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THERMAL COMFORT INVESTIGATION OF MULTI-STOREY RESIDENTIAL BUILDINGS IN MEDITERRANEAN CLIMATE WITH REFERENCE TO DARNAH, LIBYA

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ABSTRACT

The main aim of this research is to investigate occupants' thermal comfort and energy performance of multi-storey residential buildings in one of the major cities in Libya (Darnah). The work was implemented in stages as follows:

1. Gathering and analysing real weather data from a number of locations in Libya.
2. Gathering and analysing building data from residential multi-storey blocks in Darnah.
3. Conducting preliminary computer analyses using the above information to get a better idea about thermal conditions inside multi-storey block flats in Darnah.
4. Visiting Darnah and collecting real data using specifically designed survey or questionnaire forms to understand and assess how people feel while living inside their flats.
5. Analysing the computer results and field data and trying to come up with solutions to improve existing multi-storey blocks in terms of indoor climate and energy consumption and introducing guidelines for designers of new buildings in Libya.

The subjective data was collected and tabulated by using a questionnaire, which has been widely used and shown to be effective, to determine people's responds through questions modified especially for the comfort purpose. Questionnaires were collected from households of 12 buildings: involving a total of 337 flats. The questionnaires compare the significance of the thermal sensation, the thermal comfort, and the building design. The results show that the thermal comfort is not satisfied, unless modified, and improving take place in these case study buildings. Thus a modification is proposed, the results from the present study show also that the insulation material is essential in this type of climate and can help to reduce up to 63% of heat gain and a reduction of 6 degrees of indoor temperature. Results also indicate that the construction of residential dwellings using existing materials is less conducive to the climatic conditions of hot dry climates and not suitable for the occupants' requirements of comfort. Human thermal comfort was assessed using the adaptive model, to show that the climate and building's envelope have a significant impact on human comfort perception and indoor environment. This research is mainly aimed at "explaining" the trends in the energy flows within buildings under the climatic conditions of Mediterranean zones and to establish a comfort zone for occupants within this type of climate. The results should help in the formulation of design guidelines for use in the process of building design by builders, architects and engineers. Also this research is in line with the Libyan's government aim to make better use of renewable energy sources such as the sun for keeping buildings comfortable for their occupants.

ACKNOWLEDGMENTS

FIRST OF ALL, GREAT THANKS ARE DUE TO BE TO ALLAH THE ONLY ONE WHO GIVES ME THE STRENGTH AND PATIENT TO CARRY OUT THIS RESEARCH.

This thesis is dedicated to the soul of my father, the great man and the kindest person ever, who has always believed in me and supported me on my way in life.

You never said I'm leaving
You never said goodbye
You were gone before I knew it,
And only God knew why
A million times I needed you,
A million times I cried
If Love alone could have saved you,
You never would have died
In Life I loved you dearly
In death I love you still
In my heart you hold a place,
That no one could ever fill
It broke my heart to lose you,
But you didn't go alone
For part of me went with you,
The day God took you home.

I like to express my gratitude to my supervisor Dr. Mohamed Gadi without whom this work would not be completed today, just cannot thank him enough for his endless support. Also, to my beloved husband, children, Mum and family for their unwavering support and encouraged during the hard times with their endless love. Lastly and not forgettable many thanks go to all people who helped me during the field survey, my friends in the department and outside the university and to each one of the residents of the case study buildings who allowed me to enter their homes and occupy some of their time.

I declare that the research contained in this thesis was carried out by me. It has not been previously submitted to this or any other Institution for the award of a degree of any other qualification.

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NOMENCLATURE

1. ASHRAE = American Society of Heating, Refrigerating and Air-Conditioning
2. BRE = Building Regulation Environment
3. CIBSE = Chartered Institution of Building Services Engine
4. ISO = International Organization for Standardization.
5. NAIMA = North American Insulation Manufactures Association
6. ECM = Energy Conservation Management
7. URSA = is an astronomical association in Finland that founded in 1921
8. Quadrillion Btu = the amount of energy in 45 million tons of coal or 1 trillion feet of natural gas.
9. SET = Standard Effective Temperature
10. PPV = Predicted Mean Vote
11. PPD = Predicted Percentage of Dissatisfied
12. IEQ = Indoor Environmental Quality
13. SVF= Sky View Factor
14. Met = Metabolic rate, [W/m2]
15. Clo = Thermal resistance of clothing [1 Clo = 0.155 m^2. °C/W]
16. Pa = Water vapour partial pressure
17. Qc = Conduction heat gain or loss, [W]
18. Qe = Evaporative heat loss, [W]
19. Qi = Internal heat gain, [W]
20. Qs = Solar heat gain, [W]
21. Qv = Ventilation heat gain or loss, [W]
22. Ar = Air temperature
23. Tav = Average temperature
24. tc = Comfort temperature
25. TL = Lower limit temperature
26. TU = Upper temperature
27. Tn = Neutral temperature
28. toe = Operative comfort temperature
29. tin = Inside temperature
30. tout = Outside temperature
31. AC = Air Conditioning
32. FR = Free running building
33. RH = Relative humidity
34. MRT = Mean radiant temperature
35. RT= Resultant temperature
36. NV = Natural Ventilation
37. TAS = Thermal Analysis Software

INTRODUCTION

CHAPTER 1 : INTRODUCTION

1.1. INTRODUCTION

One of the main objectives of designing a building is to provide a comfort condition for the building's occupants, while at the same time minimizing the building’s energy consumption. This research deals with the regulation of thermal comfort and building energy consumption in multi-storey residential buildings. The research was carried out in Darnah, a city in eastern Libya. The city has a unique and distinct Mediterranean climate. The buildings selected for the study were designed to include open-to-the-sky atriums designed to provide natural light and ventilation. However, recently these buildings have started to witness the wide use of air conditioning units as a new technology for maintaining human comfort at a desirable level. In addition visual pollution, people have also started to suffer from high energy bills.

A number of residential multi-storey buildings were investigated in order to establish their neutral temperature and comfort range, as well as to develop guidelines for the designers of new buildings. It is intended that the occupants of these buildings will be asked to participate in a comfort survey. Field data results and comfort levels will be examined and analysed using a computer running environmental programmes such as Ecotect and TAS Building Designer. This method aims to get a clear idea about building behaviour in relation to climate. The results from both methods will attempt to find solutions to improve existing multi-storey buildings in terms of their indoor comfort and energy consumption, and introduce guidelines for designers of new buildings in Libya.

1.2. AIM AND OBJECTIVES

The research Aims are;

1. Examine a number of residential buildings as a case study of a design approach in aims to minimizing energy via the climate control system while providing acceptable thermal comfort in those buildings.
2. Increase the awareness of energy efficiency in buildings to minimize the consumption of non-renewable energy by using other mean of solutions rather than just using air conditioner system since the field survey recorded that a major part of the energy consumed consists of air conditioning requirements.
3. Calculate the energy saving that might be achieved by modifying building envelope components and identify the suitable materials that work for Darnah climate appropriately.

The research objectives are;

1. To identify the thermal comfort zone for Mediterranean indoor spaces of Darnah, Libya.

2. To investigate the impact of climate as an important factor of the environment on indoor thermal comfort.
3. To reach a building form that is fulfilling the required functions and work friendly with its environment.

1.3. Research Questions

This research will seek answers to the following questions in the context of the case study:

- What do people feel about their home?
- Which level of comfort is preferred by inhabitants and why?
- How can this work help people to save energy sources in their home beside been comfortable?
- Is it possible to improve the design process including materials to save energy in a worm climate such as the case study one?

How I Planned to Answer the Research Questions?

A field survey was designed to record and measure the comfort level indoors with related questions aimed to measure the energy consumption as well. The survey aimed to answer the first two questions of this work. Furthermore, using modelling schemas that enable to integrate local information to investigate the field survey result and also to build an ideal model for a fully environment friendly with a satisfied comfort level flats.

1.4. Limitations

In this study, the evaluation of the indoor conditions of the case study buildings includes thermal information and energy consumption. Due to time and efficiency limitations, it is not possible to simulate and enhance all the indoor environment conditions at once. Therefore, this study focuses on thermal comfort in summer, where the thermal performance of these case study buildings is at its worst during the year. Summer thermal performance is simulated and analysed, followed by suggestions for enhancement. Furthermore, because of time and cost restrictions this study could only be conducted on buildings located in one city, which was selected from an area located in the Mediterranean region in eastern Libya.

Research problems

The main problems of this research can be described as follows:

- Libya, like many developing countries, has an ambitious plan for housing production in order to meet fast growth in demand. Millions of Libyan dinars have been spent on housing and urban improvement projects in Libya, but less work has been done on the effects of climate on housing design.
- Foreign companies, designing according to international style and using new technologies, have constructed a large number of residential buildings,

especially tower blocks. Such schemes do not take into account the characteristics of local climate, which results in less attention to saving energy by using natural resources and techniques such as solar radiation and ventilation.

Furthermore, it is important to highlight some obstructions that affected the progression of this research and affected the initial stages, as listed below;

- Absence of location weather data; the researcher had to build a weather file for use at the computer modelling stage,
- Absence of data on a number of buildings in the case study,
- Absence of data on end-use energy consumption in buildings,
- Lack of research facilities, relevant professionals and requisite literature,
- Non-availability of energy-efficient appliances, materials and products for the building sector.
- In 2011 a war in the country has affected collection data that planned to be collected and resulted in loss of these data such as end-use energy consumption in buildings.

It was under these constraints that the research was planned and carried out in order to not only address the existing problem, but also to create a new strategy for local buildings via an understanding of the local climate and occupants' needs. In addition, the research aimed to create significant opportunities for people to participate actively towards saving local energy.

Furthermore, the city of Darnah was chosen as a case-study city in the Mediterranean climate, since there is a lack of thermal comfort studies in this area of the world in general and specifically in eastern Libya. A few studies have carried out research in southern and western Libya, which both have different climate types. There were also anther reasons for the choice of Darnah as a location, such as the fact that the city has recently experienced a noticeable increase in the use of air conditioning, and the city is the researcher's home town which makes it accessible for data collection.

1.5. Research Methodology

Having identified the scope and objectives of the study, it is necessary to follow an appropriate research methodology which refers to a set of methods. In this study, various research methods have been chosen to suit the different aspects of the research. These include two main methods; questionnaires and computer model, along with secondary methods such as observations and interviews. Employing these techniques helped indicating the efficiency degree of the case study buildings in terms of comfort indoor environment, exploring thermal performance of these buildings, and examining the potential effects of proposed materials. Different methods have different strengths and weakness; however, using a range of methods can produce a more complete picture (Gillham, 2008). Further, a multi-method approach has the potential of enriching, as well as cross-validating, research findings. The research methods which have been practised in this study are explained below.

The Questionnaire: the questionnaire in this study is used as a main tool to examine the indoor environment conditions; with focus on thermal comfort, and to assess occupants' satisfaction in the case study buildings. 337 flats have been studied in the 12 Multi-storey residential buildings.

Computer Model: simulation or computer model is a computer program that attempts to simulate an abstract model of a particular system. Simulation of building's thermal performance is necessary to quantify the environment to which occupants are exposed, to predict occupants' comfort, to identify energy consumption, and to examine alternate enhancements for achieving better indoor thermal environments and energy efficient buildings. The computer programme TAS (Thermal Analysis Software) is selected in this study as a main tool for the simulation that because real-life systems are often difficult or impossible to analyse in all their complexity, but computer tools very in their ease of implementation and their comprehensives. Depending on the characteristics of these buildings and on the required outputs, which are specified in this study, TAS is chosen after conducting number of tests on several computer programmes.

TAS is employed in this study at two stages as follow:

1. To assess the level of thermal comfort in the case study buildings and to analyse their thermal performance in order to get clear picture about the thermal efficiency of the fabrics in this kind of buildings.
2. To identify the potential enhancement in thermal comfort and the potential energy saving of the proposed alternate materials for buildings' envelope in order to explore the most appropriate ones. Figure 1.1 below illustrates the methodology of this research work.

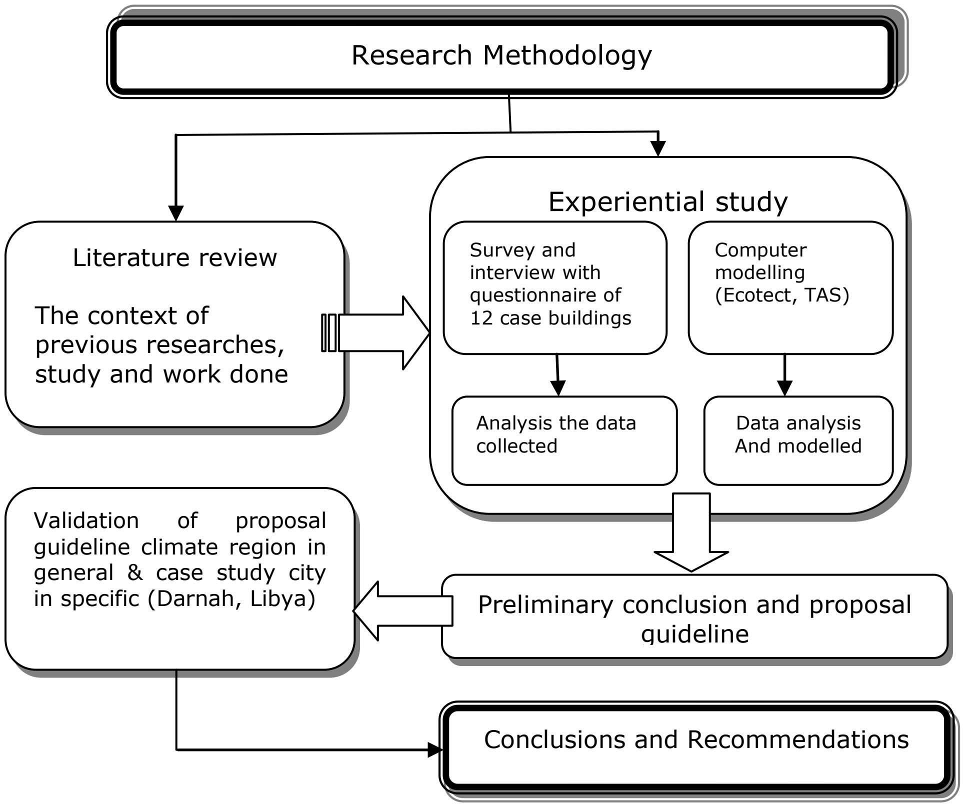


Figure 1.1: Research Methodology

Data Input for the Software Used in the Study

For all simulations, the focus was on studying the main rooms (bedrooms, living space area and kitchen) because these are the most used spaces in the homes, and the need for the occupants to be thermally satisfied is more important in these zones. Each zone was given particular properties to simulate the actual space. Some design values were upgraded such as data about the occupants, including their clothing levels (values given for amount of clothing worn), activity levels (values for the biological heat output), and a customized schedule. Within each zone, data about infiltration rates and internal gains, which affect heat gains and thermal comfort for each zone, were fixed, and internal gains were calculated using standard electricity appliances. After the field survey, the researcher used close to exact data for this purpose. Occupancy data was based on an average of six people in a family, based on a national Libyan habitation survey (2006). A custom schedule was also incorporated; a typical family rises at 7am, and the family goes to sleep between 9pm and 11pm. However, location climate data for the case study city were not available, so the researcher generated them using resources such as ASHRAE 2009, The Chartered Institution of Building Services Engineers (CIBSE), and Meteonorm online, as well as weather tools software (example on work is included in appendix 9).

1.6. Thesis Structure

The thesis is divided into two parts; part I: Background study, and part II: Research work. Part I comprises four chapters. The background study reflects research conducted on the literature review- out–source from books, journals, similar theses and the internet. The remaining five chapters are in part II which reflects the main body of the research itself. These two parts are shown graphically in Figure 1.2.

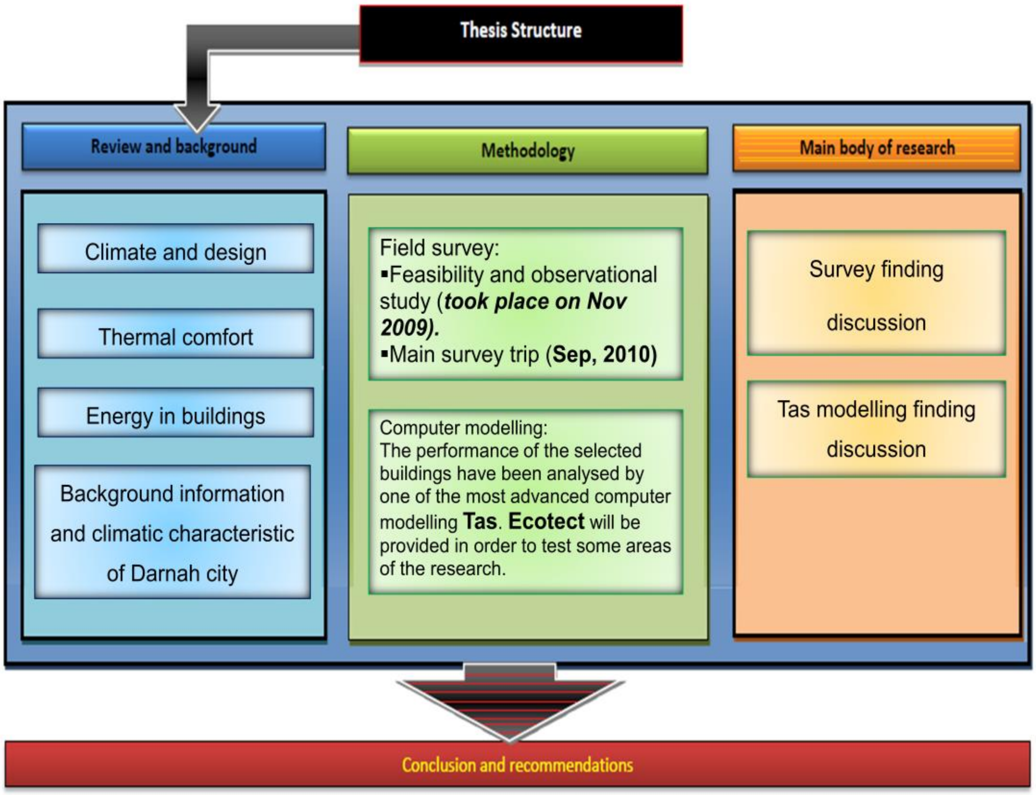


Figure 1.2: main parts of the thesis body contents

1.7. THESIS LAYOUT

Different approaches have been investigated in order to inspect the thesis' idea: how thermal comfort can influence energy performance. I started this project trying to find a way to measure the comfort level and linked it with the quantity of energy consumption. Reading about this subject helped me to decide working in two ways, develop a field survey and compare the coming result of that survey with computer modelling software. The approach chosen, focused on multi-storey residential buildings. Some work on that has been already done which is illustrated in this work, and briefly includes the following;

Chapter one: contains an introduction to this report and background information such as aims and objectives of this research also the research questions and problem Statement and then describes the methodology that will be used and finally, a chart will present the overall structure of the thesis.

Chapter two: from this chapter to chapter 4 a literature review related to thesis subject will be investigated and reviewed. Chapter 2 includes similar researches than considers the climate and design issue. Beside this chapter is closely look at principles of design factors such as orientation, people and their needs, materials and means of building form and then investigate the impact of a buildings form on the indoor climate and finish with relate the above with the case study climate (the Mediterranean) and gives some examples of strategies used there to obtain a comfortable level indoors.

<u>Chapter three</u>: this chapter looks at thermal comfort indoors, the theory of it, the importance and factors influence it. Also looks at thermal exchange, heat gain and loss and thermal balance. The chapter conclude some issues such as the role that played by occupants in order to achieve the desirable level of comfort beside some important factors such as the external environment and the materials used for buildings.

<u>Chapter four</u>: The energy in building is considered in this part of thesis, looking at factors influence the energy with a link to buildings such as orientation, building shape, solar shading, and materials and building use. The chapter conclude that the transfer of energy presented in a heat given off or taken in by people, building fabric or other equipment.

<u>Chapter five</u>: from this chapter ahead the practical work will start. This chapter present the information that the student had collected about the case study city. Some of this information gained from the internet while the rest are from observation and fieldtrip information. The chapter also includes the information regarding to the case study buildings such as location, orientation and physical built forms. Beside, this part is providing photos that were taken during site observation to show the situation of these buildings.

<u>Chapter six</u>: research methodology is illustrated in this chapter. Fieldwork representing in a paper survey and computer work are the two methods were carried out in order to investigate research questions and achieve the aims and goals of this study. Computer work was the second part after collecting the data and completing the survey to test and gain analyses and results that can be used in improving buildings materials. The main software used in simulation is TAS beside Ecotect and some other small software such as Weather Tool and PMV Tool.

<u>Chapter seven</u>: this chapter includes all the work that related to field survey. All the answers and comments that came back have been tabulated and analyses to give a clear picture of occupants' feeling towards their comfort in their home, energy consumption, space size and design and many more issues related to this work.

<u>Chapter eight:</u> computer simulations are presented here, with all the case study buildings examined from every aspect, such as room temperature, heat gain affect

of size, location, orientation and more. Results and findings are included in last part of this part of the thesis.

Chapter nine: this chapter is encloses the last step of this research is to put all investigations to work. That have been done by used the survey and computer software simulation to improve buildings' envelope with new modified materials.

Chapter ten: final results and findings are main body of this chapter beside proving some recommendations for future work.

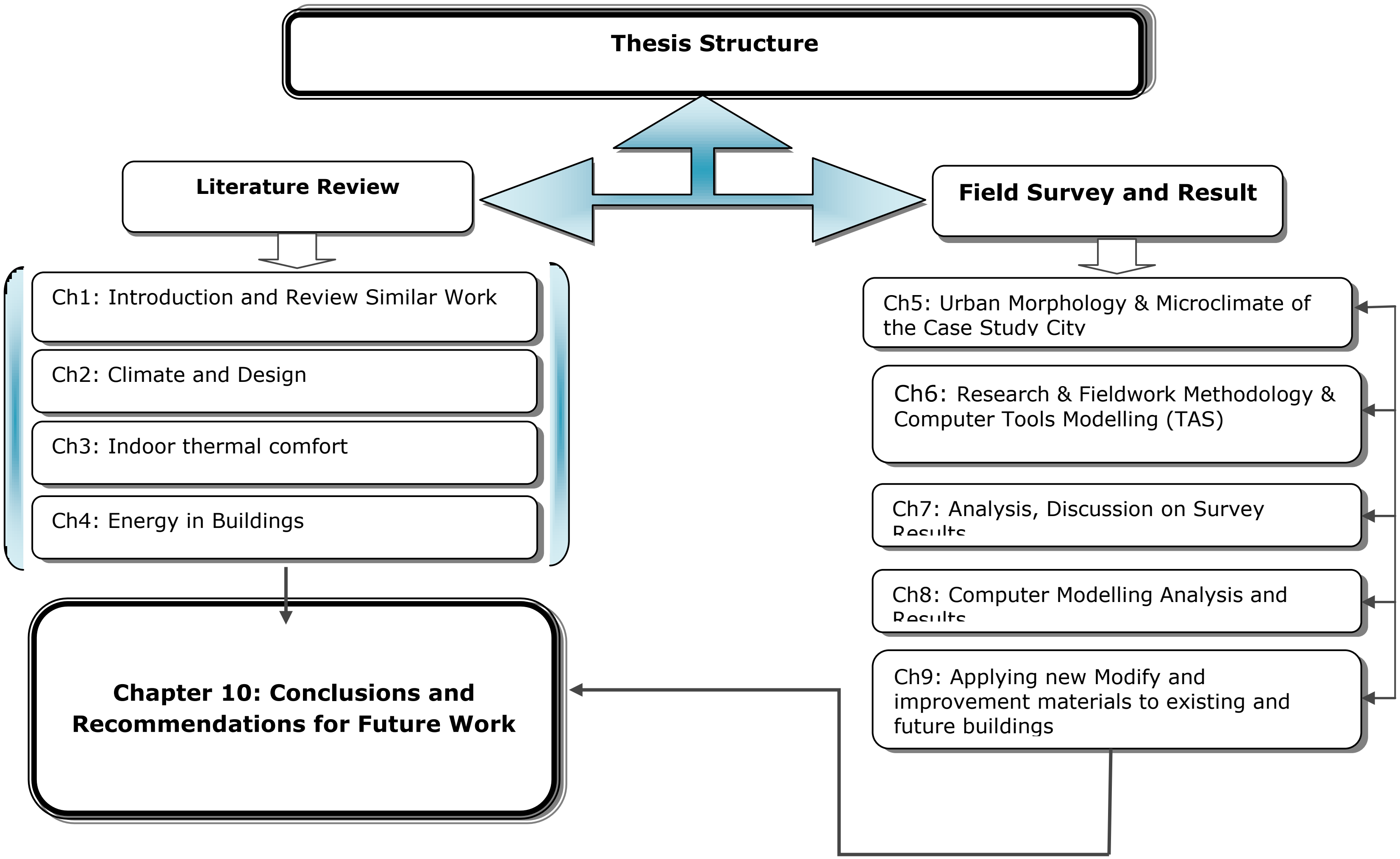


Figure 1.3: Details Thesis Structure

BACKGROUND WORK

CHAPTER 2 : BACKGROUND WORK

2.1. INTRODUCTION

In the 20th century, technology lead to the widespread application of heating and cooling in the form of air conditioning and an obsession with standardised comfort conditions has developed. This notion, that there is an optimum thermal environment is now deeply rooted and is strengthened by both field and chamber studies on comfort. However two factors have emerged which have re-opened the need to assess thermal comfort standards or models; a) the increasing demand for energy for air conditioning has prompted research in passive cooling which in turn has required more flexible ways of assessing free running buildings. b) growing disenchantment with controlled air conditioned new buildings and their association with sick building syndrome, and the observation that occupants more often like to be living in naturally ventilated buildings, has thrown doubt on the existence of these ‘optimum’ conditions.

As a consequence, the critical issue is when comfort criteria are applied to the predicted thermal conditions in proposed buildings. These inappropriate comfort criteria maybe therefore lead the designer into adopting the high energy air conditioned path. So that once a building is built, the issue of comfort criteria becomes less contentious since the occupants can now make the ultimate judgement. Irving (1994) acknowledged that temperature, humidity and air velocity are only some of the environmental factors which affect human comfort. He therefore offered a practical approach to meeting the requirements and expectations of the designer, and anticipated occupants, such that the least conflict and the best compromise in design are reached. The first part of this chapter reviews the published research carried out by other researchers worldwide. The review aims to gain a clear idea of other works and results. This is followed by the second part, which explains the factors that determine the conditions of thermal comfort, such as a dry bulb temperature, relative humidity, etc. The third part looks at the characteristics of the case study climate, which is a Mediterranean climate, and the last part takes a close look at the effect of climate on design and examples of some cooling strategies.

2.2. REVIEW OF SIMILAR RESEARCHES

The thermal performance of buildings, beside human thermal comfort, has been widely investigated by many researchers. The conclusion of all these works is that one temperature level does not satisfy everyone because of the essential factors that influence their feelings, such as their clothes, the ambient environment around them and their activities. Some researchers also agree about the importance of building form on increasing/decreasing the thermal comfort of the occupants. The first part of this chapter will give examples of some of researches carried in relation of thermal comfort. A recent study by Saleh (2011) shows that, the main reason for discomfort in hot climate regions could be a building's envelope itself. The researcher carried out a wide survey and used a computer model to investigate the thermal comfort of 155 refugee shelters in Palestine in both winter and summer. She found that during the summer a large heat gain through roofs and walls as well as poor ventilation and small areas for shelter are the main reasons for the discomfort. On the other hand, in winter the shelters are not comfortable because of the huge amount of heat loss through the roofs and walls in addition to a large degree of infiltration.

Another thermal comfort study was carried in Hong Kong to investigate human comfort in high rise residential buildings by Joseph Lai (2008). He used a questionnaire survey to rate four keys IEQ (Indoor Environmental Quality) attributes, namely thermal comfort, air cleanliness, odour and noise. He found that the importance of thermal comfort was rated highest by the occupants (0.3382 out of 1). Alsousi (2005) carried out similar research on this area in Gaza and examined 12 high rise residential buildings from two aspects: thermal comfort and energy consumption. Alsousi stated in his research that "most of the energy consumed by the building in summer is due to the huge heat gain through walls, windows and roofs". The author also has found that other "heat gains are produced by occupants, appliances and infiltration; however, this type of heat has relatively little impact on thermal performance and comfort".

Whereas, thermal performance in a multi-storey residential building in southern Brazil was examined by Enedri and Massignani (2005); the main concern of this study was to record the thermal performance in eight bedrooms located on two floors and four orientations over a 29-day period in order to see the relationship between the external and internal temperatures. The study used different variables to exam factors such as surface colour, drawing of shading on the windows and thermal properties of walls and windows. The main conclusion of this work was that U-value and facade area are the two variables that show the best correlation with maximum air temperatures and therefore should be minimized in order to improve indoor thermal conditions over summer; and that thermal capacity and thermal time lag are the two variables that show the best correlation with minimum air temperatures and therefore should be maximised to improve thermal conditions over winter.

A thermal comfort field survey has been conducted in three cities from two different climate zones in Libya by Akair (2007). All the system in the selected buildings was free running. 200 occupants from those buildings interviewed once in each month during one year. The study states that "89% of new construction buildings are not equipped with thermal insulation and their tightness to air is very poor, this due to the lack of appropriate standards". A suggestion by the study to use Griffliths method (eq. 2.1) or de Dear and Brager method (eq. 2.2) in order to calculate the thermal comfort temperature in Libya because the researcher believes such methods will allow an important energy saving compared with existing standards comparing with other methods.

$$\mathrm{T}_{\mathrm{c\_Griffiths}} = 0.518\ \mathrm{T}_{\mathrm{o-Ave}} + 10.35 \ldots\ldots \text{(eq.2.1)}$$

$$\mathrm{T}_{\mathrm{c\_Brager}} = 0.680\ \mathrm{T}_{\mathrm{o-Ave}} + 6.88 \ldots\ldots \text{(eq.2.2)}$$

Where, $\mathrm{T}_{\mathrm{o-Ave}}$ is: the monthly mean outdoor temperature.

