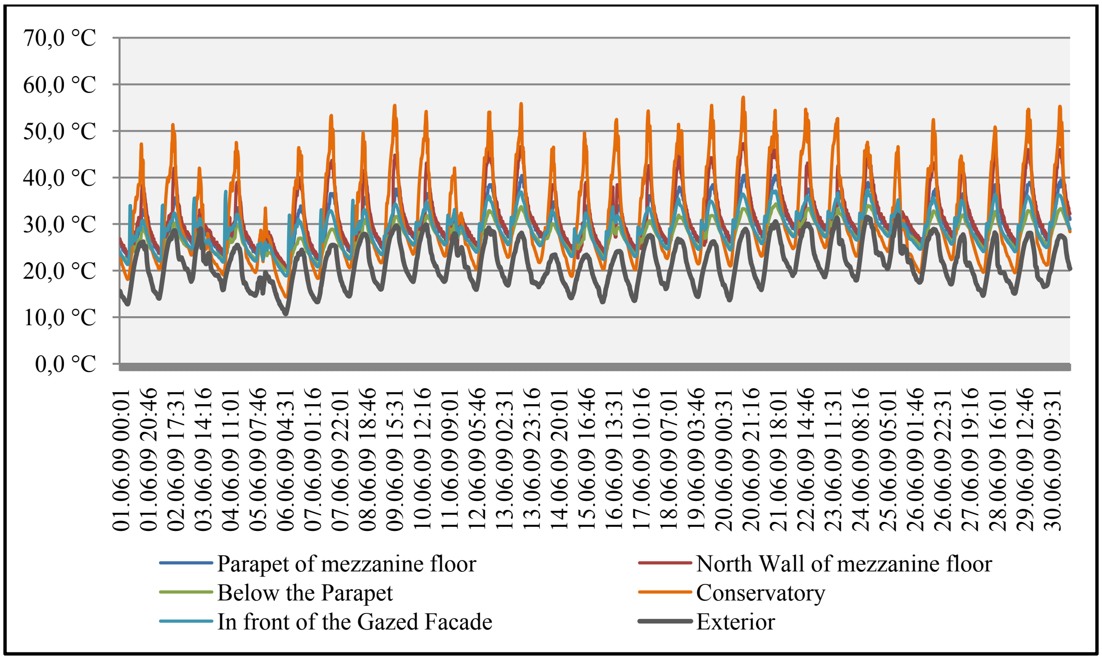

Figure C.11 Temperature chart of the Solar Building (01-30 June 2009)

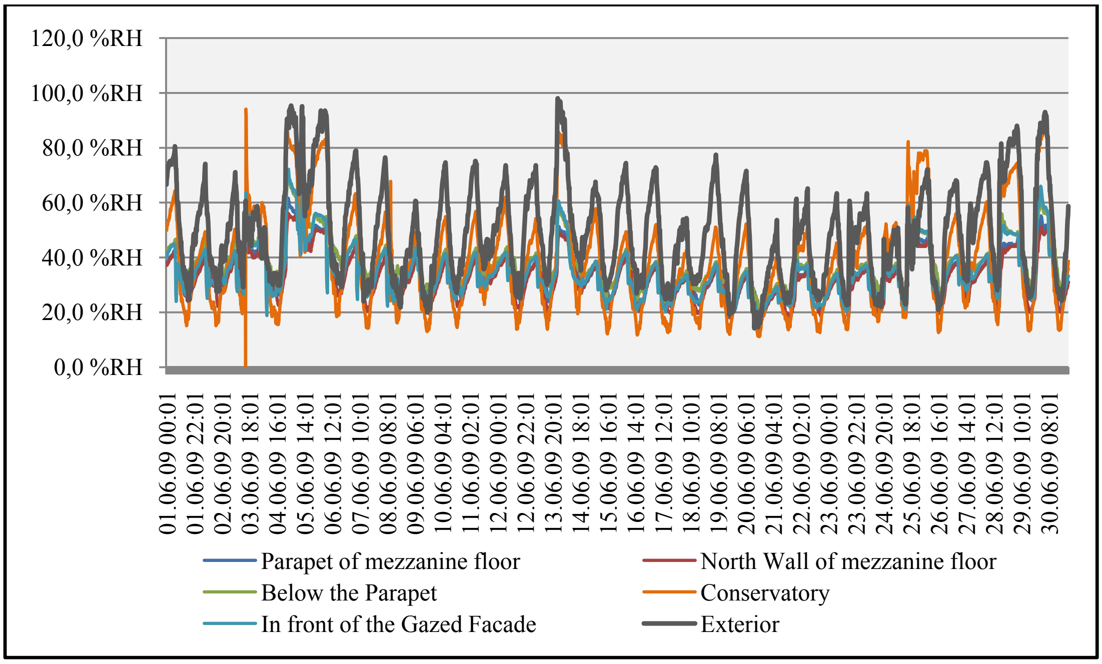

Figure C.12 Humidity chart of the Solar Building (01-30 June 2009)