Same observation was previously made by Bouden & Ghrab (2004); total number of subjects was 200 occupants spread in five cities of Tunisian. Each house has been visited once in each month of the year. The results of this study were; in autumn, people are accustomed to high temperatures after having experienced 3 months of summer. Also, in autumn, the people clothing value is lower than in spring during which, people are still wearing heavy clothes. The study as the above one recommended that, the thermal comfort temperature should be calculated using Griffliths method or de Dear and Brager method. Ghisi and Massignani (2007) stated that the energy consumption of buildings is associated with their thermal performance. The heat transfer through the building components, such as walls, windows and floors, in a mean of heat gains or losses adding to the internal heat gains and ventilation gains are considered the most important factors affecting the thermal performance. In turn, this thermal response determines the required heating and cooling energy in order to maintain acceptable thermal conditions for occupants (Aye et al. 2005). Yu et al. (2011) concluded that the most influential factor on both cooling and heating energy consumption is the heat transfer coefficient of wall, followed by the building shape coefficient.

In 2007 Aldawoud and Clark have investigated energy performance in courtyard and atrium multi-storey buildings. The main focus was on the use of glazed walls and their effect on energy performance. The study carried in four climate types;

- Hot/dry climate. Phoenix, Arizona was chosen in this climatic region.
- Hot/humid climate. Miami, Florida was chosen in this climatic region.
- Temperate climate. Chicago, Illinois is selected in this region.
- Cold climate. Minneapolis, Minnesota is selected from this region.

The result related to temperate climate shows that; in general, the four locations showed that the courtyard was an energy efficient option as a low-rise building versus the atrium which was a more energy efficient option for a high-rise building. However, as the number of stories increased, atrium reveals a better energy performance. The study also shows that using a low U- value glazing type such as double low-e and triple clear glass with low percentages for the atrium walls showed a significant improvement for the energy performance of the adjacent zones around it. Research also finds the total energy consumption of an atrium having single clear glass with 30% glazing surface area was less by 20% comparing with the courtyard with same glass type; whereas, using double clear glass with same surface area percentage was less by 21%, and when a double low-e glass where used, also the consumption was lower by 20% compared with the result of a courtyard with same condition.

Karyono (2000) carried out a field study of thermal comfort beside a study of building energy consumption in Jakarta, Indonesia on seven multi-storey buildings with different cooling systems. The study included some variables which the study believed they may affect the state of people's comfort, such as age, gender and fitness. The study reaches these conclusions: differences in people variability such as age, background, etc., showed a very slight difference and was not statistically significant regarding the natural temperature by the voluntaries, it is in line with what Fanger (1970) states in his research work about human thermal comfort, where Fanger in particular, has also found that the majority of individuals would be satisfied by an ideal set of values. As the range of values deviated progressively from the ideal, fewer and fewer people were satisfied. This observation could be expressed statistically as the % of individual who expressed satisfaction by comfort conditions and the predicted mean vote (PMV). Karyono in same research above has also finds that, natural temperatures are found to increase towards the evening by 3°C higher than in the early morning. Other conclusions are given below;

- Orientation of unprotected glazing windows seems likely to contribute to the higher energy consumption in air conditioned buildings. This also applies to the thickness of buildings, in which thin buildings will consume greater levels of energy to achieve similar levels of indoor temperatures seen in thicker buildings. Furthermore, the study emphases on the importance of chosen the correct orientation in design stage that because of the major role of it on minimize the solar gain.
- To minimize energy consumption, the building must be designed according to the prevailing climate. From his location, the researcher suggested that for naturally ventilated buildings, a shallow plan is ideal for crossing natural ventilation and also adequate daylight to reduce energy used for artificial

lighting. He also recommended that a care must be taken to protect the direct sun's radiation particularly on the glazing walls and the windows.

During the summer of 1997 and 1998 a full-scale measurements have been carried out by Howarth with others in Ghadames, Libya. The aim of this study was to calculate environmental parameters and human thermal comfort responses from 51 buildings. Selected buildings were courtyard buildings naturally ventilated and mechanically ventilated buildings with air conditioning system. The main conclusion was; the overall feeling of the occupants, reported that they are more satisfied and thermally neutral in naturally ventilated buildings than in new air conditioned buildings. In the naturally ventilated buildings, about 54% of the occupants are feeling neutral and 8% are feeling hot, compared to only 15% of the occupants feeling neutral and 33% feeling hot in the new air conditioned buildings. An argument can be made here these results perhaps are influenced by the traditional lifestyle of those people.

Nicol has conducted several surveys under different climatic conditions in aims to establish a comfort zone for Pakistan. His first survey carried in 1995, where he established a relation between comfort temperature and outdoor temperature using this equation ($T_c = 0.38T_o + 17.0$). He also took a second survey in 1999 to re-exam the previous equation, this time he found a second regression given by Eq. ($T_c = 0.36T_o + 18.5$). Those relations show clearly that the comfort temperature is related to the outdoor temperature and so to the climate, and the difference between those relations confirms that there is no universal comfort temperature. Each community must have its own perception of the thermal comfort according to its climate.

Another thermal investigation was carried out by Mahringer (1963) to exam two courtyards with different sizes in Vienna and Austria. The measurement of the smaller one is 4m × 2m and 20m deep, while the larger one measured 15m × 8m with the same depth. It was observed that the temperature inside the large one was about 1°C lower than that of the surrounding. In the smaller one, the difference was greater, at about 2°C. It was concluded that the reason for this was probably related to the reduction in the air exchange between the sheltered courtyard and its surroundings. The large heat capacity of the courtyard walls, the shading of the courtyard surfaces and the stagnation of cold air at the bottom of the courtyards. Mahringer concluded that the most important factor affecting the patterns of temperature difference seemed to be the effect of shading the surrounding walls. This fact was confirmed through the observation of the small difference in the temperature of the two courtyards at night as the main reason for this would be the absence of solar radiation.

Similarly, Gertis, K. et al., (1983) carried out an investigation about thermal micro-climate in internal courtyards in south Germany. They concluded that the main factors affecting the thermal micro-climate are insulation and shading conditions. Since the shading is one of the most significant affects in the courtyard the geometrical proportions (height/width) of the courtyard consequently influence the simulation. Also this investigation found that in narrow and high courtyards the factors dependent on construction and orientation are no longer effective as such courtyards are almost entirely shaded.

2.3. Factors determining thermal comfort

Next subsections are looking briefly to external factors that have an influence on indoor thermal comfort;

2.3.1. Amount of direct sunlight

Solar radiation is the radiant energy received from the sun. It is the intensity of sunrays falling per unit time per unit area and is usually expressed in Watts per square metre (W/m2). The radiation incident on a surface varies from moment to moment depending on its geographic location (latitude and longitude of the place), orientation, season, time of day and atmospheric conditions (Figure 2.1). Solar radiation is the most important weather variable that determines whether a place experiences high temperatures or is predominantly cold.

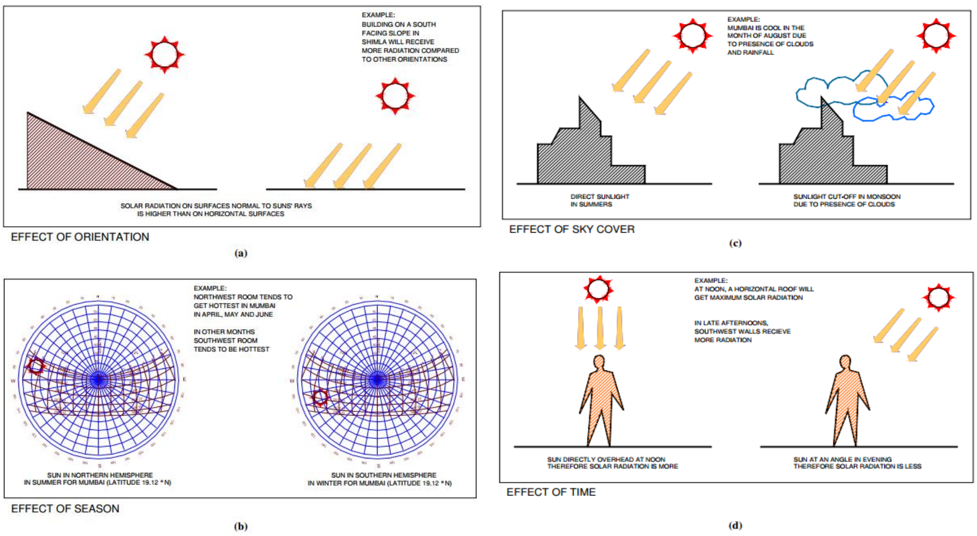


Figure 2.1: Factors affecting solar radiation effect of orientation, (b) effect of season (c) effect of sky cover, (d) effect of time_ Source: http://en.wikipedia.org

2.3.2. Ambient temperature

The temperature of air in a shaded (but well ventilated) enclosure is known as the ambient temperature; it is generally expressed in degree Celsius (ºC). Temperature at a given site depends on wind as well as local factors such as shading, presence of water body, sunny condition, etc. When the wind speed is low, local factors strongly influence on temperature of air close to the ground. With higher wind speeds, the temperature of the incoming air is less affected by local factors. It also affects human internal temperature and level of comfort. It affects temperature differences between the body and the surroundings and, consequently, affects the rate of heat lost or gained convection. The effect of various factors on the ambient temperature is shown in Figure 2.2. A simple thermometer kept in a Stevenson's screen can measure ambient temperature.

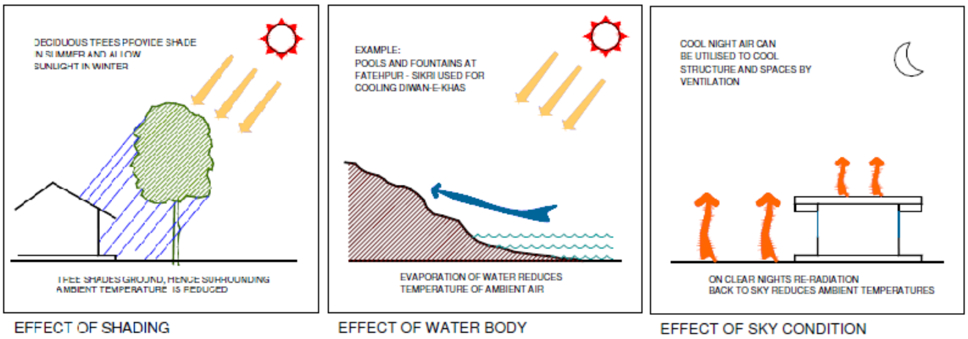


Figure 2.2: Factors affecting ambient temperature
Source: http://en.wikipedia.org

2.3.3. RELATIVE HUMIDITY

Humans are sensitive to humidity. The skins rely on the evaporation process to reduce moisture. The evaporation process itself is highly influenced by relative humidity, where the maximum temperatures under which thermal balance can still be effectively maintained through evaporative cooling at different levels of relative humidity (RH) as follows:100% : 31° C _ 50% : 38° C_ 18% : 45° C _0% : 52° C. It varies considerably, tending to be the highest close to dawn when the air temperature is at its lowest, and decreasing as the air temperature rises. The decrease in the relative humidity towards midday tends to be the largest in summer. In areas with high humidity levels, the transmission of solar radiation is reduced because of atmospheric absorption and scattering. High humidity reduces evaporation of water and sweat. Consequently, high humidity accompanied by high ambient temperature causes a lot of discomfort. The effects of various combinations of humidity and ambient temperature are presented in Figure 2.3.

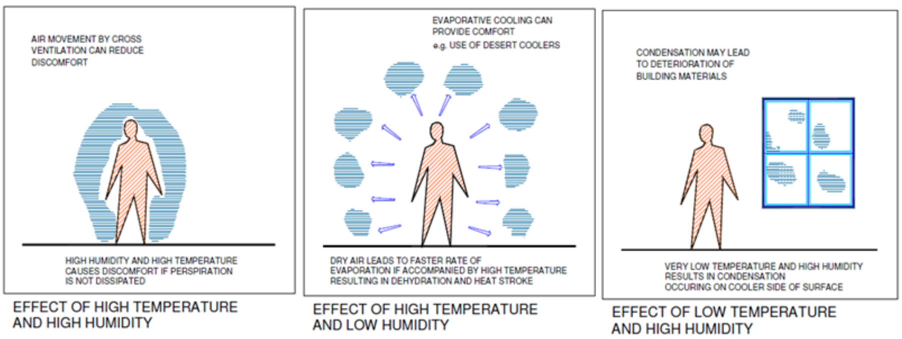


Figure 2.3: Effects of air humidity _ Source: http://en.wikipedia.org

2.3.4. WIND DIRECTION

Air circulation influences the temperature felt. The cooling effect of wind increases with lower temperatures and higher wind speed. This increased cooling effect of enhanced wind speed has another important consequence: the higher the air temperature, the higher the wind speed which is still felt to be comfortable. However, according to Szoklay (2008) evaporation is restricted in high humidity (about 85%); thus, even air movement cannot adequately increase the cooling effect. Wind is a major design consideration for architects because it affects indoor comfort conditions by influencing the convective heat exchanges of a building envelope, as well as causing air infiltration into the building (Figure 2.4).

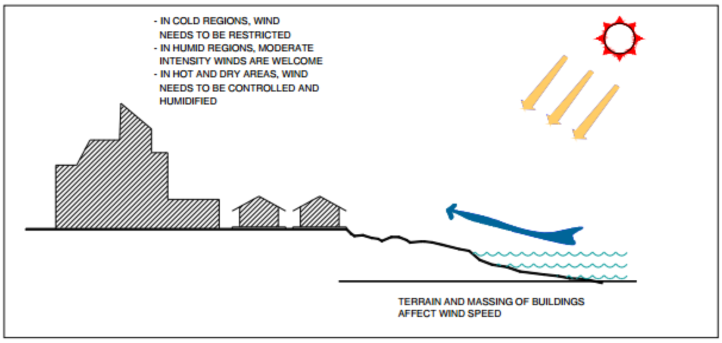


Figure 2.4: Factors affecting wind_ Source: http://en.wikipedia.org

2.3.5. PRECIPITATION

Precipitation includes water in all its forms rain, snow, hail or dew. In heavy rain conditions, people are less likely to be outside, thus their wind and thermal comfort will usually be less critical compared with other micro-climate factors. However, it may be of interest to evaluate how far under a sheltering canopy roof the precipitation will infiltrate and how often this will happen. Dampness of clothes may also be of interest because it will affect thermal comfort (Hoppe, 2002). The effects of precipitation on buildings are illustrated in Figure 2.5.

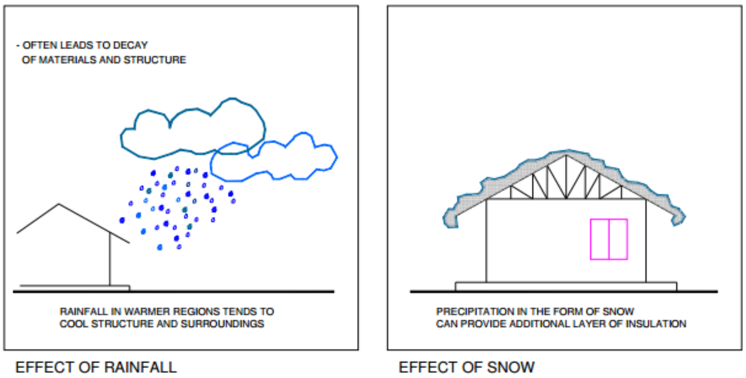


Figure 2.5: Effect of precipitation _ Source: http://en.wikipedia.org

2.3.6. SKY CONDITION

Sky condition generally refers to the extent of cloud cover in the sky or the duration of sunshine. Under clear sky conditions, the intensity of solar radiation increases; whereas it reduces in monsoon due to cloud cover. The re-radiation losses from the external surfaces of buildings increase when facing clear skies than covered skies. This is illustrated in Figure 2.6.

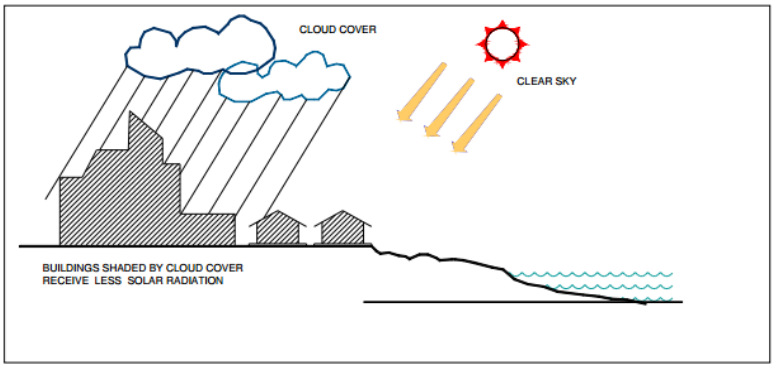


Figure 2.6: Effect of sky condition _ Source: http://en.wikipedia.org

2.3.5. Land Structure and Topography

The conditions for transfer of energy through the building fabric and for determining the thermal response of people are local and site-specific. These conditions are generally grouped under the term of 'microclimate', which includes wind, radiation, temperature, and humidity experienced around a building. A building by its very presence will change the microclimate by causing a bluff obstruction to the wind flow, and by casting shadows on the ground and on other buildings. A designer has to predict this variation and appropriately account for its effect in the design. The microclimate of a site is affected by the following factors; Landform, vegetation, water bodies, street width and orientation, open spaces and built form. Certainly, understanding these factors greatly helps in the preparation of the site layout plan. For example, in a hot and dry climate, the building needs to be located close to a water body. The water body helps in increasing the humidity and lowering the temperature by evaporative cooling. From the above short discussion it can be said that external factors and environment greatly affect the way structures are built and thus directly affecting the interior qualities of comfort level indoors.

2.4. Impact of a Building's Form on the Indoor Environment

The climatic design strategies depend on utilizing the opportunities and capabilities of the local climate. Some of these strategies remain the same in different climates (Passive Solar Industries Council et al. 1994). The layout, form and orientation of the buildings in addition to spacing between them are the most important strategies affecting indoor thermal comfort. Also, building envelope has a great influence as it separates the outdoor and indoor environment (Leylian et al. 2010). This section will clarify the most important strategies.

2.4.1 Building Form

The main principle in selecting the building form is the ability to maximize solar collection and to minimize heat losses through buildings' envelope, where the most important requirement is heating.Besides, reducing undesirable heat transfer, where the most important requirement is cooling. This can be achieved through reducing the ratio between surface area and volume to enhance building's thermal performance (Goulding et al. 1992). See Figure 2.7.

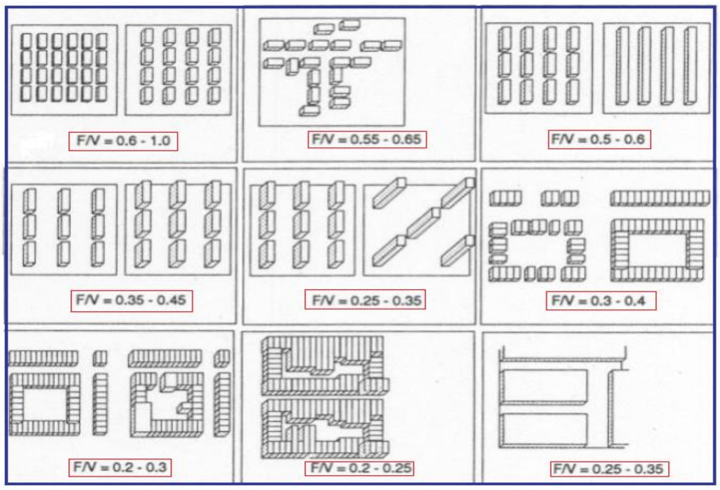


Figure 2.7: Site layouts showing different surface area (F) to volume (V) ratios Source: Goulding et al. (1992)

Moreover, some forms such as H-type or L-type can provide self-shading of surfaces which can decrease the direct solar radiation (Nayak and Prajapati, 2006). Self-shading of building usually depends on the building shape and layout arrangement (Chan, 2012). Also, the building form effects on wind channelling and air flow patterns, and the opportunities for enhancing the use of natural daylight (Goulding et al. 1992). Generally, geometry variables including length, height, and depth usually control the objective values such as the area and volume of the building (Yi and Malkawi, 2009). Building with larger floor space is smaller energy efficiency. Larger volume buildings tend to be more efficiency. Taller and narrower buildings are more energy efficient. According to Capeluto (2002) self-shading geometry forms provide the best solution for improvement energy performance in buildings. According to Lam (2005) the amount of heat coming through the building envelope is proportional the total gross exterior wall area. Figure (2.8) illustrates the relationship between building form and heat loss.

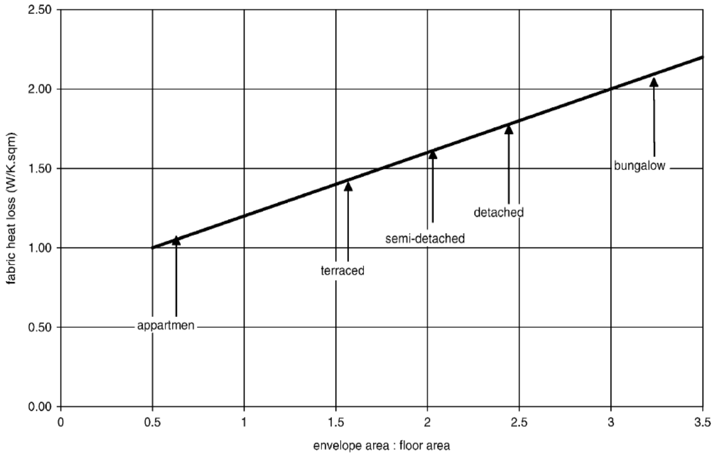
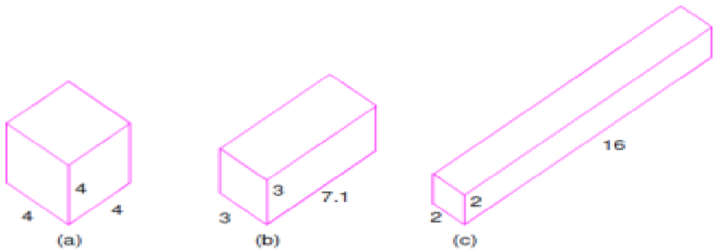


Figure 2.8: Relationship between building form and heat loss Source: Steemers, (2003)

Self-protected form is one of possible ways against the impact of solar radiation in high rise buildings. It's clear that self-shading strategies reduce solar insolation on vertical surfaces (Nikpour et al. 2011). The main proportions affects the geometric shape is the surface-to-volume ratio and the width to length ratio. Behsh (2002) mentioned that forms with different geometric shapes of the same contained volume have different surface area. This is usually expressed by surface to volume ratio. The surface to volume ratio is a rough indicator of urban grain size, representing the amount of exposed 'skin' of the buildings, and therefore, their potential for interacting with the climate through natural ventilation, day lighting, etc. However, the counter-indication to a high surface to volume ratio is the increase in heat loss during the winter season and heat gain due to exposure to solar radiation during the summer season (Ratti et al. 2003), see Figure (2.9) and Figure (2.10).



SOLID SHAPE	SURFACE AREA 'S'	VOLUME 'V'	SURFACE AREA/ VOLUME RATIO 'S/V'
a	96	64	1.5
b	103.2	64	1.61
c	136	64	2.13

Figure 2.9: Surface area to volume ratio (S/V ratio) for a few building shapes _ Increase in surface area, increases heat gain and heat loss _ Source: Nayak and Prajapati, (2006)

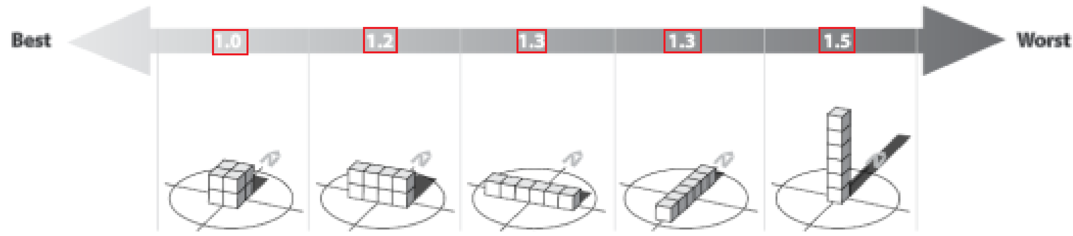


Figure 2.10: The effect of envelope to volume ratio on energy efficiency
Source: Mikler et al. (2008)

The building volume was found to have a strong influence on the air change rate of the building. The ratio of external surface to building volume is likely to decrease for increasing volumes. Therefore less external surface, where leaks can occur is available and the surface area to volume ratio is more favourable (Antretter et al, 2007). Ling et al. (2007) mentioned that the exposed surface-to-volume ratio (S/V ratio) for geometric shape depends on the width to length W/L ratio. Geometric shapes with higher value of W/L ratio contained lower value of S/V. He indicated that main factors that determine the relationship between solar insolation level and building shape are W/L ratio and building orientation. Considering the above researches it has been found that, in such climate like the case study one, the more compact the buildings plan the smaller the exposed surface area of the walls or the roof for a given volume or floor area of the building. And as identified by Hyde (2000) within Mediterranean climate section in Table 2.2 which shows that in order to reduce heat gain in summer it must minimize the west wall and moderate surface area, and then the compact low height shape might be the prefer shape for Mediterranean climate that because the heat exchange by conduction between the building and the surrounding air is decreased. In contrast, if the plan of the building is spread out, the large surface area of the walls will cause a great heat gain or loss. However, large external surfaces will offer more opportunity for natural light and more flexibility in the design of the space, and it may also enable faster cooling when comfort need to be provided by natural ventilation. In this twisted fact of selecting the optimum shape, engineers try to adopt several energy measures, such as extra insulation, develop new type of building material fabric.

Table 2.1: The preferred requirements for building form in different climate zones source: Hyde (2000)

Climate	Element and requirement	Purpose
Warm humid	Minimize building depth	For ventilation
	Minimize west facing wall	To reduce heat gain
	Maximise south and north walls	To reduce heat gain
	Maximise surface area	For night cooling
	Maximise windows wall	For ventilation
Composite	Controlled building depth	For thermal capacity
	Minimize west wall	To reduce heat gain
	Limited south wall	To increase thermal capacity
	Medium area of windows wall	For controlled ventilation
Hot dry	Minimize south and west walls	To reduce heat gain
	Minimize surface area	To reduce heat gain and loss
	Maximise building depth	To increase thermal capacity

	Minimize windows wall	To control ventilation, heat gain and light
Mediterranean	Minimize west wall Moderate area of south wall Moderate surface area Small to moderate windows	To reduce heat gain (summer) To allow (winter) heat gain To control heat gain To reduce heat gain but allow winter light
Cool temperate	Minimize surface area Moderate area of north and west walls Minimize roof area Large windows wall	To reduce heat gain To receive heat gain To reduce heat loss For heat gain and light
Equatorial upland	Maximise north and south walls Minimize west -facing walls Medium building depth Minimize surface area	To reduce heat gain To reduce heat gain To increase thermal capacity To reduce heat loss and gain

Above Table shows the architectural configuration of building envelope for different regions which are related to the building's shape: these configurations have been adapted from Hyde (2000), including the Mediterranean climate, and enables the best proportion for each to be selected for the purpose of heat gain and loss.

2.4.2. Orientation of buildings

The orientation of surfaces affects the potential capture of incident solar radiation. Different faces of the building get very different amounts of heat from the sun, for example, west facades would significantly exposure more to sun radiation and provide less shade at the hottest time of the day similar to south facades whereas surfaces that facing north would receive less sun radiation. Givoni (1969) pointed out that the amount of radiation received by the building is determined by orientation. Karasu (2010) showed that orientation has a significant influence on the cooling load. In areas where comfort is acquired mainly by air movement, it is important to orient the building according to prevailing winds. In regions where ambient temperature has greater influence on comfort than ventilation, orientation with respect to the sun is important. A north-south orientation of the main facades is preferable, since the summer sun penetrates facades and openings only marginally in these directions, while in winter when the path of the sun is lower, there is possibility of solar access (Rosenlund, 2000). Goulding et al. (1992) displayed some strategies for the building's orientation. These strategies aim to maximize the potential for solar collection through the orient of the longest side of building to face south. Also, he discussed the effect of facades orientation in multi-family housing. He mentioned that apartments with more than one external wall will have greater heat losses than those with only one external wall. The losses from an apartment situated at the northwest corner of the top floor of a conventional block can be up to twice those of an apartment in the middle of the south façade as shown in Figure (2.11).

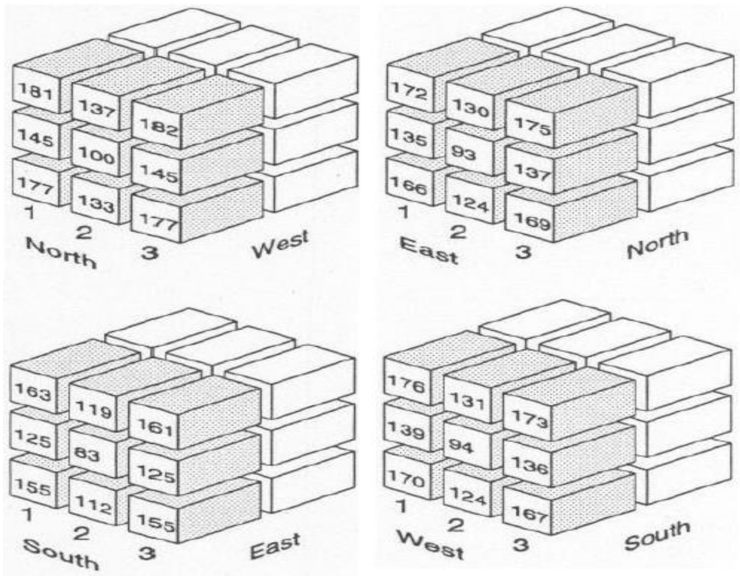


Figure 2.11: Heat losses from rooms with different positions and orientations
Source: Goulding et al. (1992)

Other strategy that considers building's orientation is passive solar heating design strategy (Figure 2.12), this strategy in particular makes use of the building components to collect, store, and distribute solar heat gains to reduce the demand for space heating. It does not require the use of mechanical equipment because the heat flow is by natural means (radiation, convection, and conductance) and the thermal storage is in the structure itself. It also assumes that building is orientated to receive as much solar radiation as possible in winter when heating is required, whilst rejecting as much as possible in summer when it is not. This strategy relies on using the right material for different orientations. However, it is also desirable to provide as much protection from the maximum summer radiation as possible, some of protection examples used in such hot climate are thick curtains, external devices or as the case in some Arabic countries where people tend to change rooms according to seasons to get maximum comfort level, such using the roof level to sleep during summer nights or staying in basement rooms to escape the overheating during summer days. Hence the optimum orientation provides maximum winter collection with maximum summer protection which, assuming the building is roughly orthogonal, involves a trade-off between the two, based on the relative amount of heating and cooling stress in the climate (Marsh, 2000).