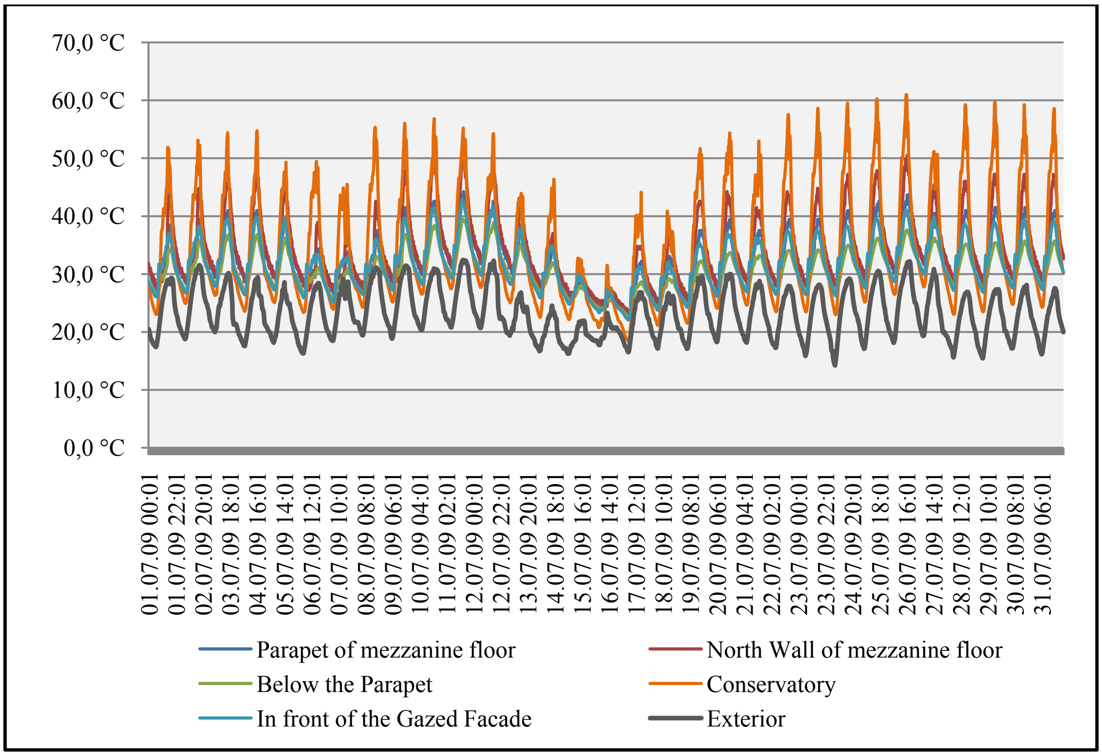

Figure C.13 Temperature chart of the Solar Building (01-31 July 2009)

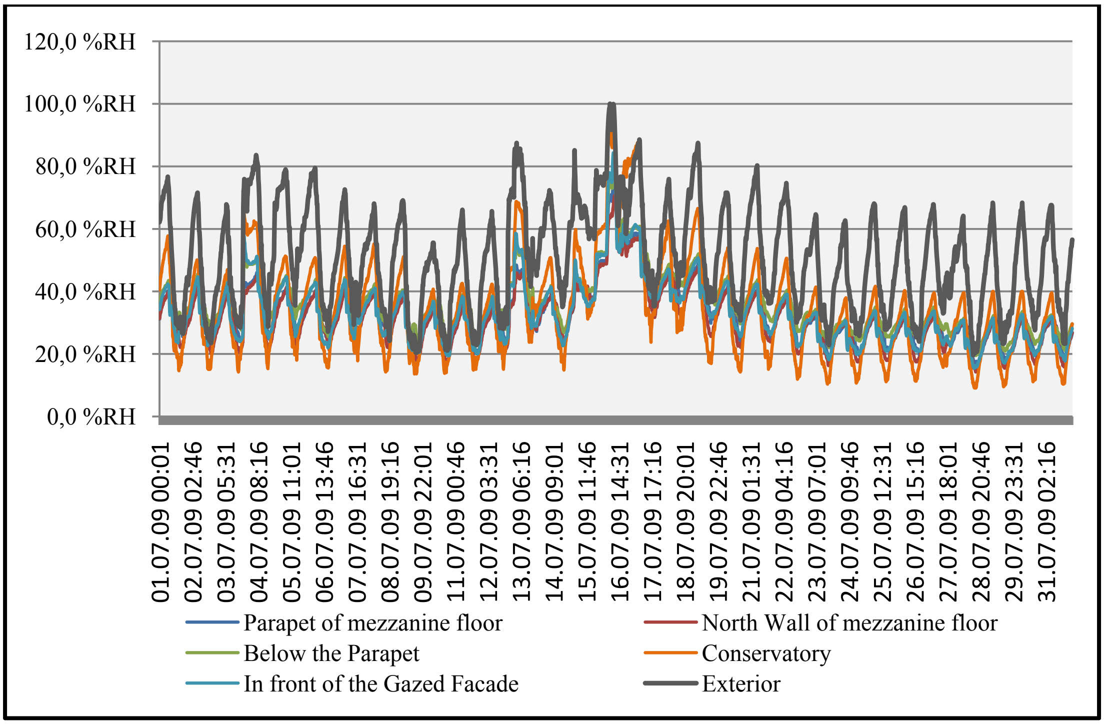

Figure C.14 Temperature chart of the Solar Building (01-31 July 2009)

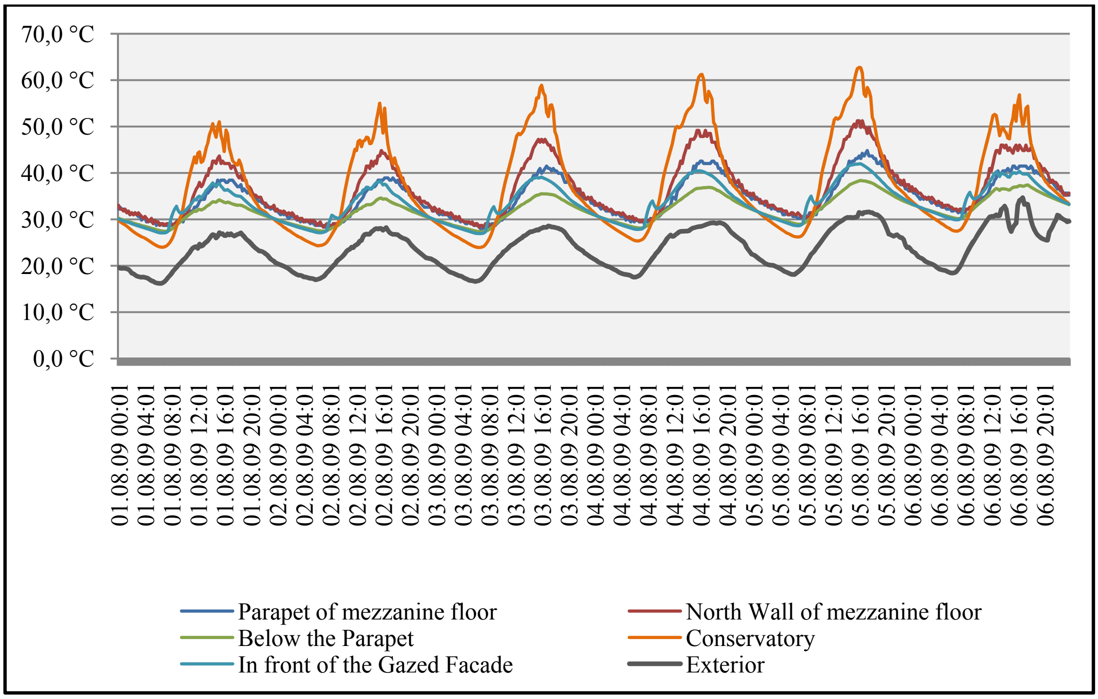

Figure C.15 Temperature chart of the Solar Building (01-06 August 2009)