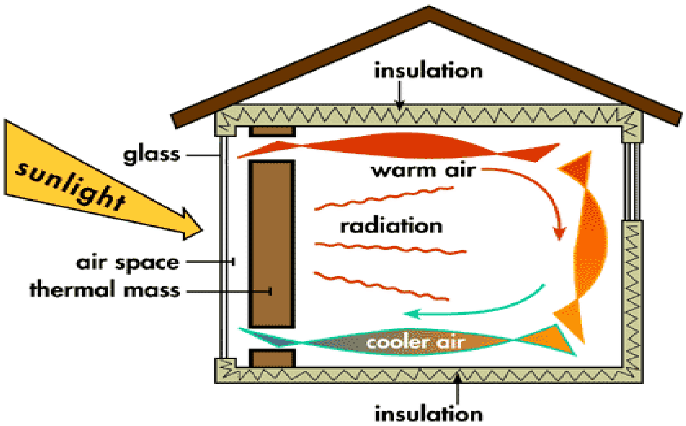


Figure 2.12: Passive solar heating strategy makes use of the building components to collect, store, and distribute solar heat gains to reduce the demand for space heating _ source: plotted after Passive solar building design at Wikipedia http://en.wikipedia.org/wiki/Passive_solar_building_design

2.4.3. GLAZED FENESTRATION SYSTEMS

The glazed system is an important strategy in passive solar design as it can cause the large portion of building's heat gain. The heat gain through the exterior window accounts for 25 – 28% of the total heat gain, and added to the infiltration, it makes 40% of the total while exterior wall heat gain represents 23–24% (Yu *et al.* 2008). Window's material, orientation and its area ratio to the wall WWR are the main factors affect the performance of the glazed system. The effective utilization of these factors with applying natural ventilation can enhance the thermal comfort by decreasing the negative effect of solar radiation (Al-Tamimi *et al.* 2010). The main influencing factor of the previous factors is the overall window to wall area ratio. On east, south, and west exposures, greater window areas will admit more solar gain during winter (Mikler *et al.* 2008).

1. Insulation: insulation has the ability to control the process of heat transfer between the buildings and the outdoor environment. This can be expressed by the term of U-value. Insulation has a great influence on reducing the amount of heat gain in summer and the heat loss in winter. This can maintain the indoor air temperature within the thermal comfort thus reducing the heating and cooling requirements (Bahrami, 2008).

2. Thermal Mass:

Thermal mass is a material's resistance to change in temperature. Objects with high thermal mass absorb and retain heat. Thermal mass is crucial to good passive solar heating design, especially in locations that have large swings of temperature from day to night. Thermal mass is crucial to good passive solar heating design. Objects with high thermal mass absorb and retain heat, slowing the rate at which the sun heats a space and the rate at which a space loses heat when the sun is gone. Without thermal mass, heat that has entered a space will simply re-radiate back out quickly, making the space overly hot with sunlight and overly cold without.

Thermal mass has virtually no effect in steady-state heat flow, which is when temperatures are relatively constant on each side of a material (Balcomb, 1995). In order to have an effective thermal mass, its material must have a high heat capacity with a moderate conductance, a moderate density, and a high emissivity (Haglund et al. 1996).

Climates and Thermal Mass

Thermal mass is most useful in locations that have large swings of temperature from day to night, such as desert climates. Even if the thermal mass does not prevent heat energy from flowing into or out of occupied spaces, like insulation would, it can slow the heat flow so much that it helps people's comfort rather than causing discomfort. In climates that are constantly hot or constantly cold, the thermal mass effect can actually be detrimental. This is because all surfaces of the mass will tend towards the average daily temperature; if this temperature is above or below the comfortable range, it will result in even more occupant discomfort due to unwanted radiant gains or losses. Thus, in warm tropical and equatorial climates, buildings tend to be very open and lightweight. In very cold and sub-polar regions, buildings are usually highly insulated with very little exposed thermal mass, even if it is used for structural reasons.

3. Shading: the main principle in shading strategy is to avoid the penetration of direct solar radiation into the building through its opening and heat absorbing materials. Trees and roof overhangs act as a shading system (Scottsdale's Green Building Program). Also, solar shading devices such as overhangs, awnings and blinds which are lightweight ventilated shading panels attached to walls and roofs can utilize to avoid unwanted solar radiation in summer and allowing it in winter. The most critical point in designing shading devices is the different solar radiation angles during summer and winter (Bahrami, 2008).

2.5. Climate Responsive Design Strategies in the Mediterranean Region

The Mediterranean region is the area around the Mediterranean Sea and includes the southern part of Europe and the northern part of Africa and the western part of Asia. Its climate affected by the Mediterranean Sea, which can be considered as an important heat reservoir and source of moisture for surrounding land areas. The region is characterized by a complex topography which plays a significant role in steering air flow. According to its location in a transitional zone, both mid-latitude and tropical variability is important and competes against each other. The Mediterranean climate is exposed to the South Asian Monsoon in summer and the Siberian high- pressure system in winter (Giannakopoulos et al. 2005).

2.5.1 Climate characteristics of the Mediterranean climates

The Mediterranean climate may occur on the west side of continents between about 30° and 40° latitude (Giannakopoulos et al. 2005). The sun is considered the most important parameter in the Mediterranean region (Behsh, 2002). It has two main seasons: hot dry summers and cool wet winters (Evans, 2007). The average conditions are not extreme and in general, the sky temperature ranges between 6 °C and 30 °C below the ambient temperature (Colombo et al. 1994). The incongruent variations in winter and summer temperatures, daily temperature variations, solar radiation and relative humidity require different solutions for different locations (Schnieders, 2009). Figure 2.13 shown Koppen climate types in Mediterranean region.

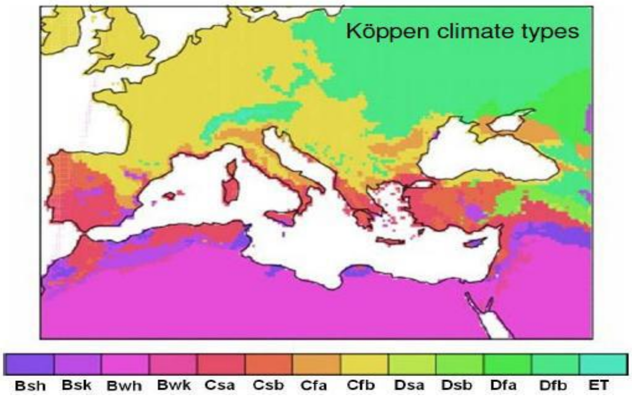


Figure 2.13: Koppen climate types in the Mediterranean region
Source: Lionello et al. (2011)

2.5.2. Responsive building strategies

The main principles in passive design strategies is to avoid unwanted heat gain in summer and increasing the heat gain and avoid heat loss in winter (Evans, 2007). Heat gain can be maximized in winter in an easily manner, however it is difficult to avoid it during summer. The presence of large amounts of water vapour in summer period in most Mediterranean areas is considered a challenge as it decrease the availability of night cooling in summer and produce mild night temperatures in winter (Colombo et al.1994). The more important passive strategies in Mediterranean climate will be introduced in the following subsections;

a. Urban Morphology

One of the main strategies of the urban morphology is the building density which mainly determines the relative surface of the roofs. Increasing the roof areas can play a significant role in increasing the radiative exchanges. This strategy can be utilized in the Mediterranean or semi desert climates which characterized by high density housing in narrow streets. The solar radiation received by roofs can be reflected away to the sky using appropriate materials in order to minimize the air temperature in external spaces especially near the ground (Goulding et al. 1992).

b. Plan shape

The optimum shape can be defined as the shape that achieves a large amount of heat gain in winter and a small amount in summer. In the Mediterranean climate, south walls are the best solar collectors during winter time, while the roof and east-west walls become at the top in summer time. Therefore, the rectangular shape with the long axis running east to west is the optimum shape. The large area of south wall can increase the solar radiation in winter as it receives three times more energy than the east or west. Also, the problems associated with the west wall can be enhanced by reducing its area to the minimum. Natural ventilation can be utilized in this shape as in any other. The square shape's performance is worse than the rectangular and the rectangular shape with the long axis, running north to south is considered the worst. Another important issue in the building shape is the height. Two story building is considered more preferable than a single one because of a small roof area which decreases heat gain in summer and heat loss in winter. Also, increasing building's height can increase the area of south walls and enhance solar access and heat gain. It's more easily to control solar radiation with vertical surfaces (Colombo et al. 1994).

c. Orientation

The optimum orientation for the Mediterranean climate is which provide both heating and cooling. The solar access is the most important parameter for heating requirements. Hence, it will be appropriate to orientate the building ± 22.5° from the south. This south-west orientation would be worse in summer, instead the building have to orientate to provide breeze and shading. It is necessary to make sure there are no obstructions affect the solar access between 9 am and 3 pm solar time in winter period (Colombo et al. 1994).

d. Material and Insulation

It’s obviously that the need for cooling is an important as the need for heating in the Mediterranean climate. Unfortunately, the summer temperature does not drop very much at night for cooling requirements. Therefore the best solution is to reduce the mass to be cooled down at night by using a light construction with internal insulation layers (Colombo et al. 1994). Colombo et al. stated that building envelope includes these elements;

Windows: Glass is responsible for the large portion of heat loss in winter and heat gain in summer. This is due the low resistance of glass elements as well as air infiltration. In Mediterranean climate, double glazing should be adapted in buildings. However, triple glazing is an unreasonable choice at present cost.

Roofs: In the south Mediterranean climate, the summer situation is even worse. Roofs expose large amount of solar radiation and this heat can transfer to the interior space. So it is necessary to use pale colours on flat roof-top. Its preferable to have a vented gab between the roof and the ceiling insulation in the case of sloping roofs. Shading and vegetation will have effective impact.

Walls: West walls must have a special concern in selection there materials and insulation in the Mediterranean climate. However, super insulation in other walls is unnecessary and uneconomic (Colombo et al. 1994). Un-insulated but high thermal capacity walls allow for the evacuation of the heat stored in the building during the day, leading to the reduction of air-conditioning need (Znouda et al. 2007).

Ground Contact Zones: It's not preferable to use insulation in the floor slab in the Mediterranean climates as it reduces the opportunity for cooling during the hot summer months.

e. Shading

Shading is an essential parameter in all climates especially in Mediterranean climates to avoid overheating at midday on sunny days. The critical period for the Mediterranean summer season is the afternoon when the sun is still hot, yet low in the sky. Shading must be provided to the west walls by trees, evergreen vegetation, trellises or overhanging roofs. It's advisable to integrate shading with insulation of the west walls. Exterior shading devices should be provided to the west windows with some air flow between the glass and the protection device, in order to maximize the benefit from internal shading systems (Colombo et al. 1994). The shadowed portion of the glazed area should be as large as possible in summer and as low as possible in winter (Znouda et al. 2007).

2.6. Adaptive Comfort Strategies Used in the Mediterranean Region

2.6.1. Atrium and Courtyard

The atrium in a house acts as a light well as well as an air-shaft, bringing both daylight and air movement to the rooms around it. The diurnal temperature changes amount to 10 °C to 20 °C during the summer months. The diurnal range is much higher in the hinterland than in the coastal regions. In the hot dry hinterland the atrium functions in three regular cycles _ as shown in Figure 2.17_ taking advantage of the diurnal range of temperatures during summer. Talib (1984) has described how courtyard functions in three phases. During the first cycle, the cool night air descends into the courtyard and fills the surrounding rooms. Walls, floors, columns, roofs, ceilings and furniture are cooled at night and remain so until the late afternoon. The courtyard loses heat by irradiation to the sky and may be used for sleeping during the summer, as can the roof. During the second cycle around noon the sun directly strikes the courtyard floor. Some of the cool air begins to rise and also leaks out of the surrounding rooms. This action sets up convection currents in the rooms which may afford further comfort. The courtyard now begins to act as a chimney. At this hour the ambient temperature is very high outside. Thick walls do not permit the external heat to penetrate to the inside of the house.

The adobe walls are excellent insulators, and the time lag for an external wall of average thickness may be as much as 12 hours. Three out of four external walls on an average are party walls; thus the house remains enclosed on all sides and is insulated from heat gain during the day. During the third cycle, the courtyard floor and the inside of the house get warmer and further convection currents are set up by the late afternoon. Most of the cool air trapped within the rooms spills out by sunset. These three cycles are illustrated in Figure 2.14.

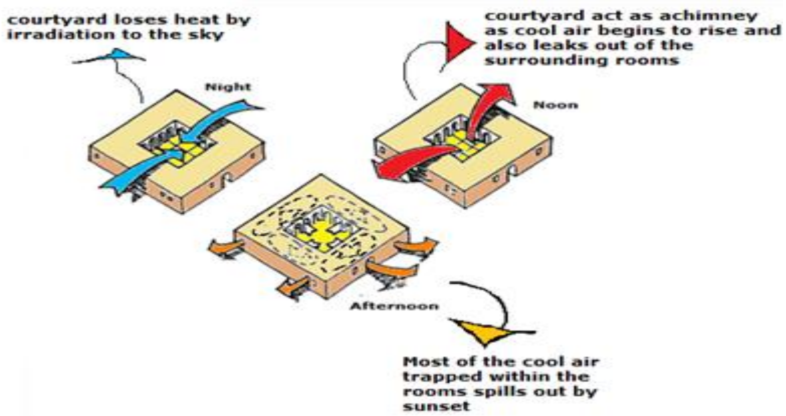


Figure 2.14: The function of the courtyard during the 24 h cycle (Plotted after Talib, 1984)

In certain cases, especially in Arab countries, wise use is made of a combination of two courtyards, one in shade and the other sunny, to create a natural air flow from the cooler courtyard to the warmer one, creating an especially pleasant environment in the intermediate premises, example on these type of courtyards are found in Egypt and Syria. In other cases, as in the Moroccan mountains, very high and narrow courtyards, (open sky atrium), are built in buildings several storeys high, acting as inverted chimneys that ventilate the innermost zones of the building.

<u>Thermal performance of courtyards:</u>

The thermal performance of the courtyard house comprises heat exchange processes taking place among the environments of three interrelated spaces; the indoor spaces, the courtyard space and the external open spaces between houses. Considering the indoor environment, heat is exchanged through:

- the inner envelope (courtyard walls)
- the outer envelope (external walls and roof)

The different surfaces of the two envelopes are constantly exposed to the outside air temperature; however their exposure to solar radiation varies with time. This emphasises the importance of studying means to control the exposure to solar radiation. In such control, the inner envelope is more critical since most of the openings are located there. Regarding the physical system, which represents the impact of solar radiation upon the indoor space passing through the inner envelope, the two subsystems are identified. The external system deals with:

- the insulation of the courtyard surfaces which is a joint function of the sun's geometry and the courtyard geometry; and
- the thermal balance of the surfaces as affected by the incident radiation

The internal system deals with the heat flow taking place through the opaque as well as transparent materials of the envelope. When outdoor conditions are very severe, the system has to resist thermal gains, minimizing hot air infiltration, solar radiation and heat conduction and to thermal losses through earth cooling, ventilation, radiant cooling and evaporative cooling.

2.6.2. Solar control strategy.

To prevent rooms from overheating it is important to shade windows from direct sunlight in the summer months. External blinds are more effective than internal blinds as they prevent the sun's heat entering the room. The basic idea is to insulate the outside from the inside, and to prevent direct sunlight from entering the space. Roof overhangs and louvers can be used to allow daylight to enter without the direct rays from the sun. Figure 2.15 shows an example of solar control system that is used in the Mediterranean region to preventing the sun's rays from entering the building during summer time.

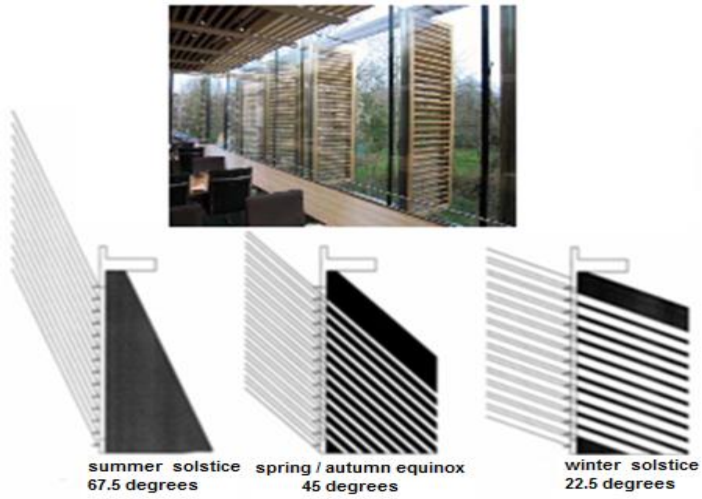


Figure 2.15: Solar control – preventing the sun's rays from entering the building
Source: http://www.architecture.com/SustainabilityHub

2.6.3. Thermal mass

Thermal mass is a concept in building design which describes how the mass of the building provides "inertia" against temperature fluctuations, sometimes known as the thermal flywheel effect. For example, when outside temperatures are fluctuating throughout the day, a large thermal mass within the insulated portion of a house can serve to "flatten out" the daily temperature fluctuations, since the thermal mass will absorb heat when the surroundings are hotter than the mass, and give heat back when the surroundings are cooler. This is distinct from a material's insulation value, which reduces a building's thermal conductivity, allowing it to be heated or cooled relatively separate from the outside, or even just retain the occupants' body heat longer.

2.6.3.1 <u>Properties required for good thermal mass</u>

Ideal materials for thermal mass are those materials that have:

- high specific heat capacity,
- high density

Any solid, liquid, or gas that has mass will have some thermal mass. A common misconception is that only concrete or earth soil has thermal mass; even air has thermal mass (although very little). A table of volumetric heat capacity for building materials is available at many sources such as ASHRAE and SIBCE.

2.6.3.2. <u>Hot humid climates (e.g. sub-tropical and tropical)</u>

The use of thermal mass is the most challenging in this environment where night temperatures remain elevated. Its use is primarily as a temporary heat sink. However, it needs to be strategically located to prevent overheating. It should be placed in an area that is not directly exposed to solar gain and also allows adequate ventilation at night to carry away stored energy without increasing internal temperatures any further. If to be used at all it should be used in judicious amounts and again not in large thicknesses.

2.6.3.3. <u>The Application of Thermal Mass</u>

Capacitive insulation (thermal mass) provides a very powerful control of the timing of heat input especially in climates with a large diurnal temperature swing as it can store the surplus heat at one time, for release at another time, when it is needed. Thermal mass in buildings can be used to avoid dealing with instantaneous high cooling loads, to reduce energy consumption and to attenuate indoor temperature swings, caused by rapid changes in the ambient conditions during the day. The benefits of capacitive insulation, or mass effect, will be greatest in hot-dry climates, with a large diurnal variation, where the temperature varies over the daily cycle between too high and too cold, where the day's mean is within the comfort zone. Massive construction may provide the full solution, as it may ensure comfortable indoor conditions without any mechanical cooling or night heating. Santamouris & Asimakopoulos in 1996 proposed that the effectiveness of thermal storage is acceptable where the diurnal variation of ambient temperatures exceeds 10 degree. Likewise, Szokolay (2008) stated that some sources propose that a mean range (the range between monthly mean maximum and minimum, averaged for the 12 months) of 10degree would require massive construction; others put this limit at 8 degree. In addition to outdoor condition, Occupancy patterns of buildings should be considered for thermal mass application. The mass effect provided by a heavy construction is beneficial in a continuously occupied building, e.g. house, where it would allow the use of intermittent heating (in cold season) or cooling (in hot season), and still keep a stable temperature. In an intermittently used building, e.g. an office, lightweight insulated construction may be better since massive construction would have a longer heating up or cooling up period in the morning increasing energy load. Amount and Distribution of Thermal Mass: The amount of thermal mass in a building and its distribution in the envelope play an important role in the building thermal performance. Thermal mass must be properly distributed, depending on the orientation of the given surface and the desirable time lag. A surface with north orientation has little need for time lag, since it only exhibits small heat gains. For other orientations; such as east, west, and south orientations, it is desirable to have a very long time lag. The roof, which is exposed to solar radiation during most hours of the day, would require a very long time lag. However, because heavy roofs will increase the structure dead load and consequently its cost, the use of additional insulation is usually recommended instead (Santamouris, et al., 1996).

2.6.4. Natural Ventilation

This is a natural way of ventilating a building, where air is supplied a space for natural ventilation and extracted by wind and buoyancy forces. The stack effect or upward displacement ventilation occurs where air enters at low level, is heated, and then vents from high level stacks atop the building (Tommy Kleiven, 2003). To be effective it requires large openings at high and low levels within the building and floor plans that are not too deep (see Figure 2.16). To promote natural ventilation the internal plans should be kept as simple as possible and open plan spaces are best as they offer little resistance to air flows. Solar chimneys create a column of air at a higher temperature, which generates higher pressure differences and so enhances the stack effect. A passive stack can also be generated through an atrium, which will also act as a buffer to reduce heat losses (Tommy Kleiven, 2003). The depth of a space for natural ventilation: Plan form has a significant role in the design for energy efficiency. Deep plan forms result in the building being reliant on mechanical cooling and artificial lighting.

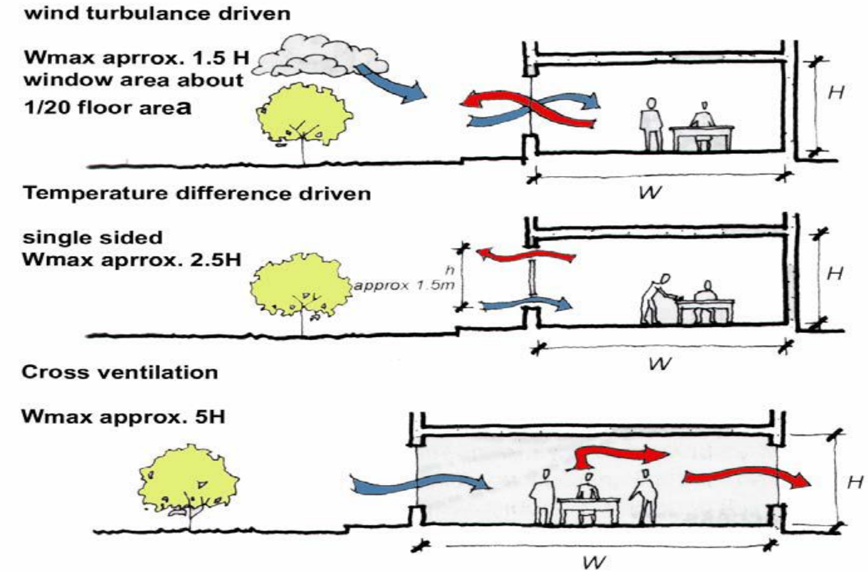


Figure 2.16: Maximum width of building (W) in relation to height (H) to make the most of natural ventilation. Source: www.passivent.com

2.6.5. Natural cooling

Evaporative cooling: A large amount of heat is absorbed by water as it evaporates. This is called the latent heat of evaporation. This heat is partially drawn from surrounding air, causing cooling to the air. Evaporation is an effective passive cooling method. Rates of evaporation are increased by air movement. The surface area of water exposed to moving air is also important. Fountains, mist sprays and waterfalls can increase evaporation rates. Passive evaporative cooling design solutions include the use of pools, ponds and water features immediately outside windows or in courtyards to pre-cool the air prior to it entering the building.

Wind forces: Wind is useful for ventilation however shelter is important to avoid excessive wind speeds. Shelter can be provided by several means; other buildings, natural vegetation or wind breaks. Deciduous trees also provide shading from the sun in the summer and let light in when the branches are bare in the winter. See Figure 2.17 (a & b).

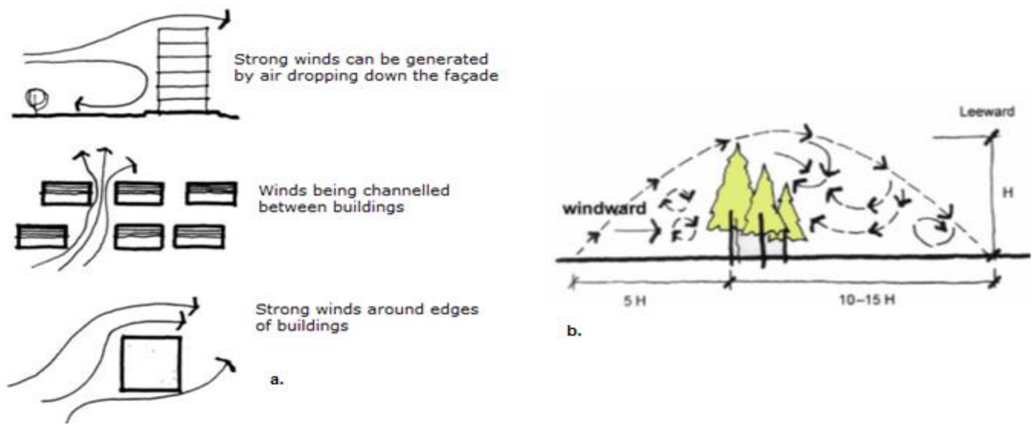


Figure 2.17: a. Natural cooling transferring excess heat from the building to ambient heat sinks_ b. trees can provide shading from the sun in the summer
Source: www.passivent.com

2.7. Chapter Conclusion

This chapter reviews some important factors, which affect building design, such as; people and their needs, climate and materials. Other factors are also given in brief such as impact of a building's form on the indoor climate, building shape and orientation and external surface. Reviewing these factors draw out some conclusions; building orientation with respect to the wind is more important factor in the Mediterranean climate, but its equal importance to the impact of solar radiation as the windows are larger orientation with respect to the sun assumes greater importance. The rate of heat loss through ventilation must be reduced in order to save energy consumption. Also, the choice of materials should take into account both the winter and summer factors. Such materials as bricks, concrete, hollow concrete blocks, lightweight concrete and insulted panels might be quite satisfactory in this region, provided that their thickness ensure the required thermal resistance. There is also, however, further lessons that can be highlighted by looking at adaptive comfort strategies that are;

- High external walls can be used to shade courtyards.
- Compact housing forms reduce the heat gained from sun exposure.
- Water can be used as a landscaping feature to provide evaporative cooling.
- Thermal mass reduces the effect of the outside temperature on the interior during the day and provides warmth at night.
- Minimise of the quantity and area of windows.
- High levels windows prevent solar radiation reaching the floor.
- Light coloured building surfaces can reduce solar radiation.
- Provide natural ventilation, especially at night.
- Semi-open areas can be used as shady/cool living spaces during the day.
- Solar chimneys create a column of air at a higher temperature, which generates higher pressure differences and so enhances the stack effect.

Next chapter looks at the theory of thermal comfort and reviews the modes of heat transfer and thermal balance. It also revealed the factors which influence the comfort of a human being in a building, some are universal comfort parameters and some are unique to buildings.

INDOOR THERMAL COMFORT

CHAPTER 3 : INDOOR THERMAL COMFORT

3.1. INTRODUCTION

To have "thermal comfort" means that a person wearing a normal amount of clothing feels neither too cold nor too warm. Thermal comfort is important both for one's well-being and for productivity. It can be achieved only when the air temperature, humidity and air movement are within the specified range often referred to as the "comfort zone". Where air movement is virtually absent and when relative humidity can be kept at about 50%, the ambient temperature becomes the most critical factor for maintaining thermal comfort indoors. However, temperature preferences vary greatly among individuals and there is no one temperature that can satisfy everyone. Nevertheless, a zone which is too warm makes its occupants feel tired; on the other hand, one that is too cold causes the occupants' attention to drift, making them restless and easily distracted. Thermal comfort is also considered as an important feature in the evaluation of the building performance and energy savings. Therefore, exploring buildings' thermal behaviour is necessary; to predict occupants' comfort, to identify energy consumption, and to examine alternate enhancements for achieving better indoor thermal environments and energy efficient buildings. Parameters that could affect thermal comfort are explicated in this chapter to help identifying the methods of prediction thermal comfort. In addition, this chapter introduces the theory of thermal comfort including its importance, definition and requirement. At second stage the chapter also highlights a brief explanation of some factors that influencing thermal comfort and lastly, the chapter will look at these following issues in brief; heat transfer, thermal mass, heat gain and loss, thermal exchange, balance and scales.

3.2. IMPORTANCE OF THERMAL COMFORT

Since the old age, builders used many strategies in order to achieve the desirable level of indoor thermal comfort whether they are private houses or public places. Macpherson (1962) described the assessment of thermal environment as one of the oldest judgements made by man, commenting on the prevailing weather by comparatively evaluating in everyday conversation. The ability to evaluate such assessment with numerical values was relative modernity, being introduced by Galileo at the beginning of the seventeenth century. It was then that the first type of air thermometer invented. By the end of the nineteenth century, scientists become more interested in comfort studies, and all four environmental parameters (temperature, humidity, air movement and solar radiation) were able to be measured and controlled in a quantitive way. Other factors like the rate of working and clothing worn or individual parameters have been recognised to be part of the assessment recently (Macpherson, 1962). The knowledge of both environmental and individual parameters has made the possibility to establish the standard of thermal comfort by many researchers such as Fanger and ASHRAE (American Society of Heating, Refrigerating and Air Conditioning Engineers). And according to Raw & Oseland (1994) there are five advantages of knowledge of thermal comfort research, which are;

1. guiding the design of buildings and enclosed environments,
2. controlling over environments which are too extreme for people,
3. improving internal air quality, reducing the risk of sick building syndrome and promoting good health,
4. reducing the production of CO^2,
5. effecting the work efficiency of the building occupants.

Considering the five advantages that mentioned above, indoor environment should be designed and controlled so that occupants' comfort and health are assured. Recently, maintaining thermal comfort for occupants of buildings or other enclosures becomes one of the important goals of (HVAC) design engineers that is because many studies and researches showed that people work better in a comfortable environmental than other states. Some of these researches which aimed to establish the right comfort zone for human being are shown in this chapter with their effects.