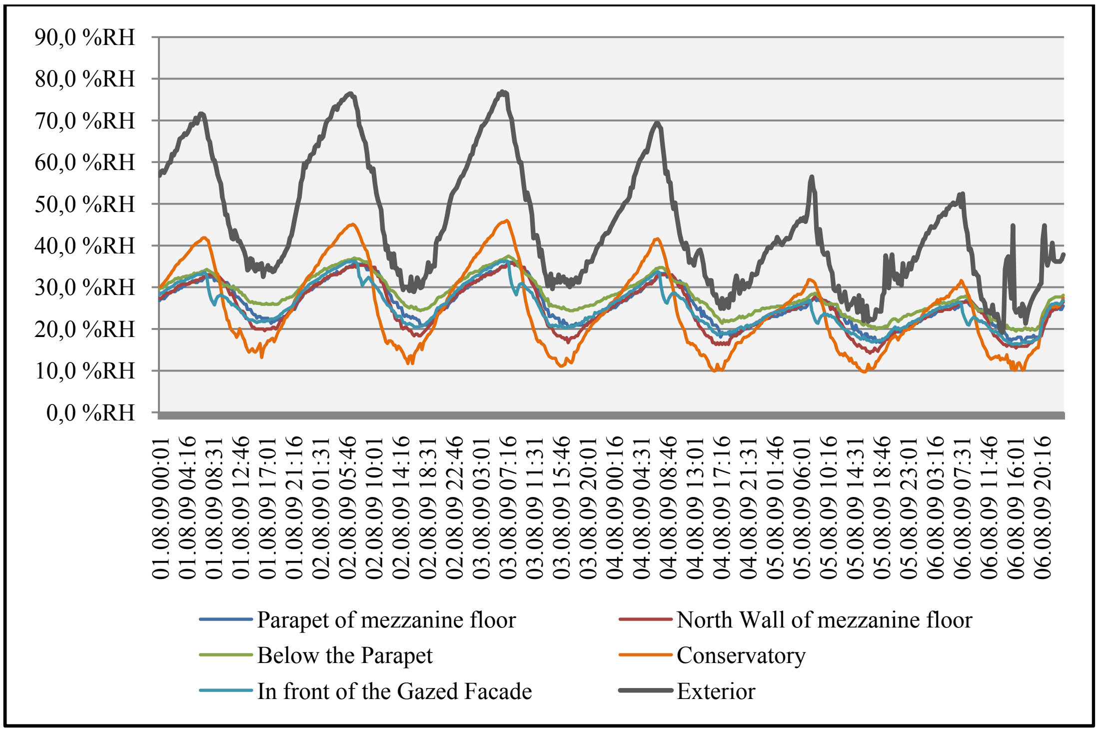

Figure C.16 Humidity chart of the Solar Building (01-06 August 2009)