3.3. The Theory of Thermal Comfort

3.3.1. Definitions of Thermal Comfort

There is no absolute standard of thermal comfort. This is not surprising, as humans can and do live in a range of climates from the tropics to high latitudes. An internationally-accepted definition of thermal comfort, used by ASHRAE, is ‘that condition of mind which expresses satisfaction with the thermal environment’ (ISO 7330). However, this definition appears to have controversial precision. Heijs (1994) referred to a psychological point of view that “condition of mind” could be the result of either a perceptual process, or a state of knowledge or cognition, or a general feeling or attitude, and could take many different forms such as a feeling of wellbeing, or in a pattern of behaviour or clothing. He also argued that if comfort is a subjective mental state, it will be indefinable because it cannot be measured objectively and it is continuously changing depending on various factors. Consequently, it is suggested that thermal comfort should be considered as “an environmental property, determining the satisfaction of thermal needs both physiologically and psychologically”. This environmental property composed three components: thermal climate, thermal environmental and thermal control. In agreement Mayer (1993) questioned the meaning of "satisfaction with the thermal environment" whether it is an objective criteria. Others have defined thermal comfort in different way such as Limb (1992) who has defined thermal comfort as "*a condition of satisfaction expressed by occupants within a building to their thermal environment".* Whereas Markus & Morris (1980) has defined thermal comfort as "that state in which a person will judge the environment to be neither too cold nor too warm_ a kind of neutral point defined by the absence of any feeling of *discomfort*".

Comfort is a subjective sensation, as seen by Evans (1980), who emphasises that; "there is no such thing as a perfect combination of conditions for comfort since it is not possible to satisfy everyone at the same time, even when the optimum thermal conditions are achieved, only 50 to 70% of the population may feel comfortable, with the remainder feeling either slightly warm or slightly cool". In terms of bodily sensations, thermal comfort is a sensation of hot, warm, slightly warmer, neutral, slightly cool, cool and cold and may not measure objectively.

3.3.2. Thermal Requirements

The human body influences by the surrounding surfaces through radiation in addition to absorbs and emits heat through the air by convection. Therefore heat transfer by both convection and radiation needs to be considered when trying to achieve thermal comfort. The body heat transfer mechanisms cause the temperature to be specified as "felt temperature" or "operational temperature" and its measurement known as room temperature corresponds approximately with the mean value of the air temperature in the room and the mean radiation temperature from the enclosing surface areas of the room. The specifications of mandatory temperatures or temperature ranges for rooms and buildings are regulated by many legislative directives of the individual countries. Generally, temperatures should always be evaluated in relation to the outside temperature. A difference of 5-6 K (temperature differences are specified in Kelvin, with 1K equalling 1°C) compared to the outside temperature has proven to be a viable definition whereby room temperatures of more than 26 °C should be avoided. Research has shown that users show higher acceptance of the room temperature if the temperature can be regulated by operable windows. Users are typically less satisfied if the temperature is controlled by a central air conditioning unit that they cannot regulate individually. Figure 3.1 shows how much impact the surface areas of a space can have on thermal comfort.

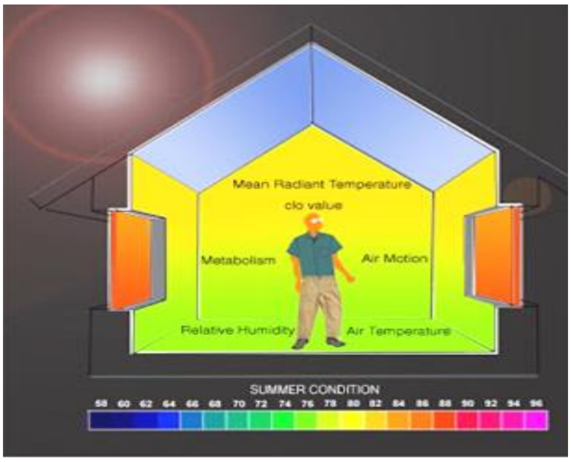


Figure 3.1: Parameters influencing thermal comfort. Many factors are responsible for the thermal comfort level. The human body emits heat through radiation and convection, but also perceives the heat/cold from the surrounding walls and the airflow in the room_ source: Ulrich Knaack and others (2007)

3.3.3. Thermal Comfort Principles

Fanger (1970) assured that the most important variables which influence the condition of thermal comfort are these six factors:

1. *activity level (heat production in the body),*
2. *thermal resistance of clothing (Clo value),*
3. *air temperature,*
4. *mean radiant temperature,*
5. *relative air velocity,*
6. *water vapour pressure in ambient air.*

Other researchers such as Evans (1980), Limb (1992), ASHREA (1997) and Szokolay (2008) have grouped these variables that influence thermal comfort into three sets as presented in Table 3.1. An agreement has been established about these variables in the above researches and the overall conclusion was that "these factors must be considered at an early design stage in the context of the local external climate, the function of the space and its location within the building that is because each building demands its own degree of comfort".

Table 3.1: factors of comfort_ produced after Szokolay, 2008 and ASHREA, 2009

Environmental	Personal	Contributing factors
Air temperature	Metabolic rate (activity)	Food and drink
Air movement	Clothing	Body shape
Humidity	State of health	Subcutaneous fat
Radiation	Acclimatization	Age and gender

Fanger (1970) in particular, has focused on thermal comfort and holds that, thermal comfort can be achieved by many different combinations of the above variables and therefore also by the use of many fundamentally different technical systems..., he also found in his research that the combined thermal comfort effect of the variables on the human body is the important one. Fanger in his work has come out with a comfort equation conditional on an idea which is that "it is impossible to consider the effect of any of the physical factors influencing thermal comfort independently, as the effect of each of them and necessary requirements depend on the level and conditions of the other factors". This idea supports the "hierarchy of human needs" which was proposed by Maslow (1984) when he suggested that starting with the dominant item 1, any further needs can (and will) only be satisfied if all lower levels had been satisfied:

1. *physical/biological*
2. *safety/survival*
3. *affection/belonging*
4. *esteem (self-and by others)*
5. *self-actualization*

Thermal comfort is one of the basic physical/biological needs. For survival our deep-body temperature must stay around 37°C. It is therefore imperative to keep thermal conditions in buildings within acceptable limits, before any of the higher level needs could even be considered. And since it has been already looked at the environmental factors in the previous chapter, the other factors will be considered in this chapter aiming to cover all the factors that are influencing the thermal comfort.

3.3.3.1 Personal Factors

In addition to environmental factors, there are physiological factors that affect a person's thermal comfort, each of which vary between individuals and the activities to be performed within any particular space; these are *Clothing Level* (Clo), *Metabolic Rate* (Met), *State of health* and *acclimatization*.

a) Clothing Level (Clo)

In the majority of cases, building's occupants are sedentary or slightly active and wear typical indoor clothing. Clothing, through its insulation properties, is an important modifier of body heat loss and comfort. The insulation properties of clothing are a result of the small air pockets separated from each other to prevent air from migrating through the material and in general, all clothing makes use of this principle of trapped air within the layers of cloth fabric. Clothing insulation can be described in terms of its Clo value. The Clo value is a numerical representation of a clothing ensemble's thermal resistance. 1 Clo = 0.155 m^2. °C/W. A heavy two-piece business suit and accessories have an insulation value of about 1 Clo, while a pair of shorts is about 0.05 Clo. Typical values of thermal resistance for various combinations of clothing are shown in Figure 3.2, which is based on ISO 7730 (The International Standards Organisation). Comfortable clothing levels are expressed as a function of operative temperature, which is based on both air and mean radiant temperatures. At air speeds of 0.4 m/s or less and MRT less than 50°C, the operative temperature is approximately the average of the air and mean radiant temperatures is equal to the adjusted dry bulb temperature.

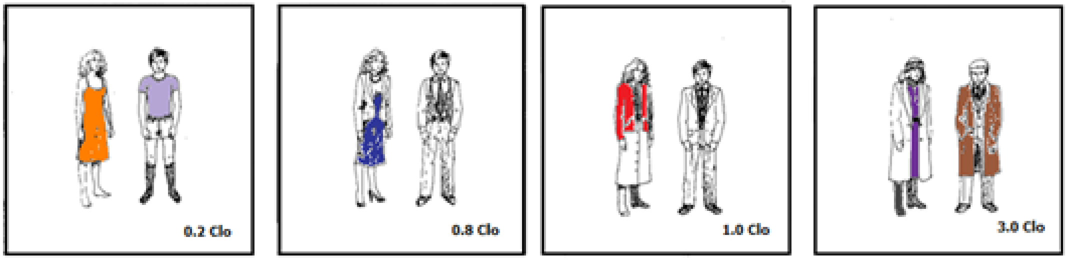


Figure 3.2: Insulation values of different kind of clothing (1 Clo =0.155 m²K/W) _ reproduced after Fanger P. O., 1985 as a source.

There is no combination of conditions that would satisfy all people all of the time. The optimum operative temperature represented by the middle line in Figure 3.3, is the temperature that satisfies the greatest number of people with a given amount of clothing and specified activity level. The upper and lower thermal acceptability limits demarcate a room environment that at least 80 percent of the occupants would find thermally acceptable.

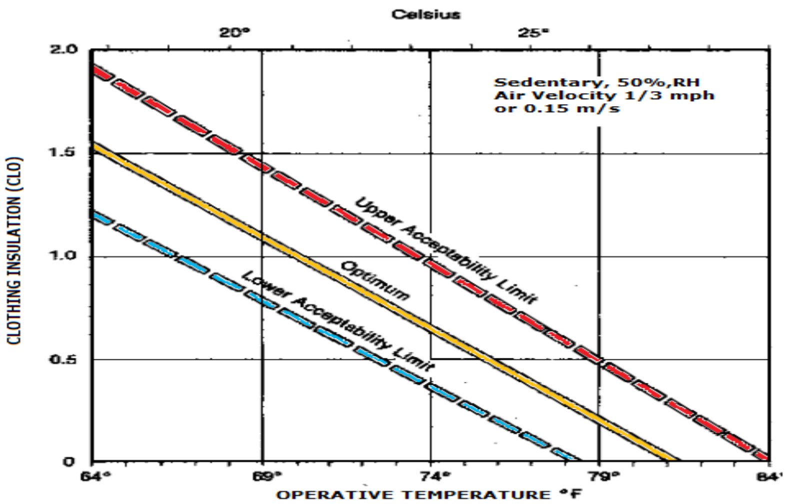


Figure 3.3: Clothing level (in Clo units) necessary for comfort at different room temperatures. (Reprinted from Standard 55)

From the 1920s to the early 1970s, energy was abundant and inexpensive. During this period, the preferred amount of clothing worn by building occupants decreased, and correspondingly the preferred temperatures increased from about 20°C for winter to the year round range of 22° to 25.5°C. Present conditions, however, make it desirable to minimize energy consumption for providing thermal comfort. By adjusting clothing as desired, the remaining occupants can satisfy their own comfort requirements. Energy savings can be achieved if the insulation value of clothing worn by people indoors is appropriate to the season and outside weather conditions. During the summer months, clothing like lightweight dresses, short-sleeved shirts or blouses, underwear, and a thin jacket have insulation values ranging from 0.35 to 0.6 Clo. The winter heating season brings a change to thicker, heavier clothing. A typical winter ensemble, including heavy slacks or skirt, long-sleeved shirt or blouse, warm sweater or jacket would have an insulation value ranging from 0.8 to 1.2 Clo.

B) Metabolic Rate (Met) or Activities

The "internal heat load" of a body depends on its metabolic activity and varies greatly, and as part of the process of being alive, people metabolize the food taken into the body, converting it into electrochemical energy. This energy enables us to carry out our normal bodily functions and to perform work upon objects around us. As with all conversions from one form of energy to another, there is certain conversion efficiency. Only about 20% of all the potential energy stored in the food is available for useful work. The other 80% takes the form of heat as a by-product of the conversion. This results in the continuous generation of heat within the body, which must be rejected by means of sensible heat flow (radiation, convection, or conduction) to the surrounding environment or by evaporating body fluids. There is a continuous draw of energy for the operation of life-sustaining organs such as the heart. This is the idle level of bodily activity corresponding to the state of rest. It requires minimum energy conversion, and thus a minimum amount of heat is released as a by-product. When the body is engaged in additional mental or physical activity, metabolism increases to provide the necessary energy. At the same time, by-product heat generation also increases. The fuel for this is drawn from food currently being digested or, if necessary, from the fat stores. When the body heat loss increases and the internal temperature begins to drop, metabolism increases in an effort to stabilize the temperature even though there is no additional mental or physical activity. In this case, all of the additional energy metabolized is converted into heat. In general, the metabolic rate is proportional to body weight, and is also dependent upon the individual's activity level, body surface area, health, sex, age, amount of clothing, and surrounding thermal and atmospheric conditions. Metabolism rises to peak production at around 10 years of age and drops off to minimum values at old age. It increases due to a fever, continuous activity, or cold environmental conditions if the body is not thermally protected.

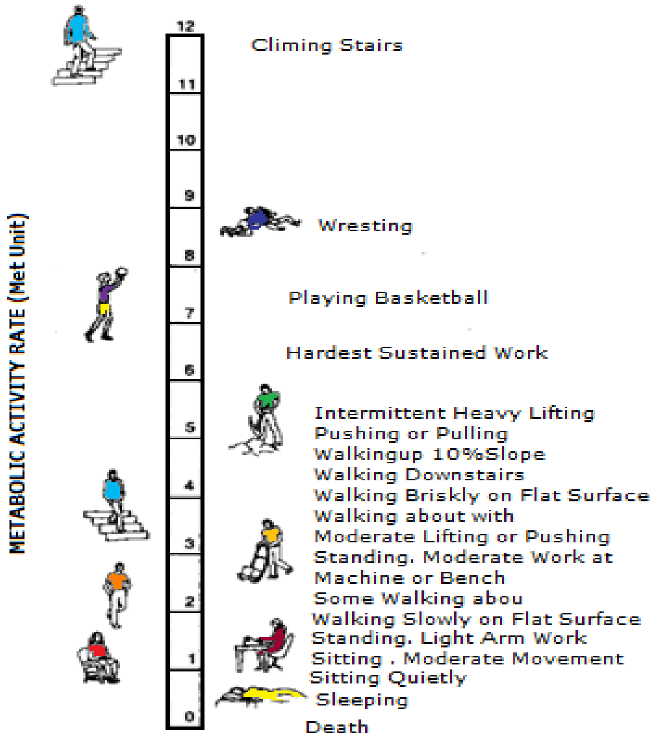


Figure 3.4: Metabolic rate of different activities (1 met = 58 W/m²) _ reproduced after Fanger P. O., 1985 as a source.

To determine the optimum environmental conditions for comfort and health, one must ascertain the metabolic level during the course of routine physical activities, since body heat production increases in proportion to the level of exercise. When the activity level shifts from sleeping to heavy work, the metabolism varies accordingly, as shown in Figure 3.4. The rate at which energy in food is converted to heat in the body is called the metabolic rate, and may be expressed in watts. The metabolic rate of an average-size male adult when seated and relaxing is about 100W = 90 kcal/hr. In order to reduce the variation between people of different sizes, the metabolic rate may be expressed in W/m^2 of body area. The average surface area of a male adult is approximately $1.8m^2$. Another unit used for metabolic rate is the met, based on the metabolic rate of a seated person when relaxed. Another factor affecting metabolic rate is the heavy, protective clothing worn in cold weather, which may add 10 to 15 percent to the rate. Pregnancy and lactation may increase values by 10 percent. The above Figure 3.4 shows the metabolic rate produce at different activates, these rates are based on ISO 7730.

c) Clo Value and Met-value, Tolerance

As mentioned above, clothing and metabolic activity have a great effect on the comfort zone. Moreover, they also influence the acceptable temperature range (tolerance). A physically highly active person can bear quite wide temperature differences, whereas a sleeping person is more sensitive to differences. Figure 3.5 below illustrates this relationship. The white and shaded areas in the Figure indicate an incidence of less than 10% of persons dissatisfied (PPD). This illustrates that the higher the Clo value or the activities level of a person, the greater his tolerance for differences in temperature will be. For example, a seated person wearing a suit (Clo = 1.0; met = 1.2) the ideal room temperature is 21.5°C with a tolerance of ±2°C. The temperatures are valid for middle-European conditions.

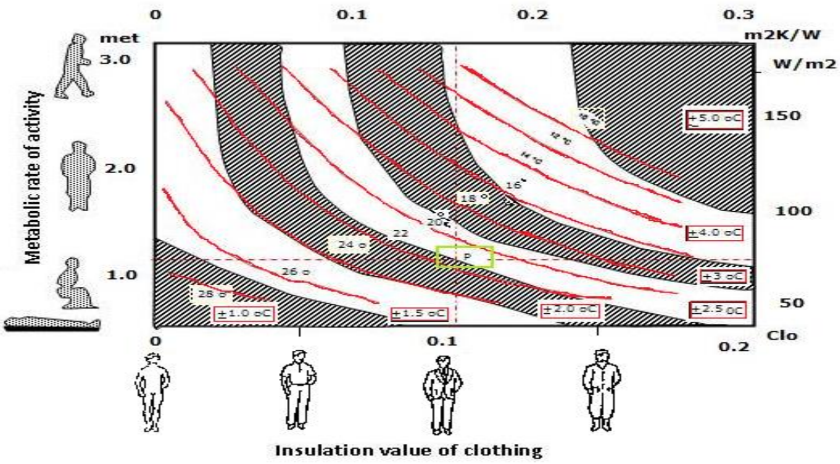


Figure 3.5: Optimum room temperature in relation to activity and clothing. Source: ISO 7730 (1984): Moderate environment, Determination of the PMV and PPD indices and specifications for thermal comfort, and element 29. (Plotted after Zurich, 1990)

d) State of Health

Drastic changes which can occur between indoor and outdoor climate, especially in air conditioned buildings, may give discomfort (stress situation) and may also be negative for health. For example, ill people lying in a hospital or people under extreme noise stress are much more sensitive to climate than people enjoying a garden restaurant. (Gut, 1993)

e) Acclimatization

To a certain extent human beings have the ability to become acclimatized. Therefore the resident population feels less stressed by a harsh climate than a passing traveller coming from another type of climate would. Analogously this can also be said for seasonal climatic changes, to which people can become adjusted. A certain temperature may be felt to be too cool in summer but too hot in winter (Gut, 1993). Table 3.2 displays an example of the seasonal changes in the comfort zone as observed in Dhahran, Iran.

Table 3.2: Reported comfort temperature in Dhahran_ Source: Ullah M.B., and others, 1982

Time	Month												
		J	F	M	A	M	J	J	A	S	O	N	D
Day	Max	22.5	22.5	28.5	30.5	32.5	32.5	32.5	30.5	30.5	30.5	28.5	22.5
	Min	18	18	22.5	18.5	29.5	29.5	29.5	29.5	28.5	28.5	22.5	18
Night	Max	20	20	20	25.5	26	29	28.5	28.5	28	25.5	20	20
	Min	16	16	16	20	20	26.5	26	26	25.5	20	16	16

3.3.3.2. Contributing Factors

There are other factors other than the climatic and personal ones influence also the wellbeing of the inhabitants. Examples on these factors are; psycho-social condition, age, sex, skin colour and air quality, acoustical and optical influences. Although these factors cannot be improved by climatically adapted construction, they should not be forgotten, because they may considerably reduce the tolerance. According to Koenigsberger et al (1973) the metabolic rate of older people is slower than the young people and they prefer higher temperature. Women have slightly slower metabolic rates and therefore prefer an average of 1°C higher compared to men. However, the studies carried out by Fanger (1982) indicated that it seems reasonable to assume that there are no important effects on preferred temperatures between different humans. All the above factors were explored experimentally in the 1970s. Many of these studies led to the development and refinement of ASHRAE Standard 55 and were performed at Kansas State University by Ole Fanger and others. Perceived comfort was found to be a complex interaction of these variables. It was found that the majority of individuals would be satisfied by an ideal set of values. As the range of values deviated progressively from the ideal, fewer and fewer people were satisfied. This observation could be expressed statistically as the % of individual who expressed satisfaction by comfort conditions and the predicted mean vote (PMV) This research is applied to create Building Energy Simulation (BES) programs for residential buildings. Residential buildings can vary much more in thermal comfort than public and commercial buildings. This is due to their smaller size, the variations in clothing worn, and different uses of each room. The main rooms of concern are bathrooms and bedrooms. Bathrooms need to be at a temperature comfortable for a human with or without clothing. Bedrooms are of importance because they need to accommodate different levels of clothing and also different metabolic rates of people asleep or awake. Peters, L., (2008).

3.4. Thermal Exchange

Several researchers such as Koenigsberger et al. (1973), McIntyre (1980), Fanger (1982) and Abdullah (1985) stated that there is some heat exchange between the body and the environment. They explained this process as illustrated in Figure 3.12, which shows the movement of heat in various forms as it is conveyed into, out of and around the building by a variety of heat transfer mechanisms.

- Conduction (Qc) in a building is the heat flow rate through walls and roofs, either inwards (+ve) or outwards (-ve).
- Convection (Qv) at building surfaces is the heat flow rate between the interior of a building and the open air.
- Long-wave radiation exchange (Qsi) is the rate of longer-wave solar radiation from building's external surface where short-wave radiation (Qs) is the rate of short-wave solar radiation incident on walls, roofs and windows.
- Internal Conditions (Qi), which include room gains from lights, equipment and occupants as well as infiltration rates and plant operation specifications, are included in heat exchange too. Other heat means are (Qe) the rate of evaporation heat loss from building's surface and (Qm) the rate of heating or cooling by mechanical means.

Thermal comfort is strongly related to thermal balance between the body's heat and its surroundings (Mabb, 2008). The body temperature must remain balanced and constant around 37°C, and in order to maintain this steady level, many physiological mechanism of the body are occurred (McMullan, 1992). The thermal exchange between the body and the environment takes place in four different ways: conduction, convection, radiation and evaporation (perspiration and respiration) _ Figure 3.6 explains in a simple way the heat exchange processes between human body and the environment.

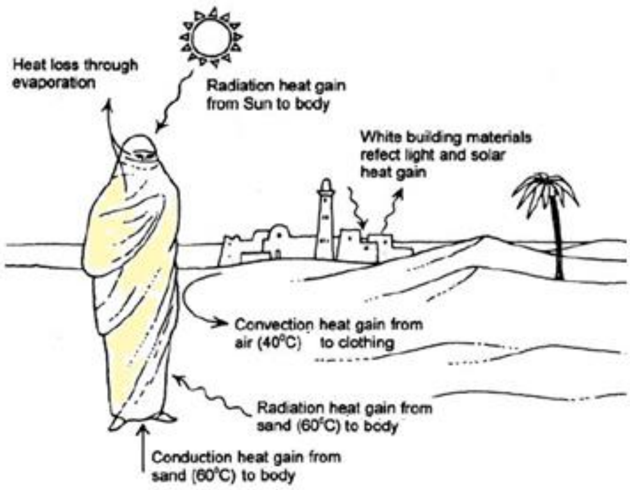


Figure 3.6: Schematic diagram of energy exchanges between human and its environment, produced after Randall Thomas (2005)

3.5. Thermal Comfort Calculation

It is possible to measure the environmental variables at a suitable number of points in the occupied zone in a given space, but these measurements should be interpreted in order to predict the comfort level in that zone. Due to the number of interacting factors affecting human comfort, including personal preferences, the prediction of thermal comfort is not an easy task. Throughout the last few decades, researchers have been exploring the thermal, physiological and psychological response of people in their environment and developed several models to predict comfort. Of this range of models, just two are selected to be discussed here which are the predicted Mean Vote (PMV) model and the Adaptive principle, that because these two models are widely known for predicting steady-state thermal comfort. The first model is based on the heat balance of the human body while the second is an approach that assumes, to a certain degree, an adaptation to the thermal environment.

3.5.1. The Predicted Mean Vote (PMV)

PMV (Fanger, 1970) describes the conditions for climatic comfort, and methods and principles for evaluating and analysing different environments from a climate point of view, with the indices of predicted mean vote (PMV) and predicted percentage dissatisfied (PPD). The concept defines conditions that must be fulfilled in order for a person to be in "whole body" climate comfort. An additional condition is the absence of any local climate discomfort. The intention was to develop a comfort equation where the above mentioned six factors (subsection 3.3.3) are needed in order to calculate in which thermal state "a normal" person is found. These calculation and estimation methods are used over the world and known as an international standard (ISO 7730, 2006). And so the PMV equation is given as below:

PMV= $[0,303._{\exp}(-0.036.M + 0,028].\{(M - W) - 0,00305[5733 - 6,99.(M - W\} - P_a] - 0,42.[M - W - 58,15]\ (1,7.10^{-5}).M.(5867 - P_a) - 0,0014.M.(34 - t_a) - (3,96.10^{-8})/\int_{C1}.[(T_{c1} + 273)^4 - (t_r + 273)^4] - [\int_{C1}.(h_c.(t_{c1} - t_a)]\}$ ………………………….. (eq.3.1)

Where,

M: metabolic rate, (W/m2)

W: effective mechanical power, (W/m2)

$\int_{c1}$: clothing surface area factor

t_a: air temperature, (°C)

t_r : mean radiant temperature, (°C)

p_a: water vapour partial pressure, (pa)

h_c: convective heat transfer coefficient, W/m^2.K

t_{c1}: clothing surface temperature, (°C)

PMV is "scaled" to predict thermal sensation votes on a seven point scale (hot 3, warm 2, slightly warm 1, neutral 0, slightly cool -1, cool -2, cold -3. Negative values indicate an uncomfortable feeling due to a cold sensation. Positive values indicate an uncomfortable feeling due to a hot sensation where. Zero is the neutral point, representing the comfort state. The major limitation of the PMV model is the explicit constraint of skin temperature and evaporative heat loss to values for comfort and 'neutral' sensation at a given activity level.

3.5.2. The Adaptive Principle

The adaptive principle suggests that people will adapt to certain climatic conditions. For instant, in warmer climate, when environmental thermal comfort parameters point at a higher PMV, people will become adaptive to the higher temperatures and still feel comfortable. As an analogy, a corresponding "PMV principle" could be written as: No change should occur that produces discomfort. In a properly designed environment, will people maintain their comfort? (Nicol and Humphreys, 200). The adaptive principle is supported by field studies in many different environments, and from these global field studies of thermal comfort rating and temperatures, Humphreys (1976) found that comfort temperature differed between groups of people. This means that comfort conditions calculated with the heat balance models did not fully agree with the comfort conditions that found in the field. By linking the comfort temperature to the climatic situations in which individuals find them. Comfort temperature is a result of the interaction between the subjects and thermal environment. Humphreys (1975) has analysed many of the completed questionnaire studies of comfort, and found the face value of comfort zones ranged from 17°C in England to 30°C in Iraq and India. Nicol and Humphreys (2001) also conclude that people with more opportunities to adapt themselves to the environment will be less likely to suffer discomfort. The main input of the adaptive models is the monthly mean outdoor temperatures T_{out} and then comfort temperatures T_c or ranges of T_c could be determined. Since adaptive models are based mainly on human behaviour and outside weather conditions, they are usually based on extensive surveys of thermal comfort in a wide range of buildings, climates, and cultures. According to adaptive models, the comfort temperature T_c could be determined by the following equations (ASHRAE,2009);

$T_c = 75.6 + 0.43(t_{out} - 71.6)_{exp} - [t_{out} - 71.6 / 61.1]^2$ ……………………….. (eq.3.2)

For climates and buildings where cooling and central heating are not required, the operative comfort temperature t_{oc} is determined by the equation:

$t_{oc} = 66 + 0.142\,(t_{out} - 32)$ ……………………….. (eq.3.3)

In general, the adaptive model is essentially a regression equation that relates the desired temperature indoors to the monthly average temperature outdoors. The only input variable used is the average outdoor temperature, which has an indirect impact upon the human heat balance. Consequently, the adaptive model does not include the six classical thermal parameters that have an impact upon the human heat balance and, therefore, upon thermal sensation.

3.6. COMFORT ZONE

According to Çakir (2006), the comfort zone may be defined as "a thermal condition in which little or no effort is required by occupants to adjust their bodies to surrounding environmental conditions". The greater the effort that is required, the less comfortable the climate is felt to be. The maximum comfort condition can usually not be achieved. However, it is the aim of the designer to build houses that provide an indoor climate close to an optimum, within a certain range in which thermal comfort is still experienced. This range is called the comfort zone. It differs somewhat with individuals. It depends also on the clothing worn, the physical activity, age and health condition. Although ethnic differences are not of importance, the geographical location plays a role because of habit and of the acclimatization capacity of individuals. Four main factors, beside of many other psychological and physiological factors, determine the comfort zone:

- air temperature
- temperature of the surrounding surfaces (radiant heat)
- relative humidity
- air velocity

A number of scales were developed for comfort zone, some of them are shown in Table (3.3).

Table 3.3: Thermal sensation scales_ Source: Rosenlund, (2000)

	ASHRAE	Fanger	Rohles & Nevins	Gagge's DISC	SET* (°C)
Painful			+5	+5	
Very hot			+4	+4	37.5-
Hot	7	+3	+3	+3	34.5 – 37.5
Warm	6	+2	+2	+2	30.0 – 34.5
Slightly warm	5	+1	+1	+1	25.6 – 30.0
Neutral	4	0	0	0.5	22.2 – 25.6
Slightly cool	3	-1	-1	-1	17.5 – 22.2
Cool	2	-2	-2	-2	14.5 – 17.5
Cold	1	-3	-3	-3	10.0 – 14.5
Very cold			-4	-4	

*SET: Standard Effective Temperature

Another scale of comfort zone is ASHRAE which has defined a comfort zone for winter and summer season. This definition is only depends on relative humidity and temperature (Sensirion, 2010), see Figure (3.7). Evans (2003) shows that there are different comfort zones defined in five successive ASHRAE standards. They also show difficulty of defining a desirable comfort zone, with significant variations proposed over a period of thirty years. Evans also in his paper on the Comfort Triangles (2003) confirmed the need to adjust the form of the Comfort Triangles to take into account the maximum possible adjustment of clothing during a typical day. Basically, the possibilities of comfortable clothing limit the acceptable thermal swing to 8 deg, a lower swing than originally proposed.

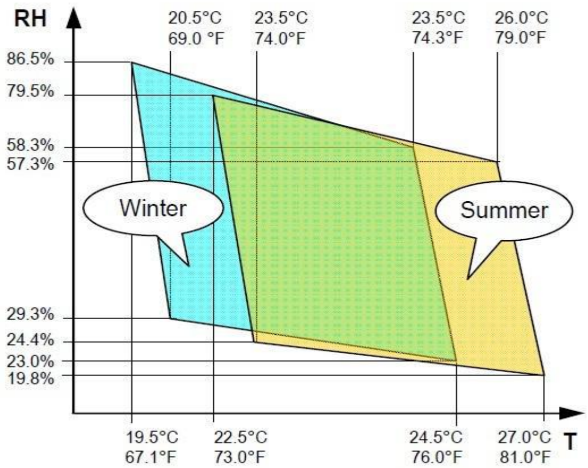


Figure 3.7: Relative humidity (RH) / temperature (T) diagram based on comfort zone according to ASHRAE 55-1992_ Source: Sensirion, 2010

3.6.1. Bioclimatic Charts

The most commonly used bioclimatic charts are Olgyay and Givoni's Bioclimatic Chart. Olgyay expresses the comfort zone in graphic form taking into consideration two climatic variables which are the dry bulb temperature DBT on the vertical axis and the relative humidity RH on the horizontal. The comfort zone is laying in the aerofoil shaped zone at the centre of this graph. The higher lines above this comfort zone indicate the effect of air movement on extending the upper boundary of the comfort zone. The lower lines below the comfort zone indicate various levels of radiation that would compensate for the lower than comfortable temperatures (Auliciems, et al, 2007). The desirable comfort zone indicated lies between 30% and 65% relative humidity (Olgyay, 1992). It is worth to mention that comfort zone here is directly applicable to inhabitants of the temperate zone of approximately 40° latitude. Figure (3.8) illustrates Olgyay's Bioclimatic chart.

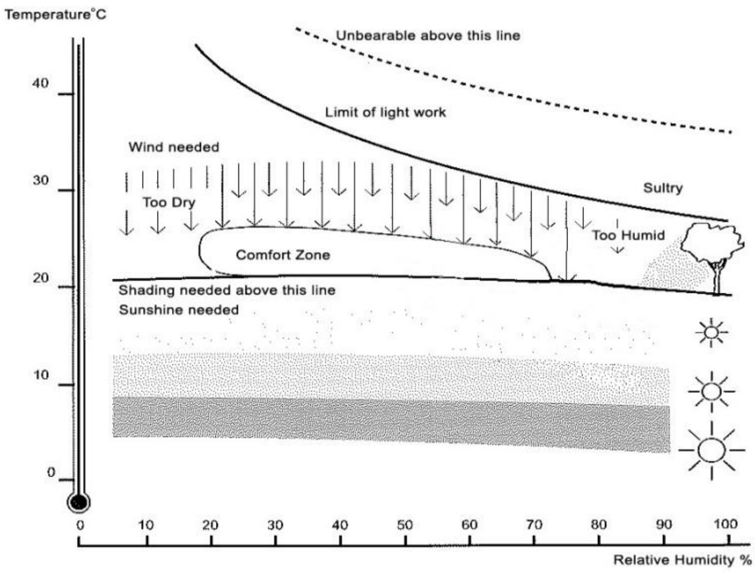


Figure 3.8: Olgyay's Bioclimatic chart _ Source: Auliciems et al. (2007)

3.6.2. Psychrometric Chart

Szokolay (2001) stated that the Standard Effective Temperature SET is the latest comfort index now generally accepted. The SET combines the effect of temperature and humidity and is defined as *"the equivalent air temperature of an isothermal environment at 50% RH in which a subject, wearing clothing standardized for the activity concerned, has the same heat stress (skin temperature Tsk) and thermoregulatory strain (skin wettedness* w) *as in the actual environment"* (ASHRAE, 2009). The comfort zone for any location and for different month can be plotted on the Psychrometric chart (Figure 3.9) as follows; (Szokolay, 2001)

1. Establish the average temperature of warmest and coldest months (T_{av})
2. Find the neutrality temperature for both and the limits of comfort

Neutral temperature Tn =17.6+ 0.31* T_{av} ……………………………….(eq 3.4)

Lower limit: $T_L = T_n - 2.5$ Upper limit: $T_U = T_n + 2.5$

3. For the side boundaries, either by following the slope of SET lines on the Psychrometric chart or constructing the corresponding sloping SET lines by determining the X-axis intercept from:

$T = T_L + 0.023*(T_L - 14) * AH50$……………………………………………(eq. 3.5)

$T = T_U + 0.023 * (T_U - 14) * AH50$ …………….…………………………….(eq. 3.6)

(Where AH50 is the absolute humidity (g/kg) at the RH 50% level at the T_L and T_U)

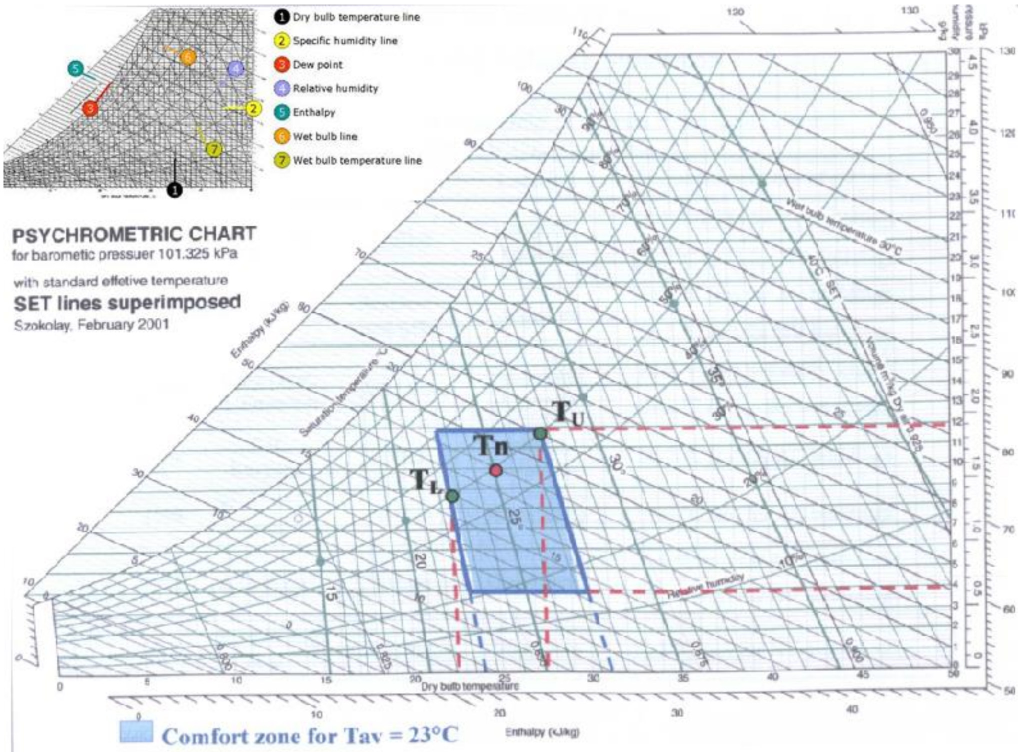


Figure 3.9: Psychrometric chart. Source: Szokolay, 2008

3.7. THERMAL COMFORT SCALES

Thermal sensation and thermal comfort are different but closely associated in the study on thermal comfort. Thermal sensation depends on skin temperature (cold through hot) while thermal comfort depends on the desired physiological state, uncomfortable through comfortable (Nicol and other, 2012). The scales used to measure these processes are briefly illustrated below;

The ISO 7730 provides a method of assessing moderate thermal environments using the PMV/PPD index, but also includes some criteria for local comfort. PMV is calculated using temperature, mean radiant temperature, humidity and air velocity of the environment as its basis, the thermal scale of -3 to 3 range that deviates from 0 (neutral) in either direction, developed by Fanger (1970) and later used as an ISO standard. Also, the standard specifies 'classes' or 'categories' of buildings according to the range of PMV that occurs within them: so Class A buildings maintain their indoor environment within ± 0.2 PMV (PPD≦ 6%), Class B ±0.5 PMV (PPD≦10%), and Class C ± 0.7 PMV (PPD≦ 15%) as explained in Table 3.4.

Table 3.4: Class A, B and C building-category specifications in ISO 7730

Category	PPD Predicted percentage discomfort	DR Draft rating	Local discomfort	PMV Predicted Mean Vote
A	< 6%	< 10%	< 3 -10 %	-0.2 <PMV < +0.2
B	< 10%	< 20%	< 5 – 10%	-0.5 <PMV < +0.5
C	<15%	< 30%	< 10 – 15%	-0.7 <PMV < +0.7

European Standard EN15251 was developed by Comité Européen de Normalisation (CEN) in response to calls from the European Union for standard to back up the Energy Performance of Buildings Directive (EPBD). The standard includes consideration of other aspects of the environment such as indoor air quality, lighting and acoustics as they impinge on the energy use of a building (Nicol, 2012). The standard follows the general lines of ASHRAE standard, although, EN15251 uses categories for buildings they are defined by the nature of the building rather than referring directly to the quality of their indoor environment (Table 3.6). These current comfort standards, [ISO 7730 (ISO, 2005) and EN 15251 (CEN, 2007)] determine design values for operative temperatures in school classrooms, based on the heat balance and the adaptive thermal comfort model respectively. However, there is no assurance that results from comfort studies performed in climate-control chambers, such as offices or university classrooms which reflect the thermal sensation and preference of school children.

Table 3.5: Suggested applicability of the categories and their associated acceptable temperature range _ Source: British Standards (BSI, 2007)

Category	Explanation	Suggested acceptable range
I	High level of expectation only used for spaces occupied by very sensitive and fragile persons	±2K
II	Normal expectation (for new buildings and renovations)	±3K
III	Moderate expectation (used for existing buildings)	±4K
IV	Values outside the criteria for the above categories	(only acceptable for a limited periods)

ASHRAE, the American Society of Heating Refrigeration and Air Conditioning Engineers controls and sponsors ASHRAE standard 55. This standard was the first international standard to include an adaptive component. Following the extensive work of de Dear and Brager (2002) and using data collected in ASHRAE project RP884 (de Dear, 1998) an adaptive standard was developed that applies to natural conditioned buildings in which the principle means of control of indoor temperature is the use of windows. See Figure 3. 10 that describe the acceptable temperature range. The standard uses the relationship between the indoor comfort temperature and outdoor temperature. The standard defines zones within which 80% or 90% of building users might expect to find the conditions acceptable. The zones are based on the comfort equation for naturally conditioned buildings derived from the RP884 ASHRAE database;

$T_{comf} = 0.31\ T_o + 17.8$ .... eq. (3.7)

T_{comf} is the optimal temperature for comfort and T_o is the mean outdoor temperature for RP884 ASHRAE survey.

$T_{accept} = 0.31\ T_o + 17.8 \pm T_{lim}$.. eq. (3.8)

Where T_{accept} gives the limits of the acceptable zones and T_{lim} is the range of acceptable temperatures; for 80% = 3.5 K and 90% = 2.5K.

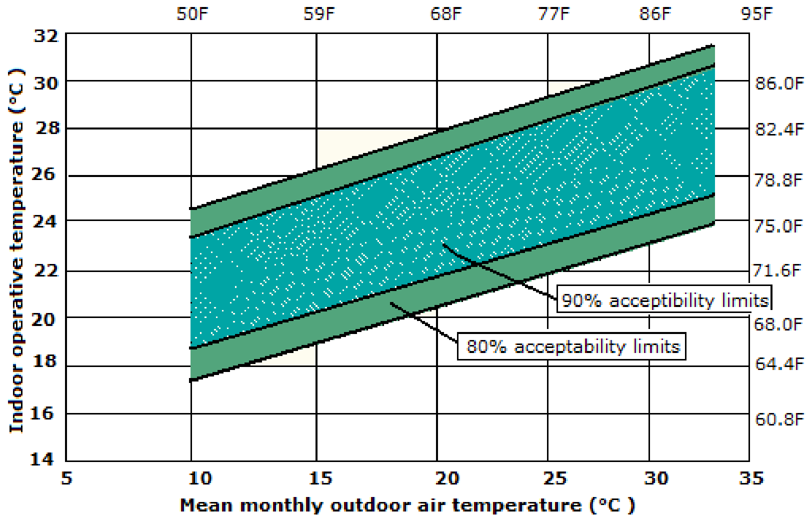


Figure 3.10: Acceptable operative temperature ranges for naturally conditioned buildings_ source: ASHRAE Standard 55, 2004

The **Bedford scale** was criticised on the ground that it consists of semantic relationship between warmth and comfort which may not be necessarily constant, whereas the ASHRAE scale contains no explicit reference either to comfort or pleasantness (Humphreys, 1976). However, it was later reported that the two scales in practice behave in a very similar way, and the results obtained by them may be compared directly with each other. Givoni used another method to scale the thermal sensation; he also used seven levels in his scale, which is showing in the Table 3.5.

Table 3.6: categories of votes for thermal sensation.

ASHRAE	Scale	1	2	3	4	5	6	7
	Description	V.C	C	S.C	Neutral	S.UC	UC	V.UC
Fanger	Scale	+3	+2	+ 1	0	_ 1	_ 2	_ 3
	Description	Hot	Warm	Slightly warm	Neutral	Slightly cool	Cool	Cold
TS-Givoni method	scale	1	2	3	4	5	6	7
	Description	Very cold	Quite cold	Cold	Comfort	Hot	Quite hot	Very hot

The main difference between the Bedford scale and the ASHRAE scale is the inclusion of comfort in the Bedford scale (Nicol, F., 2008). Bedford (Bedford, T., 1936) combines thermal sensation and comfort using a 7-point scale: much too warm, too warm, comfortably warm, comfortable, comfortably cool, too cool, much too cool, whereas in ASHRAE 55 (ASHRAE 55, 2010) thermal sensation is defined with seven categories: cold, cool, slightly cool, neutral, slightly warm, warm, and hot without indication of pleasantness or comfort (ASHRAE 55, 2010). Due to different interpretations of the words in a descriptive scale in cold and warm climates, a "preference vote" is suggested to be added to the "comfort vote" (Nicol, F., 2008). Brager et al. (Brager, G. and others, 1993) note that a combination of scales has been used in both field and laboratory studies. In addition to the commonly used 7-point ASHRAE thermal sensation scale, the 3-point McIntyre preference scale (McIntyre, D. A., 1982) has been used to explore acceptability of the thermal environment by asking the direct question, with possible responses of "warmer", "no change", "cooler". Thermal acceptability can be measured indirectly through voting within the three central categories of the seven-point thermal sensation scale (slightly cool, neutral and slightly warm) — but this is not necessarily equal to a direct measure of acceptability, since neutral temperature in cold climates is lower than the optimum or preferred temperature and vice versa in warm climates (McIntyre, D., 1978).

Therefore to conclude, it has been found that among these four scales considered above, are both ASHRAE and Bedford scales, considering that the researcher used ASHRAE scale in this study to measure the thermal comfort in the case study buildings and subsequently in case study city.

3.8. Thermal Balance

The purpose of the thermoregulatory system of the human body is to remain an essentially constant internal body temperature. Figure 3.11 shows the balance of the human body with its thermal environment. Explanation for the heat balance in human's body is shown in equation 3.10;

$$\mathrm{H\ \_\ Ed\ \_\ ESW\ \_\ Ere\_\ L = K = R + C} \text{..............................} \quad (\text{eq.3.9})$$

Where,

H= the internal heat production in human body
Ed= the heat loss by water vapour diffusion through the skin
Esw= the heat loss by evaporation of sweat from the surface of the skin
Ere= the latent respiration heat loss
L= the dry respiration heat loss
K= the heat transfer from the skin to the outer surface of the clothed body (conduction through the clothing)
R= the heat loss by radiation from the outer surface of the clothed body
C= the heat loss by convection from the outer surface of the clothed body

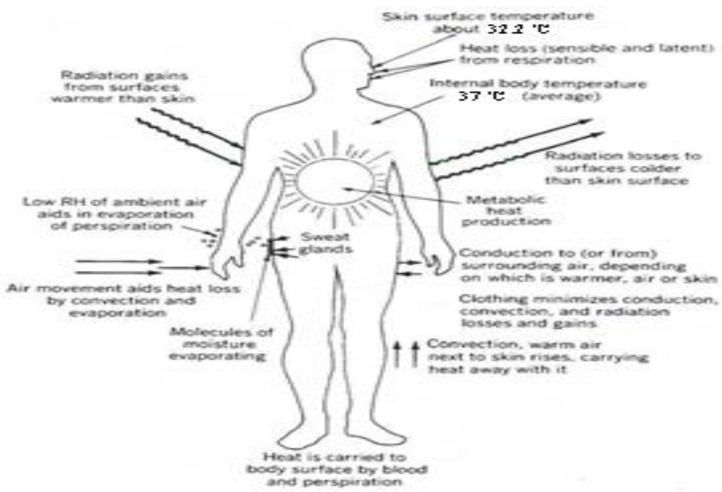


Figure 3.11*:* Heat balance of the human body in relation to its environment _ plotted after Burberry, 1997

Burberry (1997) set main factors that must be maintained in proper balance in order to reach the thermal comfort inside a building; these factors are shown in Figure 3.12 and Table 3.7. Note that only the contribution of the heating installations and, to some degree, the ventilation can be varied in operation. The other factors are either not capable of modification, such as the heat gain from occupants, or must be settled by the fabric of the building and the form and fenestration relation to solar heat gain.

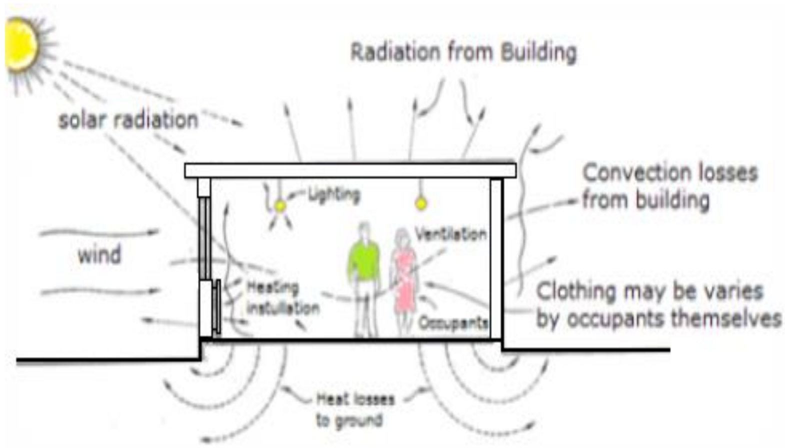


Figure 3.12: Heat balance of a building under external and internal influences _ plotted after Burberry, 1997

Table 3.7: Factors that affect the heat balance of a building

Initial conditions + Heat gains - Heat losses conditions = satisfactory comfort			
▪ Thermal properties of the building ▪ Absolute humidity of the air (unless air conditioning with humidity control is provided)	▪ Solar radiation ▪ Heat from occupants, lighting, mechanical installations and equipment ▪ Heating installation	▪ Radiation to sky ▪ Convection to air outside ▪ Ventilation losses to ground ▪ Refrigeration plant	▪ Mean radiant temperature ▪ Air temperature ▪ Relative humidity

Burberry (1997) has divided the factors that affect the heat exchange into four groups; the initial conditions which include thermal properties of the building such as density, thermal conductivity and specific heat capacity beside, including absolute humidity of the air to be the second condition. Factors that cause the heat gains in building are presented in the second column of the above Table that are solar radiation, internal heat sources and heating installation. Factors help to loss the heat are radiation to sky, convection to outside environment, ventilation and refrigeration plant. However, to achieve a satisfactory comfort level these three elements must be at a comfortable range; mean radiant temperature, air temperature and relatively humidity. Even with no activity a building will be warmer inside as the solar gain becomes a heat source following transmission through glazing it is absorbed by building surfaces;

Solar heat gain = Thermal losses

Solar gains happened through;

- absorbed by opaque fabric
- transmitted and absorbed by transparent elements

Thermal losses are lost;

- through fabric, through mass transport and through thermal radiation

The mechanism of heat transfer begins during the day, when the external wall temperature increases as a result of the heat balance between the gain caused by incident solar radiation and the losses by the convection and radiation. As the time passes, some of the heat is absorbed by the wall and the temperature increases according to the material's thermal properties and the boundary conditions. The heat moves, then, through the wall, towards the inside surface. During the night, a reverse process takes place, as the temperature outside decreases and there is no solar radiation. Hence, the wall temperature decreases, depending again on the thermal properties of the materials and the boundary conditions. All the heat flux happens from the higher temperatures locations to lower temperatures places, in an effort to reach a balance. Higher outdoor wind velocity increases convective losses. Similarly, on the inside wall surface, increasing the air movement enhances the heat losses and the dissipation of the stored heat (Santamouris and Asimakopoulos Ed, 1996). Thus, higher the thermal inertia of the building, slower the mechanism of heat transfer through its structures will be. The mechanism of heat distribution within a room can be by convection (forced or natural) or by radiation (short-wave or infrared). Most of the heat that flows from the building material surfaces to the indoor air is by radiation and a smaller, but important proportion of this exchange is carried out through convection. The fact that the radiation exchange within a room is dominant is the main reason that direct gain is a viable solar strategy (Balcomb, 1983).

Forced and natural convection are essential for heat dissipation. In the internal surfaces of the building, heat is first conducted from the hot surface to an interior thin layer adjacent to it. Air has a small heat capacity and tends to rise as heating decreases its density. Air velocity and temperature changes are limited to a thin region next to the surface – the boundary layer, where the regime is laminar. However, depending on the conditions, at some distance, turbulent air flow may occur. This phenomenon displaces cooler air at some other location within the building and results in the establishment of convective loops. Sometimes the hot air simply accumulates at the top of the room, resulting in temperature stratification. Whenever the air motion is due entirely to the action of gravitational forces, the heat transfer mechanism is known as natural convection. When the heat transfer rate is enhanced by introducing a forced flow over the surface, it is known as forced convection (Santamouris and Asimakopoulos Ed, 1996); (Balcomb, 1983). The temperature distribution within the building materials also varies with time, boundary conditions and material thermal properties heat storage takes place in the normal materials of the building. The use of thermal mass for heat storage in buildings can have a dual purpose. During the heating seasons, the thermal mass can store desired heat, which can be used later, when temperature outside drops. During cooling seasons, it also can keep temporarily unwanted excess heat, which can be removed later in the day. The main material properties, which are related to the process of heat storage, are thermal conductivity (λ), specific heat (c) and density (ρ). As mentioned before, the higher the product $\lambda\rho c$, the higher the heat storage capability of the material. To conclude, the effectiveness of thermal storage depends on several parameters, such as materials' properties, the exposed surface area, the thickness of the storing elements and its location and orientation within the building (as an external or an internal partition), among others.

3.9. Chapter Conclusion

This chapter provides a review of thermal comfort research. It begins by discussing the problem of defining and assessing thermal comfort using subjective rating scales. It then describes the derivation of several models employed by current standards and guidance to predict thermally comfortable environments. It has presented the personal parameters (i. e. clothing and activity levels), as well as the four physical parameters (i.e. air temperature, air velocity, relative humidity, and mean radiant temperature). In order to achieve the research objectives, this chapter has addressed the main issues of both conceptual and scientific methods. Recent research has suggested that thermal environments have significant effects on humans, especially, on their productivity, health, physical energy. Due to the number of interacting factors affecting human comfort, including personal preferences, the prediction of thermal comfort is not an easy task. There are various models developed by researches to predict thermal comfort. The predicted Mean Vote (PMV) is concluded to be the most comprehensive model for thermal comfort assessment up to date since it is flexible tool includes all the main parameters that affect thermal sensation. However, PMV overestimates thermal sensation in hot climate, particularly in natural ventilated buildings. Because of that, some modifications to the original PMV model have been proposed and tested. The most promising application is the extension of the PMV model in which PMV is multiplied with expectancy factor (e) depending mainly on the duration of the hot weather over the year and the proportion of air-conditioned buildings in the region. The range of acceptable comfort conditions, which is expressed as the comfort zone, is presented with reference to several studies that attempt to determine it with combination of different parameters. It was clear that the comfort zone could not be the same under different location or various conditions. The next chapter is related to previous one that because people often use energy to be comfy in their home. The chapter will look at heat energy in buildings and energy conservation in buildings.

THERMAL COMFORT AND BUILDINGS' THERMAL PERFORMANCE

CHAPTER 4 : THERMAL COMFORT AND BUILDINGS' THERMAL PERFORMANCE

4.1. INTRODUCTION:

The thermal performance of buildings depends mainly on the outdoor climate, indoor thermal conditions, and design of building as the form and the elements. These elements effect the energy simulation within buildings and at sometimes leave occupants with no choice other than using air conditioner system almost all day during summer months which lead to high level of consumption all over the country. According to The World Fact-book 2010, Libya produce electricity 21.15 GWh and consume 18.18 GWh (1gigawatt = 1million kilowatts) which 44% are domestic use. Alongside, a study by the ministry of electricity and renewable sources of the Libyan government called "Electricity used in residential sector in Libya (2012)" show that 72 % of electricity used goes to A.C usage. Figure 4.1 (a, b) shows details of energy resources and electrify use in Libya.

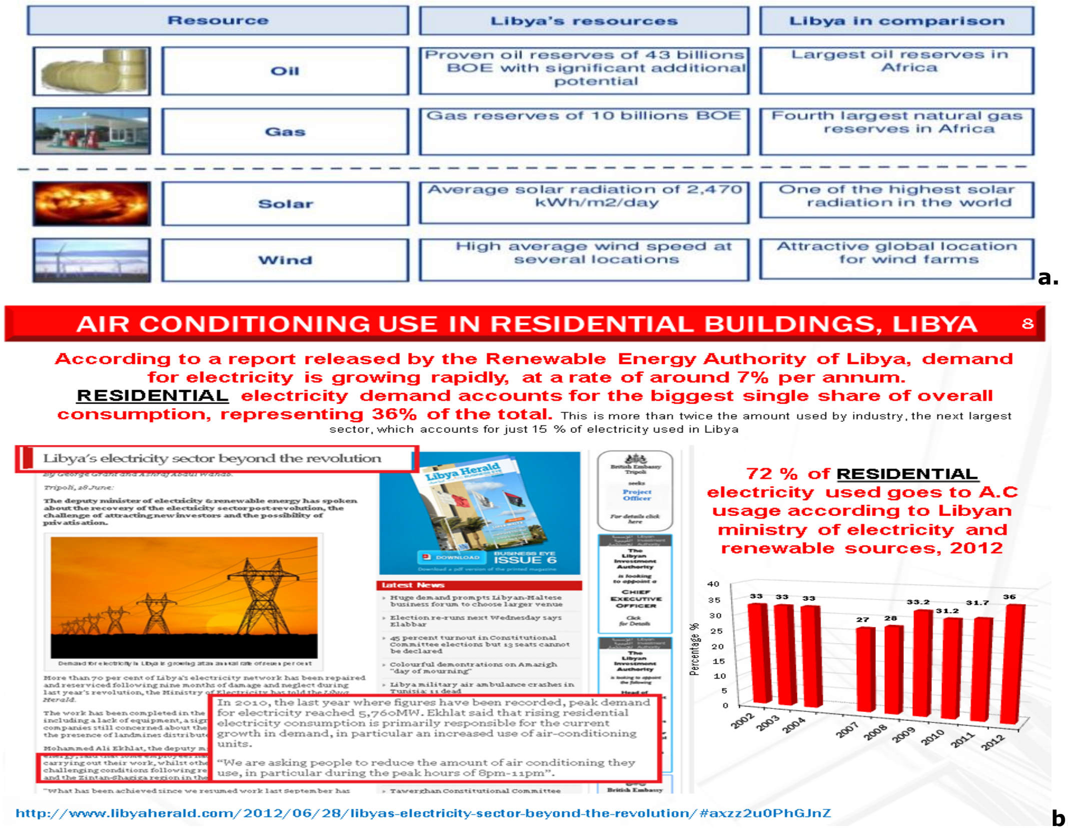


Figure 4.1: a. energy resources in Libya & b. Electricity used in residential sector in Libya and AC system consumption in residential sector. Source: ministry of electricity and renewable sources. http://www.gecol.ly/aspx/main.aspx and http://www.libyaherald.com/2012/06/28/libyas-electricity-sector-beyond-the-revolution/#axzz2u0PhGJnZ

In this chapter, the first part will look closely at design of buildings and its elements with its form, also their effect on the building thermal performance. Second part considers the energy consumption in buildings; selection of site, layout and grouping of buildings, building shape and size, use of building, fenestration and orientation and lastly, thermal performance of the fabric.

4.2. Energy Conservation in Buildings

Energy efficiency is defined largely as cost-effective ways to reduce energy consumption through existing and improved technologies as well as through sound energy use practices. The idea behind energy efficiency is quite simple - if people consume less energy, there will be less emission of greenhouse gases as the result of the burning of fossil fuels. That, in turn, means a greater supply of fossil fuels which can then be used for other purposes in both developed and developing nations. Energy efficiency technologies and practices can therefore play a significant role in reducing the threat of global climate change. (NAIMA: North American Insulation Manufacturers Association, 1996)

One of the easiest and most effective energy efficient technologies available today is insulation. Overall benefits from insulation are numerous, including thermal performance, personal comfort, sound control, condensation control, fire protection and personnel protection. The thermal insulating properties of insulation materials provide important energy and environmental benefits. Made from a variety of substances including fibre-glass, mineral wool, foam and other materials, insulation products are primarily designed to reduce the transfer of heat through building structures in residential, commercial and industrial applications. By their very nature, insulation products enable consumers to reduce more energy use and more emission of pollutants annually than it takes to manufacture them. This results in a very positive overall energy and environmental balance for thermal insulation. Several researches took place in this field, for instance, Burberry (1997) looked at some factors which govern energy consumption in buildings in which he believed designers need to consider careful in order to reduce energy consumption; these factors are briefly described in the next subsections.

4.2.1. Selection of Site

This factor is controlled by town planners while the architects are rarely able to have much influence on allocated sites for development. For example an exposed site with increase wind speed can increase ventilation rates and decrease surface resistances. Burberry (1997) claimed that a 20% increase in energy consumption may result if the wind speed is high throughout the year, also elevated sites will be colder and more subject to rain and mist.