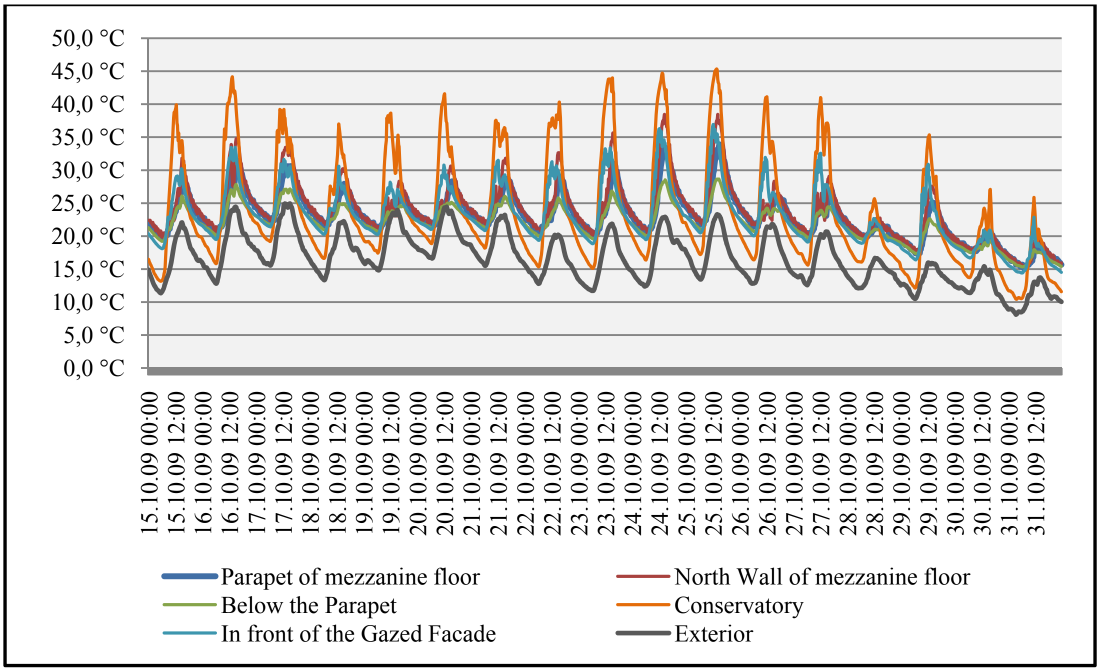

Figure C.17 Temperature chart of the Solar Building (15-31 October 2009)

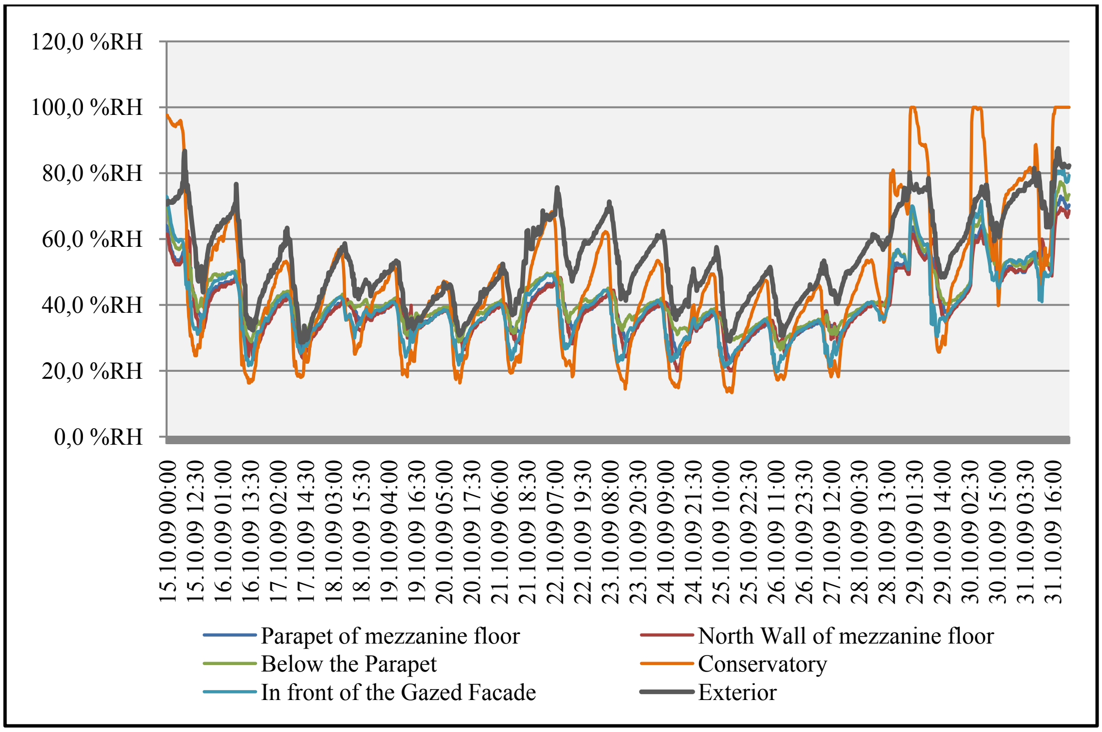

Figure C.18 Humidity chart of the Solar Building (15-31 October 2009)