4.2.2. Built Form and Grouping of Buildings

A variety in heat loss from dwellings can be significantly large even if these dwelling were built with same standard of insulation, this differences can be influenced by internal layout and built forms (Building Research Establishment (BRE), 1978). Figure 4.2 displays the estimated annual heat requirements of a number of different dwellings. Each dwelling has a volume of $200m^3$ and each is assumed to have the same fraction of external walling as glazing. On the base of conduction losses, with a common ventilation loss, a single storey intermediate floor flat has the lowest heat load for a given inside to outside temperature difference. Unlike, a centre terrace 2 storeys dwelling when its heat load was about two-thirds. A single level top flat, on the other hand, has a heat load about equal to that of centre terrace dwelling because of the increased conduction losses through the roof. The end terrace dwelling and semi-detached have a load some 40 to 50% larger than the centre terrace. The detached house has heat load almost twice as much. Comparing the two extremes the on level intermediate flat is likely to have a heat load only about a third of that for detached house, for the same volume and same fraction of exposed walling as glazing. To conclude, grouping building to take a high density buildings form could have an important influence on energy consumption in these buildings and in the whole country as well and then compact design is the most favourable when it comes to energy consumption.

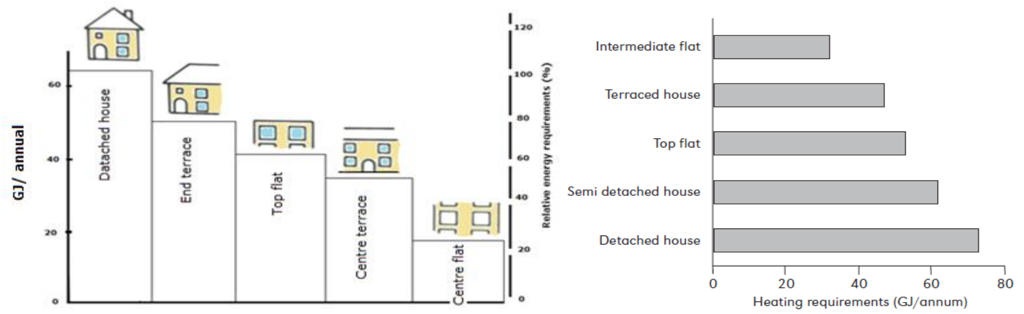


Figure 4.2: a) Relative energy requirements of a dwelling of 200 m³ volume in various grouping_ plotted after Burberry, 1997. b) Influence of built form on heating requirement in the UK according to Building Research Establishment (BRE) data_ source: Owens, 1986

4.2.3. Building Shape and Size

Extreme variations of shapes, such as transforming a compact building into a tower block, have major effects on energy consumption. Not only is the surface area extremely greatly increased, the exposure of the upper part is made worse and in many cases the solar gain wind and stack effects will dictate that air conditioning must be used (Thomas, 1999). Energy requirements vary almost directly with the volume of the building, as will be described in section 4.4 (also in tables 4.3 and 4.4), that because of the area of exposure surface. Figure 4.3 demonstrates the relationship between volume and energy more clearly where is shown that the bigger surface area to volume the quicker it will lose heat, as it has a bigger surface where the heat can rise and travel out from. If the volume is the same but the surface area is smaller, heat will stay in for longer as there is only a small area for the heat to escape from, meaning that the heat that is lost does not account for the mass.

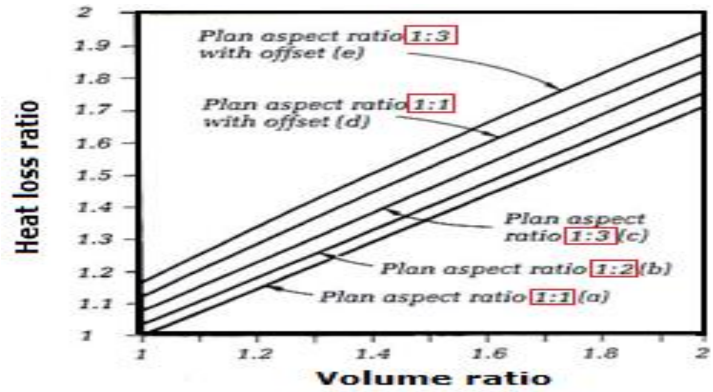


Figure 4.3: Demonstrates the relationship between volume and energy_ Burberry, 1997

4.2.4. Use of Building

Reduced internal temperature which may require the occupants to wear more clothes can save a considerable amount of energy. The average temperature difference between inside and outside in the heating season is approximately 10 °C for buildings with night setback of heating. If the daytime temperature is reduced by 1°C the energy savings could be 5-10 % per year. As well as reducing ventilation rates gives substantial energy economy but be careful when controlling ventilation not to reduce to a level where condensation becomes a problem.

4.2.5. Fenestration and Orientation

Unobstructed windows facing south which are curtained at night gain approximately as much heat from the sun during the hot seasons as they lose. On other orientations the gain is very much reduced and there is a net heat loss. It is therefore important for energy conservation that windows are orientated as far as possible towards south. Table 4.1 demonstrates the significance of energy balance variation with orientation.

Table 4.1: seasonal heat balance for 1m single glazing curtained at night in a centrally heated house

Orientation	Solar heat gain through 1m² unobstructed window (MJ)*	Net heat loss through 1m² glazing over heating season (MJ)
South	680	0
East and West	410	270
North	250	430

U= 3.4 W/m²K (BRE value for windows curtained at night)_ Average temperature difference= 10 C (BRE value)_ Length of heating season= 20×10^6 s (33 weeks)_ Heat loss through 1m² single glazing= $3.4 \times 10 \times 20 \times 10^6$ = 680 MJ

4.3. Energy and Building's Form

Moore (1993) state three forms of building type in response to climate, from climate responsive through combination to climate rejecting (Figure 4.4). Moore believes that in the past architects had to utilize the building envelope as the principle mediator between exterior and interior environmental conditions. Building envelope was the principle means of controlling the thermal environment and the building was completely an adapted to its environment. An example on climate adapted building is the old Arabic house, which is inward looking with rooms arranged around a central court, and the external walls often are windowless and so houses can be built up against one another, except for the facade which faces the street. The street is also designed to create a comfortable micro-climate. Unfortunately, industrial revolution changed all of that type of buildings and the development of the structural frame where the role of external walls was reduced to that of a skin to exclude wind and rain and large area of glazing where fitted within these new buildings without considering the environment around these buildings. Therefore, thermal qualities of the massive construction were lost, and this functions replaced by mechanical heating and cooling systems. Buildings were motivated slowly from completely climate friendly to combination buildings and then complete rejected buildings with no concern extended to energy consumption. Figure 4.4 illustrate the stage of change through architecture development.

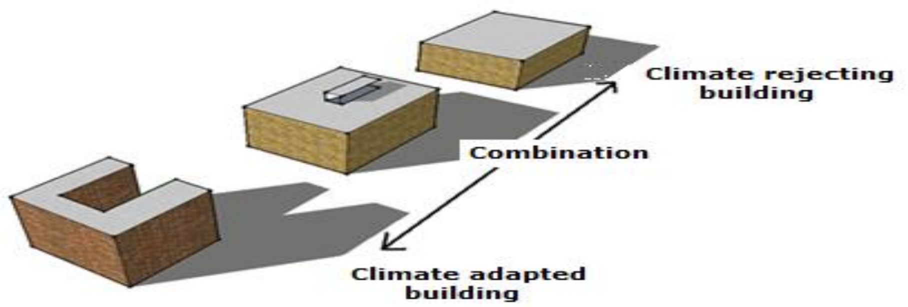


Figure 4.4: Continuum of building climate response_ plotted after Moore, 1993

And so, building form and envelope parameters have a significant effect on thermal comfort and energy saving indoor which have to deal with it carefully, that is because achieving a correct form for its climate could enhance the free running condition in some periods during the year. This research is concerned with a form of buildings that described by Hawkes (1981) as a selective mode which work with the environment even so it is not easy to achieve all the points listed in his mode. Table 4.2 illustrates this mode and compared it with other mode (exclusive mode).

Table 4.2: comparison between selective and exclusive modes_ source: Hawkes, 1981

Selective mode	Exclusive mode
Environment is controlled by a combination of automatic and manual means and is a variable mixture of natural and artificial	Environment is automatically controlled and is predominantly artificial
Shape is dispersed, seeks to maximise the use of ambient energy	Shape is compact, seeks to minimize the interaction between exterior and interior of environments
Orientation is a crucial factor	Orientation is relatively unimportant
Windows are restricted certain directions. Solar control is required sometimes	Windows are generally restricted in size
Energy is a combination of ambient and generated. Its use is variable throughout the year	Energy is primarily from generated sources and is used throughout the year in a relatively constant quantity

Subsequently, Thomas (1984), mentioned that buildings with interior open space such as courtyards and open atria showed the possibility of a significantly reduce energy demand, if passive solar heat gain is accounted for. If not, it is advised to avoid using the court or any complex forms which tend to increase the surface area and may cause self-shadowing. This advice brings another effort towards numeric characterisation of building shapes, the relation between volume and area is explored as related to building's fabric heat loss as argued by Markus and Morris (1980). Utilizing the standard formula for steady state building heat loss calculations, their research established the following relationship between heat loss and building geometry. For instance, in rectangular buildings the ratio of surface area to volume is established by using the height (H), length (L) and width (W) variables of the building. The ratio of surface area to volume is given by:

$A.V^{-1} = 2.H^{-1}.\gamma$.. (eq. 4.1)

Where,

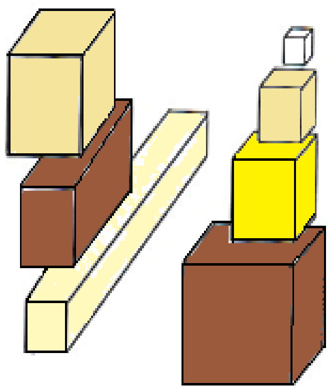
$\gamma = \left((1+\beta).\alpha^{-1}.\beta^{-1}\right) + 1$

$\propto = W.H^{-1}$

$\beta = L.W^{-1}$

To compare the surface area to volume ratios of buildings with different shapes, the volumes must be equal; Table 4.3 explains the relation using three forms with same volume and four cubes having different volumes. It has been stated that cube has the least surface area to volume ratio as compared to other shapes with the same volume. (Markus &Morris 1980).

Table 4.3: surface area, volume and ratio_ source: Markus & Morris 1980.

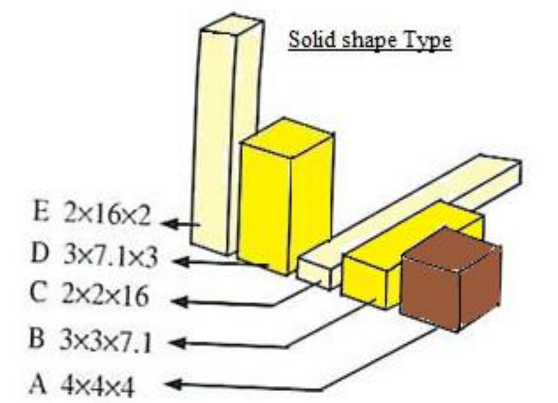


Dimension	Surface area (A)	Volume (V)	Ratio (A/V)
4× 4×4	96	64	1.5
3× 3×7.1	103.2	64	1.61
2× 2×16	136	64	2.13
1× 1×1	6	1	6
5× 5×5	150	125	1.2
10×10×10	600	1000	0.6
20× 20×20	2400	8000	0.33

Table 4.3 shows that the ratio decreases as the dimensions of the cube increase. The relation between the height of the building, its volume and plan shape is also investigated by the same authors to obtain minimum envelope heat loss per unit volume; these results are shown in Table 4.4. It is observed that the ideal height increases rapidly with changes in volume when the building is small, but when it is

large the rate of increase is much less. It is also obvious that the less compact the building the smaller the ideal height becomes.

Table 4.4: Relation between surface area and volume _ source: Markus &Morris 1980.



	Surface area (A) 5 faces	Volume (V)	Ratio (A/V)
A	80.0	64	1.25
B	81.9	64	1.28
C	104	64	1.63
D	94.2	64	1.47
E	182	64	2.01

In conclusion, this study showed that the cube produced the minimum ratio of surface area / volume, and the tall block produced the maximum one, also the study showed that there are unlimited numbers of possible building configuration, beside the interrelated effects of the radiant heat gains, are of openings, orientation,. etc, which all make the optimization impractical. Another conclusion can be drawing from the above discussion, is that one factor in relation to the energy conservation and human factor in the hot and worm climates would be to minimize exposed walls to high solar radiation especially east, west or south walls depends on solar latitude, minimize surface area particularly the roof, maximise shade and integrate opening area and location within the form analysis to provide adequate ventilation and natural light with no glare.

4.4. Buildings' Orientation

Building orientation affects the quantity of solar radiation falling on its different faces at different times of the day. Radiation and temperature are both acting together to produce the heat experienced by the surface. Therefore, architects must consider the direction of their building in relation to the predominant climate. For example, in the hot zones under conditions of excessive heat, the orientation of building should decrease the undesirable solar impact and in turn reduce the air conditioning requirements (Alsousi, 2005).

Many researches show that there is a direct relation between orientation and the energy to be consumed by the building to maintain internal comfortable conditions. Both annual energy use and design peak loads would be affected. Givoni (1981) concludes that with adequately insulated walls of light external colour, and effectively shaded windows, the changes in internal temperature due to orientation may be negligible. In this case, orientation is more important with respect to wind direction and ventilation than in relation to the patterns of solar radiation.

Figure 4.5 illustrates the importance of site orientation in relation with energy gain/loss in buildings, for example, trees and landscape planting are essential elements to be taken into account when site planning for passive solar energy. Vegetation and landform can complement passive solar design, reducing heat loss by providing shelter. However, if poorly positioned in relation to buildings, tall vegetation will reduce solar gain by overshadowing, and obstructing sunlight. Here are some key principles in Mediterranean regions;

- Shelterbelts should be orientated to the south-west of development and distanced 3-4 times their mature height from south facing elevations.
- Trees that will grow above the shadow line should be deciduous as they allow sunlight to pass through when at a low angle in winter and provide beneficial shading in summer.
- Small scale tree and shrub planting should be used to provide privacy for ground floor south facing living room windows.

Urban green space (trees, grass and shrubs) has a number of beneficial impacts on the micro-climate and cities where the consequences of climate change will be most severe. By creating daytime shade and evaporative cooling at night, green space can moderate the urban heat island _ Figure 4.5.

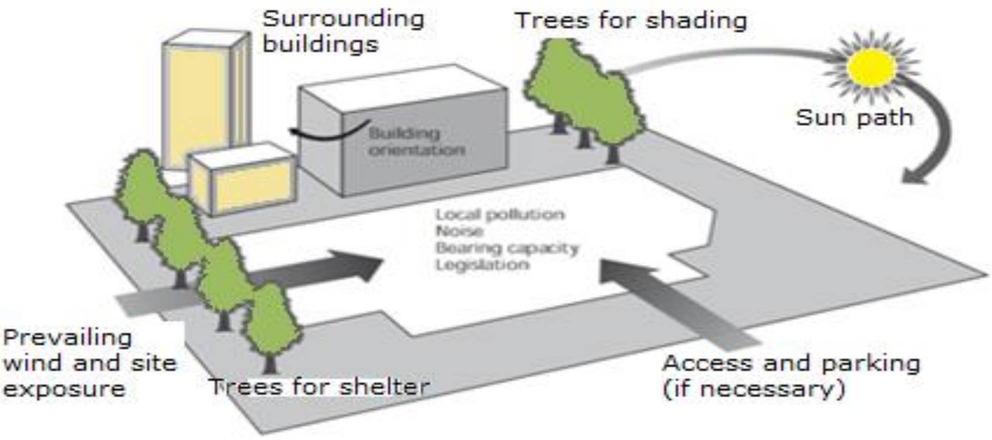


Figure 4.5: Site considerations _ source: SIBCE Guide F, 2009

4.6. Solar Shading

Potential shading of the building caused by structures in its locality needs to be examined during the initial design stage. In an urban environment, it might not be necessary to provide sun protection because neighbouring buildings shield off the sun, see Figure 4.6. But if the building does not benefit from a neighbouring building, insulations must be provided to reduce the direct summer insolation to the minimum that in order to reduce the cooling load. Many researches, such as Waheeb (2005), Muhaisen (2005), Hyde (2000), Moore (1993), Givoni (1976), and

Evans (1968), approved that easiest orientations for solar shading are south and north, while the hardest orientations for solar shading are east and west surfaces that because sun angles are low.

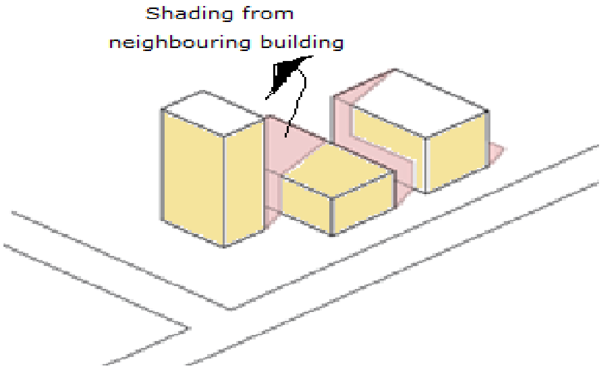


Figure 4.6: In an urban environment it might not be necessary to provide sun protection on all sides of the building because neighbouring buildings shade parts of the façade Source: Schröpfer and others (2007)

In addition, building direction; the equator-facing facade of a building is the easiest to control solar radiation on as the position of the sun in the sky throughout the year is favourable to the use of simple horizontal shades. The east and west facades are much more difficult to shade due to high-intensity low level sun in the early mornings and late afternoon. There is some scope to take advantage of the changing sunrise/sunset positions between summer and winter using angled vertical shades; however such systems must be designed with great care. The east and west facades can be protected using large deciduous trees or a trellis system with creeping vines, however vertical shades are the usual option.

4.7. Solar Radiation

An observation was made by Ludwig (1970) whose Figure illustrates solar radiation for different H/W ratios (Figure 4.7). On the flat plan, most of the absorbed solar radiation is re-radiated to the sky as long-wave radiation. In a medium density of H/W= 1, most of the reflected solar radiation hits other buildings, as well as the ground, until it is absorbed near or at the ground. For higher densities of H/W= 4, most of the absorption takes place at a high level of the canyon, reducing the amount of radiation that reaches the ground.

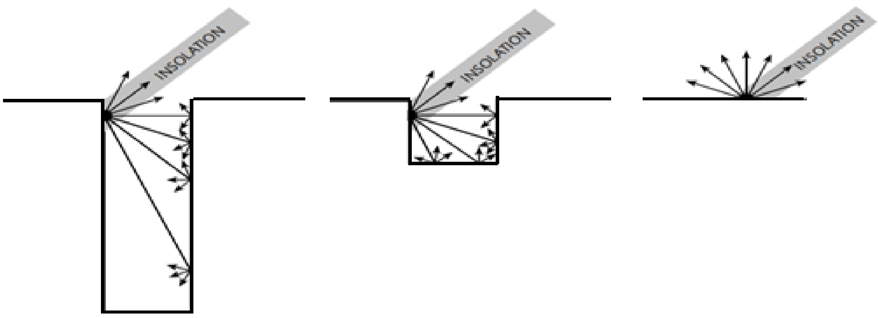


Figure 4.7: Solar radiation for different H/W ratios_ Source: Ludwig (1970)

Dealing with solar radiation: There are a range of techniques can be used to prevent solar radiation from reaching building surfaces:

- Shading Devices: devices such as wide roof overhangs, shading fins, thick vegetation or external shutters can be used to protect windows and wall surfaces. It is also often possible to shape the building such that some parts of it are self-shading.
- Surface Colouring: if opaque building elements exposed to solar radiation are painted white or very light colours, much of the incident radiation can be reflected away from the surface.
- Insulation: any surface that is exposed to high levels of solar radiation in summer should be well insulated to reduce the transfer of heat. The best location for this insulation is on the outside surface; however this may not always be practical. In climates with a high diurnal range in summer (hot days and cold nights), it may be preferable to store daytime heat for release later at night when the temperature falls. In this case, exposed surfaces should comprise a thick layer of heavyweight material with a high thermal capacitance and a thermal lag of around 8-10 hours.
- Double Roof Systems: a double roof system, as shown in Figure 4.8, uses a ventilated air gap between an upper exposed roof and a lower protected roof. Much of the solar gain from the upper leaf is carried away by the air before it can pass to the lower leaf.

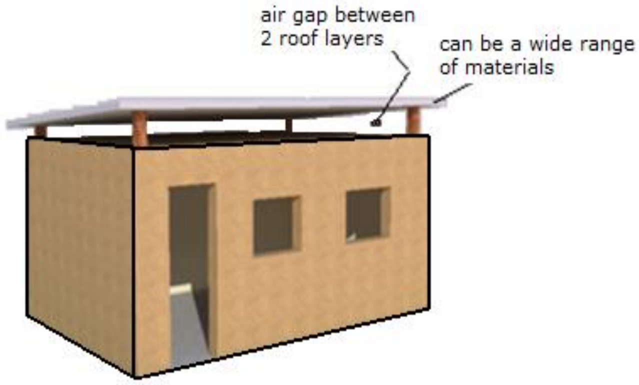


Figure 4.8: diagram illustrated a double roof system with an air gap between the main roof and the shaded roof

A study by Behzad (1991) investigating the effect of roof shading on the ceiling surface temperatures, in this study two types of roofs were modelled; un-insulated, and insulated having 50mm of insulation material in the form of the "warm roof" type and both roofs were with same colour and have a solar absorptivity of 0.5. External surface temperatures of roofs on the 21st of July when there is no obstruction to intercept direct solar radiation together with those when they are shaded were calculated. The study found that shading the roof can significantly reduce the surface temperature of the asphalt. For example, the maximum surface temperature of the asphalt in a well shaded (90% shaded) un-insulated roof is 11.6°C lower than the corresponding value when it is not shaded. The corresponding difference for the insulated roof is 13.2°C as shown in Figure 4.9 (a). While the calculated cooling requirements of the reference house during a three days simulation period, from 20th to 21st July, are depicted in part (b) of Figure 4.9. The cooling requirements of the well shaded (90% shaded) uninsulated roof is practically the same as that of the insulated but unshaded roof.

- Thermal Mass: this too applies only Behzad study in such climates with a high diurnal range (Iran climate). In this case, lots of thermal mass is used in the interior of the building to even out temperature fluctuations. To be effective when used in this way, the mass must be exposed internally and not covered over with carpets, cupboards or panelling.

There is some design flexibility here as, depending on the exact conditions at night, some delayed conduction gain may be desirable or not.

- If so, the form of the building can be designed such that exposure is limited to certain surfaces at specific times to control the collection and release of conducted heat. If not, then shading, surface colour and insulation should be used on the outside surfaces to reject solar gains. It may also be desirable to use a night-purge ventilation system to cool the mass down at the end of each day (see the night-purge ventilation section).

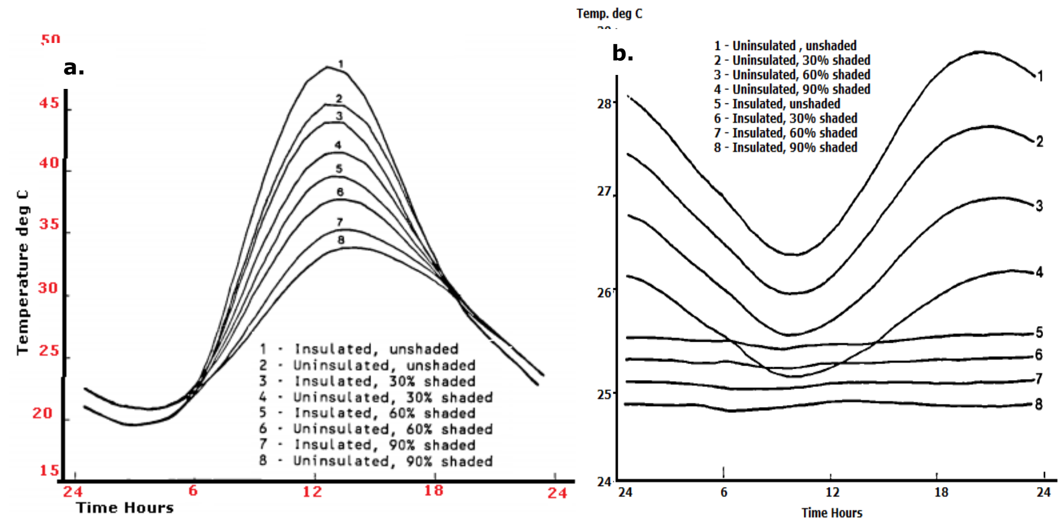


Figure 4.9: a) the effect of roof shading on the roof surface Temperatures .b) the effect of roof shading on the ceiling surface temperatures (21st of July) Source: behzad sodagar, 1991

- Solar Control Glass: if external window shading is not practical, highly reflective glass can be used. This will not be as effective and may even be against local planning regulations in some places where bright solar reflections are a hazard. Heat absorbing glasses and internal blinds/curtains are the least effective option as they allow the radiation to enter the space (either directly or as long-wave radiation from the heated glass) before shading the occupant and if user control is necessary, use blinds encased in a double glazed unit where excess heat gains are vented to the outside (Figure 4.10).

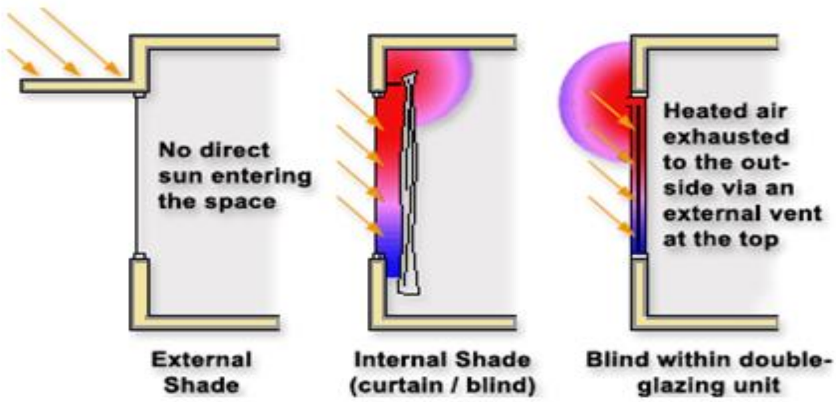


Figure 4.10: the effects on internal heat flow of external versus internal shades
Source: www.wiki.naturalfrequency.com/wiki/solar_control

4.8. Energy and Buildings' Materials

The materials of construction should provide adequate insulation and appropriate thermal response. Construction with low thermal capacity internal layers used with heating system capable of controlled and variable output can give considerable economy during the hot season where heating is not required, these low thermal capacity lining require less heat to warm them and also lose less at night. While, high thermal capacity linings absorb a great deal of heat to raise them to comfort temperatures then lose part of it when temperatures are reduced at night. In 1996, a study carried out in USA by Energy Conservation Management found that "because of home insulation, drastically less energy is needed to heat and cool homes in the United States today when compared to the same homes without insulation, this difference results in energy savings of 51% or 10.4 quadrillion Btu nationwide". Table 4.6 below summarizes the energy savings realized from insulation examined by the above study.

Table 4.5: Energy Use in USA (Quadrillion Btu) _ Source: "Green and Competitive: Energy, Environmental, and Economic Benefits of Fibre-glass and Mineral Wool Insulation Products," by Energy Conservation Management, Inc., et al, June 1996.

	No insulation	Baseline (existing)	Savings	% Savings
Residential	20.41	10.00	10.41	51%
Commercial	8.21	6.70	1.51	18%
Residential & Commercial	28.62	16.70	11.91	42%

The study also considered the potential for additional energy savings and environmental impact if insulation levels were increased to meet standard energy codes. For example, if all residential buildings were insulated according to the Council of American Building Officials' Model Energy Code (MEC) 1992, a minimum energy efficiency standard for houses, and an additional two quadrillion Btu in energy savings would be achievable. Add in energy savings potential from the commercial and industrial sectors, and the study estimates that it would be possible to save 2.2 quadrillion Btu of energy annually.

4.8.1. Opaque Materials

There is a continuous exchange of heat between a building and the outside climate. The amount of heat penetrating depends mostly on the nature of the building materials used (Alsousi, 2005). For comfort, air movement is essential and internal surface temperatures should be kept as low as possible during the day and the night. Light and reflective roofs are needed to reduce solar heat gain during the day and avoid the storage of heat which will increase discomfort at night. Koenigsberger and Lynn recommended that the reflectivity and the insulation should not rise more than 4.5°C above air temperature when the external surface is subject to solar radiation. (Koenigsberger and Lynn, 1965)

In general, each climate has its suitable materials (for walls, roofs and floors) which have been recommended by many researches and can be funded in many standard references such as ASHRAE and SIBCE, for example, earth and masonry are the favourable construction materials for an area with low rainfall, heavy walls and roofs are suitable for hot regions because of that they are associated with advantages time-log where the maximum heat load is delayed till the cooler hours of the evening affect the interior.

Figure 4.11 shows the route of sun heat into an opaque surface, this route is differ if the surface (wall or roof) is insulated. As the external structure heats up the insulation layers will prevent/slow down transmission of the energy through the structure helping to maintain the internal environment cool but there is one problem with highly insulated structures is that solar radiation entering through windows that cannot be absorbed by internal structural elements (thermal mass) which tends to produce a rise in internal air temperature since the air has a low specific heat capacity which means a small amount of energy input can produce a large change in temperature. On other hand, if the surface (wall or roof) is un-insulated, and if the element is thermally massive, it will absorb the solar energy striking it and delay the entry of this energy into the room for a number of hours. If there is sufficient thermal mass it may delay the entry of energy until night time when cooler outside air can be used to cool the structure. Yet, if the element is thermally light the solar energy heats up the external surface and this energy is quickly transferred through the structure resulting in rise in internal air temperature.

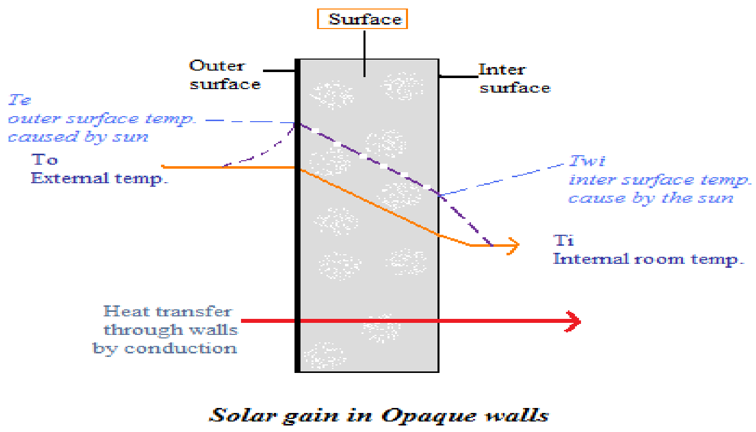


Figure 4.11: Solar gain in opaque surface_ Source: Ludwig (1970)

4.8.2. TRANSPARENT MATERIALS

The issue is compounded by the fact that windows do not let all of this radiation into the building — some is reflected, some absorbed and some transmitted. Glass is transparent in the visible and in the near infrared portion of the sun's radiation. It is opaque, however, for radiation emitted by a heated room. Tinted "heat absorbing" glass absorbs much of the near infrared emitted by the sun while remaining largely transparent over the visible portion. Part (a) in Figure 4.12 below illustrates how glass indirectly transmits far infrared from a heated room. The thermal radiation from the room is absorbed by the surface of the glass. This absorbed heat is conducted through the thickness of the glazing and then radiated, conducted and convected to the outside. A small amount of the incident radiation is reflected back into the room. This process occurs in conjunction with conduction and convection heat transfer to and from the air on both sides of the glass. The transmission of solar radiation through standard window glass is illustrated in (b) drawing of Figure 4.12. Some of the solar radiation incident on the glazing is reflected. The reflected fraction increases as the angle between the radiation beam and the glass decreases. The fraction absorbed by the glass is dependent on the thickness and absorption coefficient of the glazing. The absorbed radiation is converted to heat, which raises the temperature of the glass. In some cases the glass temperature will be greater than either the indoor or outdoor temperature. Some of the heat absorbed by the glass will therefore be re-radiated and convected into the building.

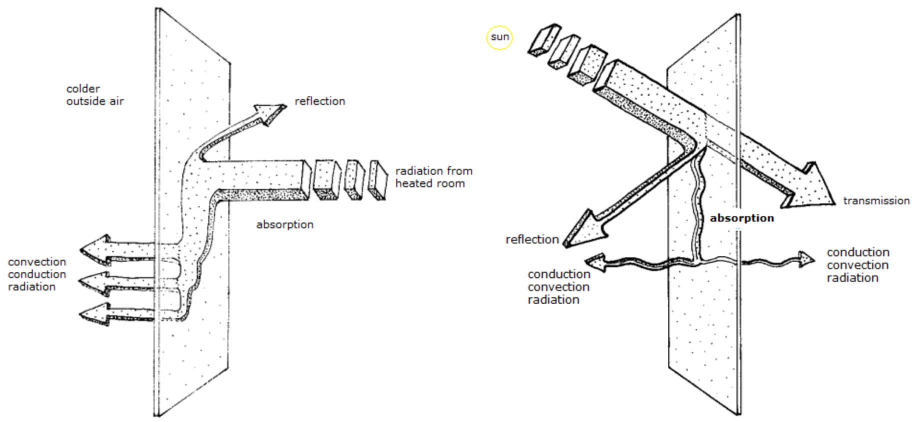


Figure 4.12: solar striking glass, a. the transmission of far infrared through glass & b. the transmission of solar radiation through glass _ source: plotted after John Wiley& Sons, 1991

The above process is also affected by different windows' types and window/blind systems, an example on that is approved by CIBSE as included in guide (A) under table "5.7". Clearly the highest type of glazing to transfer the heat is single glass type and if reducing the cutting solar heat is desirable so the obvious way of reducing that gain is to reduce the area of glazing. If this is not possible or desirable then windows can be shaded. Alternatively, tinted or reflective glass can be used to cut down on the solar heat gain as shown in the below Table where the solar gain reduced from 0.76 S_c in single glass to 0.29 S_c when double glazed with blind has been used.

Table 4.6: Example average solar gain factors_ taken from CIBSE Guide A (Table5.7)

Glazing type	Solar gain factor, $\bar{S}_c$
Single clear glass	0.76
Single clear glass with blind	0.34
Double glazed, clear glass	0.62
Double glazed with low-e inner pane	0.62
Double glazed with blind	0.29
Triple glazed, clear glass	0.52
Triple glazed with low-e mid pane	0.53

CIBSE also has provide the importance of the glazing role on thermal comfort to a building's occupants, this role can be underlying as principles briefly outlined below;

- comfort criteria dictate that there should not be more than 4 K between any surface and air temperature. Outside of this margin, extra heat is needed to compensate for the increased feeling of discomfort.
- in a building where the walls are well insulated the temperature difference between the wall surface and room temperature is minimal, but the temperature differences between glazing and room temperature (assuming an indoor room temperature of 21 K) can be significant according to glazing type:
- between single glazing and air temperature can be around 20° C.
- between double glazing and air temperature will be around 8° C.
- between triple glazing and air temperature will be around 4° C (i.e. within the comfort zone).

4.9. Insulation used as a resistance to heat flow

4.9.1. Mechanism of thermal mass

It is important, to understand the mechanism of thermal mass performance in order to achieve the best possible results. Thermal mass, in the most general sense, describes the ability of any material to store heat. For a material to provide a useful level of thermal mass, a combination of three basic properties is required:

- High specific heat capacity – to maximise the heat that can be stored per kg of material.
- High density – to maximise the overall weight of the material used.
- Moderate thermal conductivity – so that heat conduction is roughly in synchronisation with the diurnal heat flow in and out of the building.

Heavyweight construction materials such as brick, stone and concrete all have these properties. They combine a high storage capacity with moderate thermal conductivity. This means that heat transfers between the material's surface and the interior at a rate that matches the daily heating and cooling cycle of buildings. Some materials, like wood, have a high heat capacity, meaning that their thermal conductivity is low, which limits the rate at which heat is absorbed. This combination, which results in low thermal mass, can be useful in other ways. Steel can also store a lot of heat, but in contrast to wood, steel possesses a very high rate of thermal conductivity, which means heat is absorbed and released too quickly to create the lag effect required for the diurnal temperature cycle in buildings. Concrete and masonry steadily absorbs heat that comes into contact with its surface, conducting it inwardly, and storing it until the surface is exposed to cooler conditions and its temperature begins to drop. When this occurs, heat will begin to migrate back to the cooler surface and be released. In this way, heat moves in a wave-like motion alternately being absorbed and released in response to the variation in day and night time conditions. The ability to absorb and release heat in this way enables buildings with thermal mass to respond naturally to changing weather conditions, helping stabilise the internal temperature and provide a largely self-regulating environment. When used appropriately, this stabilising effect helps to prevent overheating problems during the summer and reduces the need for mechanical cooling. Similarly, the ability to absorb heat can help reduce fuel usage during the heating season by capturing and later releasing solar gains and heat from internal appliances. Figure 4.13 below illustrates outdoor and indoor temperature fluctuations as a result from applying thermal mass. The red line is the outdoor temperature fluctuation and the orange line is the indoor temperature fluctuation. The indoor temperature curve is delayed behind the outdoor temperature curve by some time. This delay of the peak of the orange line curve behind the peak of the red line curve is referred to as the time lag (φ) measured in hours. The reduction in cyclical temperature on the inside surface compared to the outside surface is knows and the decrement factor. Thus, a material with a decrement value of 0.3 which experiences a 20 degree diurnal variation in external surface temperature would experience up to 6 to 8 degrees variation in internal surface temperature.

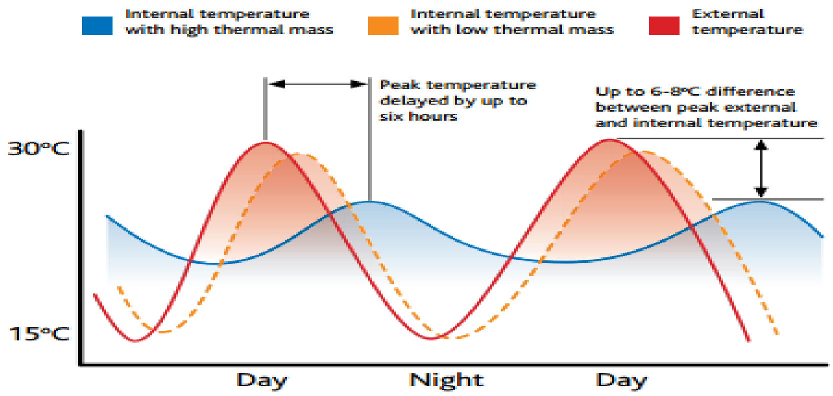


Figure 4.13: Stabilising effect of chapter on internal temperature. Source: Tom de Saulles, 2009

4.9.2. INSULATION LOCATION

The location of the insulation relative to the mass layer affects both the time lag of the heat, flux through a wall and the ability of the wall mass to dampen interior temperature swings. A study by S.J. Byrne R.L. Ritschard (1985) on three wall configurations (insulation inside or outside of the mass or with the insulation and mass well mixed) shows that the wall with insulation outside always performed better than the wall with insulation inside of the mass, The savings in heating load for the integral insulation case was normally greater than either of the other wall types and the cooling load savings was normally between the performance of the other walls. However, the relative performance of the three wall types changed slightly with climate, building design and total wall U-value, see Figure 4.14. Same study also stated that "In general, if the wall mass is exposed directly to the interior space it will be more effective in dampening interior temperature fluctuations and in reducing both heating and cooling loads, For this reason, many commonly built masonry walls that are furred out (with gypsum board and a narrow airspace or insulation) on the interior surface do not make the most effective use of the available wall heat capacity". See Table 4.8.

Table 4.8: Wall characteristics used in S.J. Byrne R.L. Ritschard (1985) simulation

Wall characteristic	Wall type		
	Mass wall with insulation outside	Mass wall with insulation inside	Mass wall with integral insulation
Mass Conductivity W/m °C	0.86	0.86	0.05

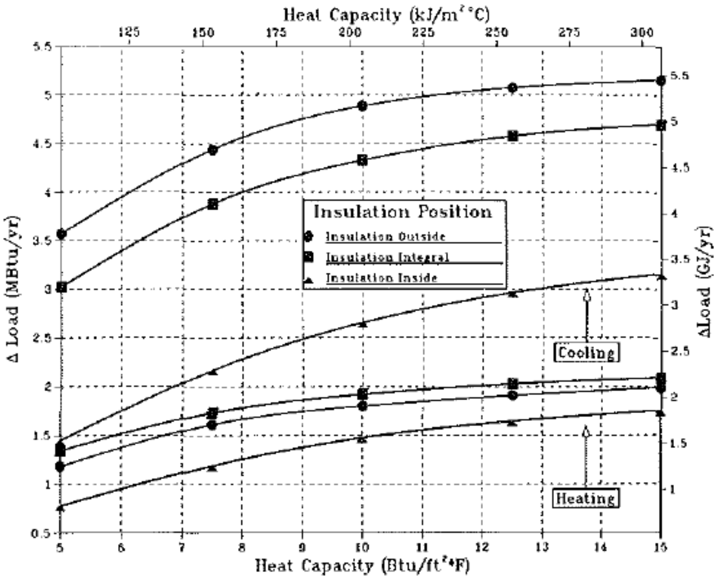
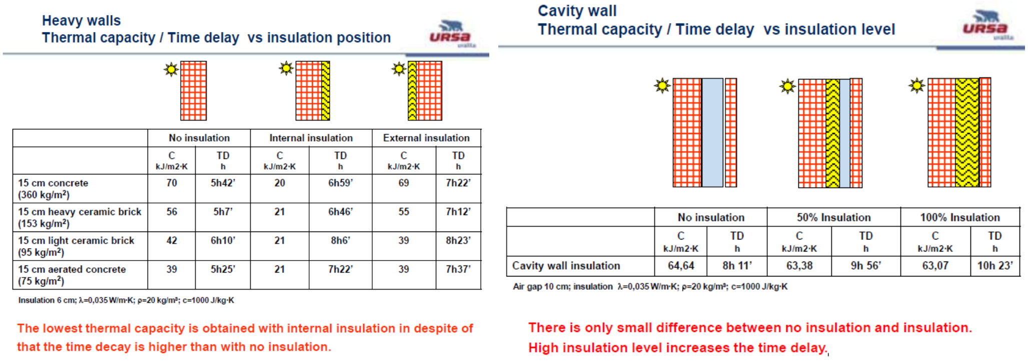


Figure 4.14: Annual delta heating and cooling loads as a function of mass heat capacity for three wall insulation locations _ results of S.J. Byrne R.L. Ritschard study, 1985

4.9.3. Time delay vs insulation position

Capacitive insulation (thermal mass) provides a very powerful control of the timing of heat input especially in climates with a large diurnal temperature swing as it can store the surplus heat at one time, for release at another time, when it is needed. Thermal mass in buildings can be used to avoid dealing with instantaneous high cooling loads, to reduce energy consumption and to attenuate indoor temperature swings, caused by rapid changes in the ambient conditions during the day. The benefits of capacitive insulation, or mass effect, will be greatest in hot dry climates, with a large diurnal variation, where the temperature varies over the daily cycle between too high and too cold, where the day's mean is within the comfort zone. Massive construction may provide the full solution, as it may ensure comfortable indoor conditions without any mechanical cooling or night heating. In addition, the location of the insulation relative to the mass layer affects both the time lag of the heat, flux through a wall and the ability of the wall mass to dampen interior temperature swings. A simulation by S.J. Byrne R.L. Ritschard (1985) on three wall configurations, with insulation either inside or outside of the mass or with the insulation and mass well mixed. The total wall U-value was held constant at 1.13 W/m^2 C and the heat capacity of the mass layer was varied from 102 - 306 kJ/m^2 C by changing the thickness of the mass. In the two multiple layered walls, the mass conductivity was 0.86 W/m C and in the homogeneous wall the conductivity varied with the wall thickness in order to hold the U-value constant. Santamouris & Asimakopoulos in 1996 proposed that the effectiveness of thermal storage is acceptable where the diurnal variation of ambient temperatures exceeds 10K. Likewise, Szokolay (2008) stated that some sources propose that a mean range (the range between monthly mean maximum and minimum, averaged for the 12 months) of 10K would require massive construction; others put this limit at 8K. Another study published by URSA Eurasia in 2009 investigate building insulation in north Mediterranean countries, came to a slightly different result from the S.J. Byrne R.L. Ritschard study. URSA study shows a variety heat reduction between inside and outside insulation. URSA state that "in the warm climates of Southern Europe, heating is less of a problem than in Central or Northern European climates. With minimal total energy consumption, buildings can be kept comfortable all year round. Both heating and cooling requirements need to be considered when defining insulation levels and glazing specifications in Southern Europe, detailed planning and engineering as well as expert installation are essential for an excellent energy performance" (URSA, 2009). Figure 4.15 (a, b) explains the results of some walls type in this study.



	No insulation		Internal insulation		External insulation	
	C kJ/m2·K	TD h	C kJ/m2·K	TD h	C kJ/m2·K	TD h
15 cm concrete (360 kg/m²)	70	5h42'	20	6h59'	69	7h22'
15 cm heavy ceramic brick (153 kg/m²)	56	5h7'	21	6h46'	55	7h12'
15 cm light ceramic brick (95 kg/m²)	42	6h10'	21	8h6'	39	8h23'
15 cm aerated concrete (75 kg/m²)	39	5h25'	21	7h22'	39	7h37'

	No insulation		50% Insulation		100% Insulation	
	C kJ/m2·K	TD h	C kJ/m2·K	TD h	C kJ/m2·K	TD h
Cavity wall insulation	64,64	8h 11'	63,38	9h 56'	63,07	10h 23'

Figure 4.15: Effect of insulation position in a) a heavy wall on thermal capacity b) a cavity wall on thermal capacity _ source: URSA, 2009

4.9.4. INSULATION AND HEAT FLOW

All materials allow a measure of heat to pass through them. Some, such as metal, glass or air, allow heat to pass through more easily. Others, including animal fur or wool, thick clothing, still air or products such as fibre-glass, rock wool or slag wool insulation, are much more resistant to heat flow, and are referred to as insulators. The term 'insulation' refers to materials that provide substantial resistance to heat flow. Fibre-glass, rock wool and slag wool insulation resist the flow of heat. Heat is a form of energy — it always seeks a cooler area — typically flowing out of the building in winter and into the building in summer. In a 1996 study of the energy and environmental benefits of fibre-glass, rock wool and slag wool insulation materials prepared for the North American Insulation Manufacturers Association (NAIMA), researchers compared the energy used to make insulation with the energy currently being saved by insulation products installed in the building envelope of residential and commercial structures. According to the report, prepared jointly by Energy Conservation Management, Inc. (ECM), the Alliance to Save Energy, and Barakat & Chamberlin, Inc., the benefits from insulation far outweigh the cost, with the ratio of energy investment to energy savings having a range of (12 to 1) per year. This ratio means that for every Btu (1btu = 0.29 W) invested in the manufacture of thermal insulation, 12 Btu in energy savings are realized in the first year of service. The above study looked specifically at the energy saving benefits of the insulation currently in place in the United States in residential and commercial buildings as well as in industrial applications. The study reached the conclusion that "because of home insulation, drastically less energy is needed to heat and cool homes in the United States today when compared to the same homes without insulation_ see the previous Table 4.6. The difference results in energy savings was 10.4 quadrillion Btu that is equivalent to a 255-day supply of gasoline for the entire United States or to 51% of the total annual industrial energy consumption in the United States. In the commercial building sector, the study found that insulation currently in place saves 1.51 quadrillion Btu annually, or a 37-day supply of gasoline for the entire United States, Figure 4.16 along with the above Table (4.8) add more illustration to the energy savings realized from insulation currently in place in these sectors, the Figure is shown that the better insulated the buildings, the higher the cooling energy savings. In a well-insulated building it makes nearly no difference for the amount of cooling energy needed whether it was built in massive or lightweight construction.

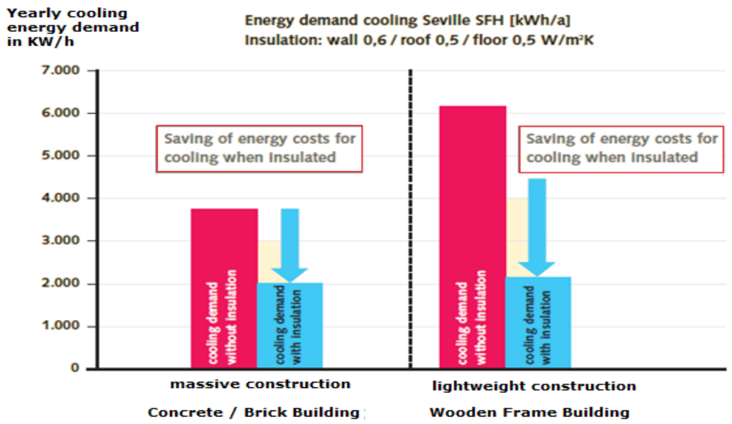


Figure 4.16: Potential saving in energy when insulation is in place source:http://www.naima.org/insulation-resources/insulation-the-environment.html

4.9.5. THERMAL MASS IN SUMMER

The benefit of thermal mass in residential buildings is well understood in warmer parts of the world, but is also becoming increasingly relevant to other regions where the impact of climate change is leading to more frequent occurrences of overheating. Its application in commercial buildings is also growing, where one of the key benefits is lower running costs of air conditioning systems. During warm weather, much of the heat gain in heavyweight buildings is absorbed by the thermal mass in the floors and walls, helping prevent an excessive temperature rise and reducing the risk of overheating. This makes naturally ventilated buildings more comfortable and in air conditioned buildings with thermal mass the peak cooling load can be reduced and delayed. The thermal capacity of the building fabric allows a significant amount of heat to be absorbed with only a small increase in the surface temperature. This is an important quality of heavyweight construction as the relatively low surface temperature results in a beneficial radiant cooling effect for the occupants, allowing a slightly higher air temperature to be tolerated than would otherwise be possible. By allowing cool night air to ventilate the building at night, heat that has built up in the fabric is removed. This daily heating and cooling cycle of the thermal mass works relatively well in the UK for instant as the air temperature at night is typically around 10 degrees less than the peak daytime temperature, making it an effective medium for drawing heat out of the fabric, Figure 4.17 illustrates the process of thermal mass in summer.

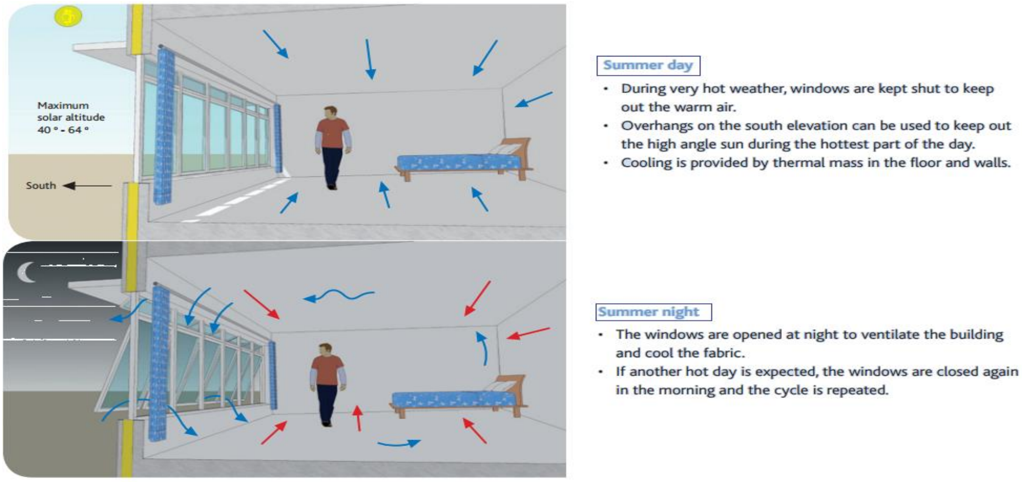


Figure 4.17: Thermal mass in summer, how it works. Source: Tom de Saulles, 2009

4.10. Chapter Conclusion

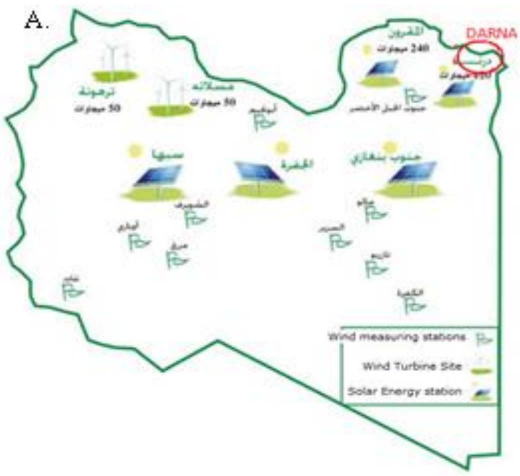
The process of heat gain and loss determines the energy balance of a building. Factors influencing energy balance are building fabric, widows' size and type, level of ventilation, orientation; therefore, a series attention should be paid before chosen site, materials, shape and layout for development or design buildings. Also, considering the insulation issue within the buildings it can be seen that time delay, thermal capacity are no representative for heat flow or real temperatures in a room the only parameter linked to thermal fluxes is U-value (average value) and the periodic transmittance (peak value). In insulated building elements periodic transmittance is very few influenced by the position or nature of insulation (it is not the same in a non or very poor insulated building elements). Thermal behaviour of a building is then described by various types of heat transfers which include heat transfer through building fabric, windows, ventilation and internal gain. In hot climates, the use of insulation in the building envelope is primarily to reduce heat flow in order to lower solar heat gains. The main categories of thermal insulation materials are presented with clarifying of their application and parameters that affect their effectiveness. In addition, thermal characteristics of glazing materials including a number of their types are reviewed followed by explanation of the major aspects that affect the selection of the materials in hot humid climates. Another conclusion from the above chapter is that the essential part of the mass structure in the thermal comfort of buildings as well as saving energy. Generally, a high mass building has a smaller interior air temperature variation than a low mass building while there is a decrease and a time lag of the peak cooling load. For locations with large diurnal temperature swings, this process can significantly reduce the energy consumption of the mechanical cooling system. This technique is more applicable to offices and other buildings which are unoccupied during the night, so that the structure can be cooled with night time ventilation. Air conditioned buildings can also be pre-cooled during off-peak hours, for considerable energy savings. Resulting small indoor temperature variations have also a positive influence on occupant thermal comfort. For the designer, the primary objective is to calculate the optimum thermal mass of a building and to then distribute it in such a way as to optimize temperature fluctuations and heat return rate into the indoor environment. Material selection is also important, since thermo-physical properties influence the overall performance of heat storage systems. And in order to make use of strategies and improvement of thermal situation of the case study buildings the next part of this research will start look at the local climate, buildings site and building form and orientation of Darnah in the next chapter than will continue with more details such as results and observation of the field survey and using these data as a simulation information with one of design tool software (TAS) in order to get outputs that will help improving the situation of thermal comfort in these case study buildings.

URBAN MORPHOLOGY & MICRO-CLIMATE OF DARNAH

Chapter 5 : Urban Morphology & Micro-climate of Darnah

5.1. Introduction

Libya enjoys massive renewable energy resources represented by the solar ray, wind, underground thermal energy and live mass, that is according to many international studies which outlined the technological and economic capabilities of renewable energy resources in the Mediterranean countries, among of which is Libya that they have huge capabilities vary from one state to another state. One of these states is Darnah also spelt Derna (population 163,857 up to 2009 according to national population statistics) which is the chosen case study city. The city is a well-known port city located at the eastern end of Libya at the foot of Green Mountain spread over 7000 km^2, and geography is located at latitude: 32.76 (32°45'36"N); longitude: 22.64 (22°38'24"E); whereas its altitude:140 m.



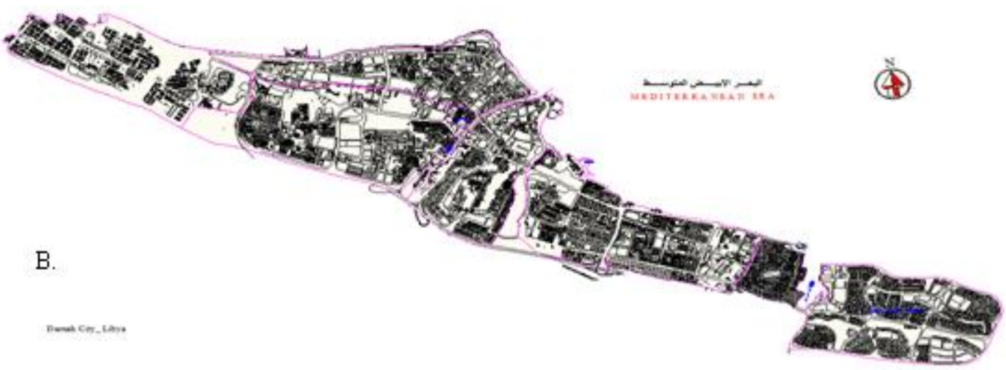


Figure 5.1: a. Future stations of conventional renewable Energy, b. map of Darnah the case study city_ Petro energy Libya, source (a): www.petroenergylibya.com source (b) planning and housing section at Local Darnah Council

5.2. General Climatic Data

Since It is important to understand the sources of climate data that the case study buildings performance are based on and in order to obtain occurred results beside to ensuring the validation of the analysis, the climate of the case study were collected during a field study trip in 2010 from a meteorological station of the city which is located south-east of the city (Al Fitayih centre). Below is a brief illustration of Darnah climate;

The city climate is classified within the Mediterranean climate; and as the majority of the regions with Mediterranean climates Darnah has relatively mild winter and very warm summer. Climate data of the city were obtained to be used as an input data in computer modelling stage of this research. Table 5.1 summarizes the climatic data for each month based on averaged for over the 22-year period (Jul 1983 - Jun 2005). The table indicates that July has the highest solar radiation (8.45 kWh/m² a day), and therefore observation also shows that July is the month with clearest sky in the year, even so a general look to the table indicated that Darnah has a relative clear sky even in winter months and sun almost present when there is only partial cloud cover. There is an average range of hours of sunshine in Darnah of between 5.4 hours per day in December and 12.5 hours per day in July. On balance there are 3235 sunshine hours annually and approximately 8.9 sunlight hours for each day. Temperatures on other hand are somewhat high and along with relatively humidity of 88-98%, and never falling below 80% are increasing the discomfort feeling during summer time. August is the hottest month of the year and February is the coldest one, at 35.90°C and 15°C respectively.

Table 5.1: Darnah, Libya - Solar energy and surface meteorology_ data obtained from Meteorological Station in Darnah, Al Fitayih centre, 2010

Variable	1	2	3	4	5	6	7	8	9	10	11	12
Insolation, kWh/m²/ Day	2.76	3.77	5.07	6.61	7.50	8.42	8.45	7.73	6.37	4.71	3.19	2.52
Clearness, 0 – 1	0.52	0.56	0.60	0.66	0.68	0.74	0.75	0.74	0.71	0.65	0.56	0.52
Temperature, °C	15.9	15.0	17.3	27.0	29.5	32.5	34.7	35.9	34.9	22.7	20.2	17.5
Wind speed, km/h	23.0	24.6	23.3	21.1	19.7	19.6	21.9	21.1	20.2	18.6	20.5	22.7
Precipitation, mm	94	66	45	19	4	1	0	0	10	46	44	82
Wet days, d	12.0	10.2	7.1	3.4	2.2	0.3	0.2	0.1	1.1	3.9	6.3	10.1

Wind speed is given in the Table above as well, generally, this wind are pleasant as the dominant winds blow from the north and northwest in all seasons, as in summer the Mediterranean breezes are of great benefit to the coastal zone. However, in July and August this zone is affected for many days by wind from the south, the Ghibli (hot dry wind with dust _ see picture 5.2, which blow from the Sahara Desert and raises the temperatures and dries the air in this region and it cause increasing in temperature up to 45 °C.

Figure 5.2: Gabli winds pictured on 27th of August 2004_ source: the researcher

On other hand, precipitation and wet days Figures show that the city has the characteristic of the Mediterranean climate which is characterised by warm to hot, dry summers and mild, wet winters as data shown in the above Table 5.1. For more illustration, data in Table 5.1 were plotted in chart and Figures formal using Ecotect and Excel. Figure 5.3 comprises climates data of maximum, minimum and mean temperatures, humidity, and rainfall beside wind direction sunshine hours; all these data are explained briefly in this section.