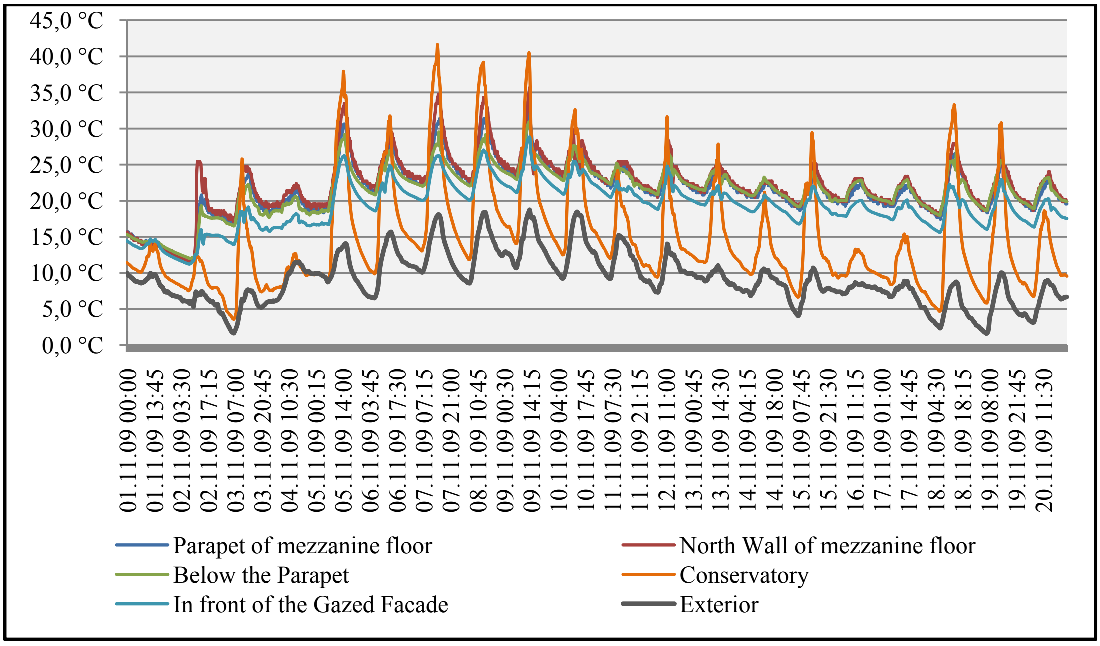

Figure C.19 Temperature chart of the Solar Building (01-20 November 2009)

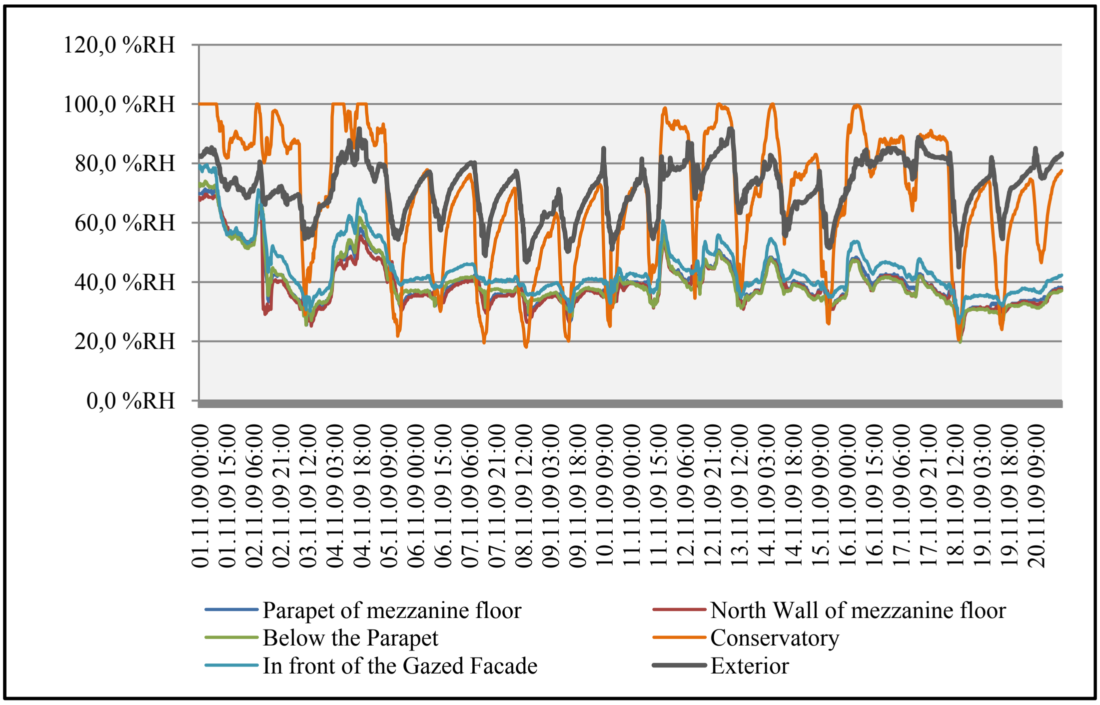

Figure C.20 Humidity chart of the Solar Building (01-20 November 2009)