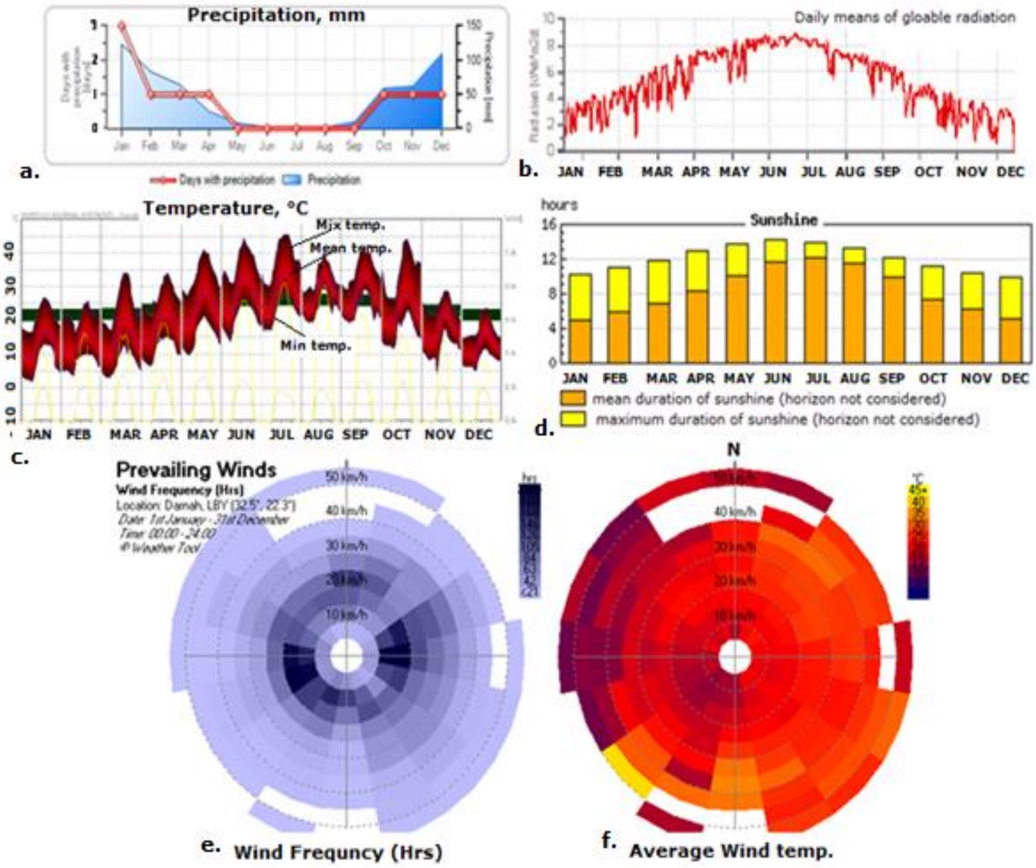


Figure 5.3: Darnah climate data plotted using Ecotect and Excel after data collected during fieldwork trip, 2010.

5.3. Comfort Zone

Comfortable zone is intended to provide acceptable thermal environment for occupants wearing typical indoor clothing and at a near sedentary activity. Acceptable thermal environment is an environment which at least 80% of the occupants would find thermally acceptable. Programs such as Ecotect plot climatic data points hourly onto a psychrometric chart, showing where they lie relative to the comfort zone. Such chart is structured around to identify the condition required to move the environment into the comfort zone, and refer to, the 'comfort zone'. The comfort zone is defined as the range of climatic conditions within which the majority of persons would feel thermally comfortable. Using Ecotect along with Darnah climate data Figures 5.4 and 5.5 have been produced in order to identify the comfort zone in both summer and winter for the city.

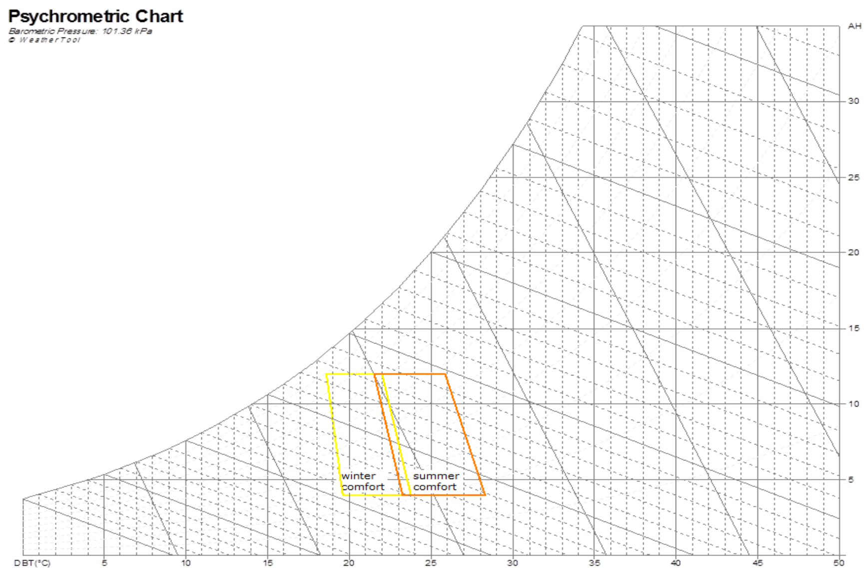


Figure 5.4: Comfort Zone in Darnah city in; a) summer, b) winter_ produced using weather Tool v2 in Ecotect software

The above Figure (5.4) identifies the temperatures at which the vast majority of people will feel comfortable for both summer and winter conditions. In summer the comfort zone is <23.2℃ and >28.5℃ while in winter time the comfort zone is between 19.5°C to 24°C. As can be seen, there is a 1°C–2°C variance within the optimal temperature ranges identified. So, effective control and management can have a dramatic impact on the cost effectiveness of keeping most people comfortable.

Another consideration were plotted within the psychrometric chart, this time observe the location of comfort zone on monthly temperature range, Figure 5.6 displays a single line for each month between the average monthly maximum and the average monthly minimum each line marked with a character representing the first letter of each month name. Figure 5.5 reflects that the climate of Darnah ranges from the very cold zone indicated in winter months to the very hot zone indicated at hot summer months. This implies that, to achieve comfortable conditions in Darnah, heating is required during the cold period, while cooling is required during the hot period. However, even at the upper range of hot summer temperature the chart show that Darnah climate needs ventilate and shading systems and in most days the need for mechanical cooling neither is require as observation during filed survey recorded a huge use of air conditioner during summer.

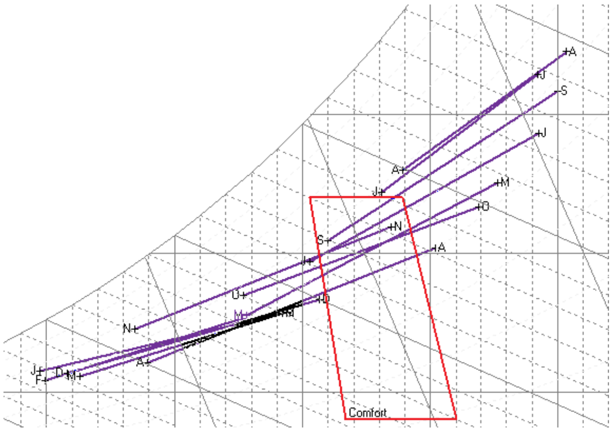


Figure 5.5: Comfort Zone in Darnah city in summer with display of monthly max/min temperatures range of each month as presented in their first letter_ produced using weather Tool v2 in Ecotect software

5.3.1. PLOTTING THE COMFORT ZONE

The comfort zone can be plotted on the psychrometric chart by the following procedure:

1. Find the annual mean temperature (T_{av}): this is done by adding up, all the average dry-bulb temperature readings taken through the year (by the month) and dividing the total by the number of months (12).

In our example (Darnah) the 12 average values given in the climatic data under 'Monthly Average Hourly Dry Bulb Temperatures (°C) will be used with the following equation;

Tav = monthly average temperature / 12

Tav for Darnah city will be = 20.20°C

2. Find the thermal neutrality (T_n): thermal neutrality is the temperature averaged for a large sample of people, when the individuals feel neither cold nor hot. It has been shown conclusively that this thermal neutrality is influenced by the climate, which the individuals are used to (a result of physiological acclimatisation, but also of habits) and correlates with the outdoor mean temperature (T_{av}) as
$T_n = 17.6 + (0.31 \times Tav)$
provided $19.5 < Tn < 28.5$

In the case of Darnah,
Tn = 23.86°C

3. Find the lower (L) and upper (U) limits of Tn

Lower limit L = Tn – 2.5	*Upper limit U = Tn + 2.5*
TL = 21.36°C	*TU = 26.36°C*

4. Find the SET slope expressions: over the last 50 years or so, numerous thermal indices have been constructed, to express in a single number the combined thermal effect of at least some of the four environmental variables. The latest one (as of 1987) is the standard effective temperature (SET), which combines the effect of DBT and humidity, when

the MRT is the same as the DBT and there is no significant air movement. The SET lines are given as follows:

** Up to 14°C, SET lines coincide with the DBT (vertical) lines.*
** Above 14°C, the SET coincides with DBT at the 50% RH curve, but the lines have a slope of 0.025 x (DBT - 14) for each g/kg (AH) vertical distance.*
The slope expressions become:

For lower limit L = 0.1965 degC/(g/kg) *For upper limit U = 0.309 degC/(g/kg)*

5. Find the base line intercepts for L and U from the SET slope expressions

Base line intercept for L = L + [AH(L) x 0.1845)]

$L_{base\ intercept}$ = 23.31°C

Base line intercept for U = U + [AH(U) x 0.2845)]

$U_{base\ intercept}$ = 30.0°C

6. The next step is to plot the values calculated above on the psychrometric chart (as shown previously in Figure 5.5)

Thermal neutrality for the city of Darnah

The results from the above psychrometric chart were putted into an examination by applying comfort equation that have been considered early in chapter three and four, re-examine these result were based on another psychometric chart result the one is produced by ASHRAE for 32°N Latitude, and stated the range of 18-28 °C to be suitable for keeping the occupants thermally comfortable.

Other methods such as Auliciemes (1969) and Humphrey (1978) were applied using climate data of the city to compare the result and get more occurred values. Humphrey and Auliciemes investigated the thermal neutrality of the human body, it was defined as the temperature at which the person feels thermally neutral (comfortable). Their studies were based on laboratory and field works in which people were thermally investigated under different conditions. The results of their experiments were statistically analysed by using regression analysis. Humphreys showed that 94% of the neutral temperature is associated with the variation of outdoor mean temperature. For free running buildings, the regression equation is approximated by;

$Tn = 11.9 + 0.534\,Tav$................................ (eq. 5.1)

While Auliciemes has a different empirical correlation function that is;

$Tn = 17.6 + 0.314\,Tav$.................................... (eq. 5.2)

Based on the above equations, the predicted neutral temperature for Darnah for the average summer and winter days are as indicated in Table 5.2. The Table indicates that Auliciemes overvalues the thermal neutrality temperatures for the winter, while Humphrey does the same for the summer months. The summer neutrality temperature for Darnah is about 28.5°C whereas in winter it drops to about 18°C. Table 5.2 reveals the final result of comfort temperatures in Darnah city after considering Humphreys and Auliciemes methods, these methods were just reliable in summer time while not that suitable for the winter season. These results are in range with the previous one that produced using the psychrometric chart.

Table 5.2: Darnah comfort band, according to Auliciemes and Humphreys natural temperature methods

Comfort limits, °C	Winter		Summer	
	Humphreys	Auliciemes	Humphreys	Auliciemes
T_U Upper temp $=T_n$+2.5 °C	21.3	24.1	28.6	28.0
T_n Neutrality tem = T_n	18.8	21.6	26.1	25.9
T_L Lower tem $=T_n$_ 2.5 °C	16.3	19.1	23.6	23.4

Final result of comfort temperatures in Darnah city according to the above methods

Comfort limits (°C)	Winter	Summer
$= T_U$	24.2	28.6
T_n	21.7	26.1
T_L	19.2	23.6

5.4 Building Form and Orientation of Darnah City

The strength of vernacular architecture is that it blends buildings into various settings so that there is a natural harmony between climate, architecture and people. In countries such as Iran, Iraq and Egypt there have evolved buildings which not only demonstrate this harmony and unity between people and their environment but also offer a combination of engineering and architecture which has an aesthetic quality. In the past, people in Libya built their houses according to their real needs and in harmony with the environment as well as with optimal utilization of the available local building materials. In spite of the hot long summer with the dry bulb temperature of up to 40°C, human comfort was achieved in those traditional buildings by the utilization of natural energies. This was the result of repeated cycles of trial and error and the experience of generations of builders. It is worth mentioning that builders had to rely mostly on the locally available material to construct the buildings with the exception of timber which was imported from India.

In the 1940s the country's economy flourished as a result of oil discovery, and electricity was introduced. Modern technologies were adopted without studying their suitability with regard to culture and climate. An architectural heritage that survived for centuries because of geometric, technical and constructive principles that work for the society, is being sadly destroyed under the guise of modernization. Traditional buildings are being abandoned as it is perceived that they reflect underdevelopment and poverty.

In general, square and rectangular is the regular form for medium-rise building in the city of Darnah, and buildings’ entrances are usually facing either south or north directions to get the most benefit from the natural light and warm sun coming from the south in winter season that includes the medium-rise building. The form of the building is simply roofs that are absolutely horizontal built from medium to lightweight concrete and paint with asphalt to reduce the effect of moist-ration of the wet days, however the black surface absorb a high solar radiation. However, researches showed the in the high and multi-storey buildings vertical wall is the most critical surfaces to be protected from overheating, and these walls are built with single layer of concrete block and two thin layers of cement each side of the wall also the inside layer usually paint with plaster and almost all these buildings have more than one balcony as an outside area. In Darnah, multi-storey buildings normally have an atrium which range between 9m² to 64m² used for ventilation and neutral light, see Figure 5.6. However, in the last few years, this type of building starts to witness a wide use of air conditioner units as a new technology of keeping human comfort in a desirable level which may suggest that the size of these atriums do not cope with the building needs.

Figure 5.6: Open to the sky atriums pictured in the case study building_ Source: the researcher, summer 2010

5.5 Characteristics of the Case Study Buildings

5.5.1 Building Materials

A major design consideration was the visual impact of the building. Buildings were constructed of materials that are not suitable for the region's environment (steel and concrete). Dwellings constructed as a large enclosed glazed space with no provision for ventilation and protection from the sun and almost all buildings are constructed of a reinforced concrete system, which is used in columns, beams, floors and roofs, with hollow cement blocks or limestone for the exterior walls and interior wall partitions without any insulations materials. For the case study buildings, there were no different as observation find that, the main building materials used are steel, cement, hollow cement blocks, concrete and marble. Figure 5.7 (a& b) shows the building's finishing materials.

a.

b.

Figure 5.7: a) Building materials and construction system used in Libya in general including the case study Danah. Concrete floors & roofs, steel and hollow concrete blocks _ b) Photos shown examples of city mid-rise buildings (B1, B3, B6, B8 & B10) as well as shown finishing materials _ source: Site visits photographs, summer 2010

Table 5.3 summarizes the principal indicate of typical modem buildings that were the identical elements in case study buildings, such as architecture design, construction, building materials and micro-climate. Beside other influenced factors like social customs and economics. All these principals directed the new buildings in other way than suitable to its climate. In the case study city, and as shown in Table 5.3 modern residential architecture is constructed primarily of a reinforced concrete system, which is used in columns, beams, floors and roofs, with hollow cement blocks or limestone for the exterior walls and interior wall partitions without any insulations materials. Wall built of different thickness (15-20 cm) and plastering exterior and interiors by mortar cement. In addition, varieties of materials use on exteriors such as marble and neutral stone. Also, the majority of houses have flat roofs which usually constructed from reinforced concrete slabs with 10-12 cm thickness as well as some roofing materials such as asphalt, cement mortar and roof tiles or just a light concrete layer of 5 cm thickness. Mostly have not use insulation materials.

Table 5.3: Principal points for typical modern buildings_ source: Ealiwa, 2000

Architectural design
1. House as enclosed cube. Each floor, where more than one any extension, built on side and consist of different style and type (villa on or two storey, ground house, flats. **2.** Usually No courtyard replaced by balcony and terraced. Rooms look outwards to garden or road at front **3.** Flat roofs with parapet, not always high enough to prevent being overlooked. Some houses have pitched roof **4.** Most floors same height **5.** Outside full of openings on to street and neighbours **6.** Consequence this type has not courtyard, so garden at front or back or even between houses, which offered shaded
Construction and building materials
7. **a)** Wall construction: The construction systems in most houses were Skeletons frame. Wall is usually constructed without cavities and from heavy or lightweight materials. in general there are three main types of blocks used in wall construction • Sand and limestone; • Lightweight cement blocks; • Clay blocks. Wall built of different thickness (15-20cm) and plastering exterior and interiors by mortar cement. In addition, varieties of materials use on exteriors (e. g.) Marble, neutral stone. **b)** Roof construction: The majority of houses have flat roofs except in some houses where pitched roofs are common. The roofs usually constructed from reinforced concrete slabs with 10-12cm thickness as well as some roofing materials such as asphalt, cement mortar and roof tiles or just a light concrete layer of 5 cm thickness. Mostly have not use insulation materials **8.** Building takes minimum of 6 month **9.** Most houses have decoration inside and outside and different use of colour **10.** Most rooms have one purpose **11.** More covered area
Micro-climate
12. Climatic conditions were not prospers considered during design **13.** House built usually separated which exposed all side to the sun **14.** Surface area (in plan and elevation), exposed to direct solar radiation is greatly increased, as is thermal gain **15.** Houses faces on to wide streets. No shadow protected from Climate during summer (hot, dusty), winter (cold, rainy) **16.** Most houses build by reinforce concrete in roofs and hollow cement block in wall which high thermal conductivity **17.** Most houses paint different colour in exterior, which absorb the heat
Social customs
18. Most families are nuclear **19.** Families living in such houses are usually no similar income levels. Any relationship between neighbours may depend on the Occupants' status **20.** Most neighbour hoods newly established and people do not know one another **21.** Privacy is not considered in external
Economics
22. Larger plots put high demand on land for houses. Result higher costs **23.** Loose sprawling layouts increase infrastructure costs **24.** Most building materials are use not available in local Markets. Result high cost. Construction by professionals & trades people
Factors of influence
25. Housing policy **26.** Technological and building materials **27.** Planning system **28.** Development of social and cultural **29.** Population growth **30.** Economic factory

From observation, some of materials are produced locally, but wood, mosaic, and marble were imported. These constructions are dependent on new technology, which leads to the appearance of different patterns and forms. The different colours used in the external and internal walls of the house are unsuitable for the climate particularly the internal walls colour when observation show that 90% of colours used is dark type. Most of all, the table above estate some very essential factors that influence the use of this materials along with other elements; these factors are, building policy in the country, planning system, social development and population and economy growth.

5.5.2 HOUSE LAYOUT

Ensures the opening orientation of house layout position is in the most suitable location regarding to climatic conditions and the long sides of the houses are exposed to the north to capture the cold breeze in summer and to the south to obtain sun-rays in winter. For instance, in Tripoli Libya the opening orientation of houses layout is in the most suitable location regarding climatic condition and the long sides of the houses are expose to the north to capture the sea's breeze in summer and south to obtain the sun's-rays in winter;

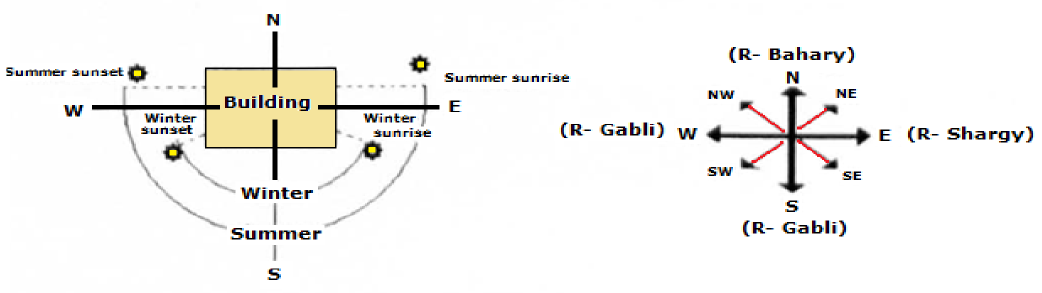


Figure 5.8: Suitable orientation of houses in coast cities of libya according to wind direction and sun rays _ source: Amear, 2007

5.5.3 THE CLIMATE

1. Insulation of walls is crucial to create a comfortable temperature within the house. This could be attained by the following methods: "Use of the cavity walls or thermal insulation to increase lag-time of the wall will increase insulation. Since hot air rises a considerable amount of air movement can be created by simply providing a vent at the top and bottom of a wall. Hot air can rise and escape of course these vents should be suitably screened to keep out insects, or natural materials such as mud mixed with straw should be used and filling between double walls besides planting trees and climbing plants to shade it; "Heavy masonry is desirable for outer walls particularly those on southern and western sides.
2. The construction of mostly flat roof that means the major part of the summer sun's heat falls on the roof of a building, due to its position with respect to the sun and has frequently to be protected to avoid overheating the spaces beneath. In addition to that, the roofs of houses which release most heat

through radiation to the night sky, especially those constructed by reinforced concrete as observed in most contemporary housing. Based on these problems above, the roof ought to be insulated from the sun. This can be accomplished by the following: " Shade can be achieved by using a double roof with a layer of air between or by covering the roof surface with hollow bricks; insulating materials such as fibre-glass and lightweight blocks;

- The shape of the roof is also of considerable importance in a sunny climate. Pitching or arching the roof has several advantages over a flat structure. Using domes and barrel-vaulted designs increase the speed of any air flowing over their curved surface and is effective in minimizing direct solar radiation.
- Using a roof garden is plants can solve a great deal of the roof thermal mainly by creating a shady area. Another advantage could be gained from these plants in that their roots retain a certain amount of moisture, which can help to keep the roof surface temperature down. A useful idea is to shade the roof more naturally by designing it to suit popular traditions such as loggias or open galleries.
- High solid parapet walls around the roof would, for example, create a stagnant pool of not air and should, therefore, be avoided.

3. The other most important concept of design in relation to the climate is that of windows. These must be placed suitably in relation to prevailing breezes to permit natural air flow through internal spaces and be suitable for heating during the winter. Accordingly the orientation of openings is determined by two factors:
   - Towards the prevailing breeze during the warm humid season, to utilize its cooling effect
   - Towards the sun during the cold season, to utilize the heating effect of radiation entering via windows
   - Encourage the use of shading elements to reduce heat within the house. South and West facing windows require different shading solutions and this can be achieved by vertical and horizontal devices
   - Shading could additionally be created by trees being sited near to windows. Deciduous trees can, however, beneficial for providing shading from glare and overheating during the summer, whilst the bare branches will permit solar access during the winter.
4. In sunny weather, external surfaces can became very hot, facilitating the transfer of heat to the building interior. Therefore, the reflection of radiation is another method of providing insulation. The colours of the surfaces of a building, which are exposed to the sun, play a large part in reducing heat

passing into the interior. When sunshine falls on a solid surface, part of the heat is reflected and part absorbed. Light colours and bright metal surfaces reflect a great deal of the sun's heat. Certain paints may reflect as much as 85% of visible radiation and dark coloured surfaces should be avoided in all cases.

5.5.4 Related to climate and building materials criteria

<u>Housing Design Guidelines proposal (climate):</u>

1. Use of cavity walls or thermal insulation to increase lag-time of the wall. This will increase insulation. Since hot air rises, a considerable amount of air movement can be created by simply providing a vent at the top and bottom of a wall. Hot air can rise and escape so these vents should be suitably screened to keep out insects, or natural materials such as mud mixed with straw should be used and filling between double walls besides planting trees and climbing plants can offer shade;
2. Heavy masonry is desirable for outer walls particularly those on western and southern sides.
3. The construction of the roofs let a major summer sun's heat falls directly on the roof. This made the roof responsible for releasing a large source of the heat through radiation to indoors, especially those constructed by reinforced concrete, as observed in most contemporary housing. Based on these problems above, the roof ought to be insulated from the sun.

This can he accomplished by the following:

- Shade can he achieved by using a double roof with a layer of air between or by covering the roof surface with hollow bricks; insulating materials such as fibre-glass and lightweight blocks;
- The shape of the roof is also of considerable importance in a sunny climate. Pitching or arching the roof has several advantages over a flat structure. Using domes and barrel-vaulted design increases the speed of any air flowing over their curved surface and is effect in minimizing direct solar radiation;
- Using a roof garden is plants can solve a great deal of the roof thermal mainly by creating a shady area. Another advantage could be gained from these plants in that their roots retain a certain amount of moisture which can help to keep roof surface temperature down. A useful idea is to shade the roof more naturally by designing it to suit popular traditions such as loggias or open galleries;
- High solid parapet walls around the roof would, for example, create a stagnant pool of not air and should, therefore, be avoided.

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   - Towards the sun during the cold season, to utilize the heating effect of radiation entering via lie windows
6. Encourage the use of shading elements to reduce heat within the house. South and west facing windows require different shading solutions and this can be achieved by vertical and horizontal devices.
7. Shading could additionally create by trees being positioned close to windows.

5.6 THE CASE STUDY BUILDINGS

Figure 5.10 shows the case study locations on the city map, these case buildings have 5 to 9 storeys; also they have about 120 m² of floor space per family unit as an average. In many examples the blocks share party walls and the central courtyard loses its original importance and it begins to function as a light well. The living areas of the dwelling are, therefore, found to open outside onto the street. Access to the dwellings is by a staircase. Every dwelling is equipped with a loggia or balcony. The dwelling consists of one living room of about 30 m²; 2 or 3 bed rooms, one guest room, a kitchen and a bath and in some cases a dining room which altogether arranged around one entry hall or corridor. Very often, there are 2 corridors, one connecting the main rooms and another linking utility rooms or bath with bed rooms. The reinforced concrete is used in structural frames; floor and roof slabs whereas filling walls are of stone or concrete blocks.

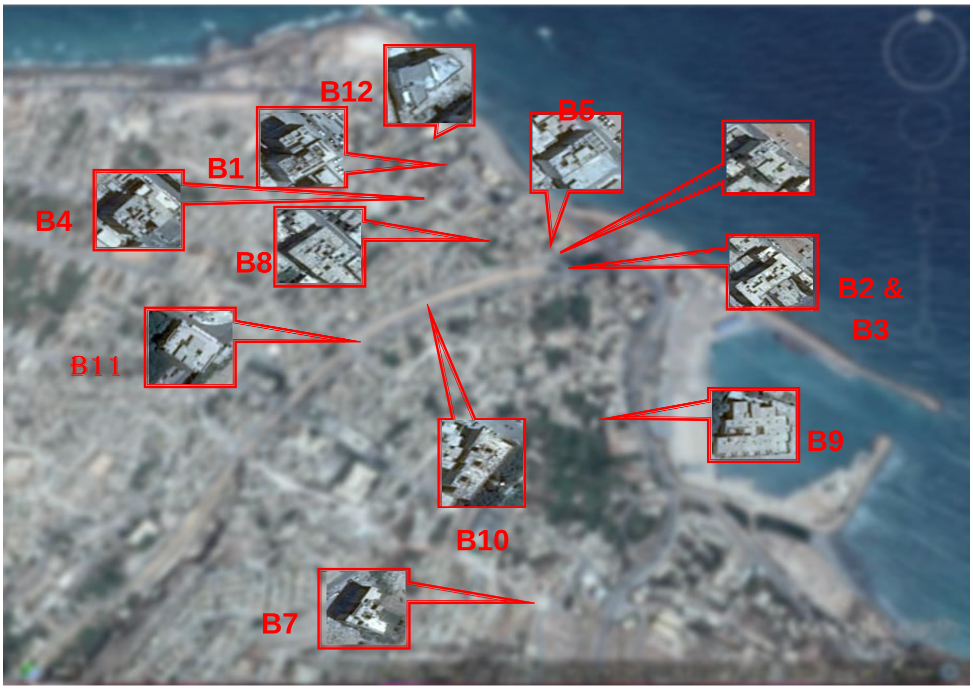


Figure 5.9: location of case study buildings on Darnah's map _ source: planning and housing section at Local Darnah Council, 2010

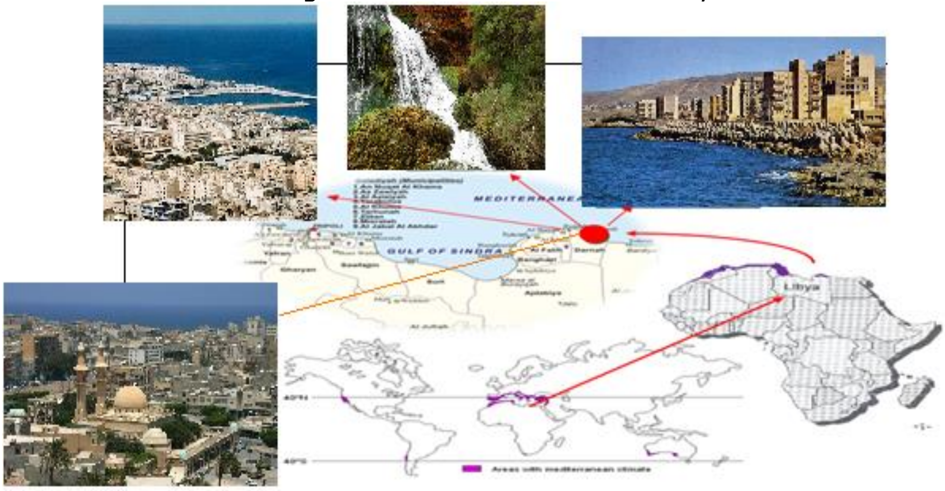


Figure 5.10: Darnah's location and pictures_ highlighted areas with purple colour on world map indicated areas with Mediterranean climate around the world_ source of world map: http://en.wikipedia.org/wiki/Mediterranean_climate

The selection of buildings' sample was based on the following considerations:

1. the samples consisted of both naturally ventilated and air conditioned buildings or hybrid.
2. sample must consist of buildings which have at least, north-south and west-east orientations, considering the different levels of incoming solar radiation penetrating the buildings which is expected could lead the different amount of energy used by the buildings.
3. all the sample buildings have to have an atrium or more, that in order to see the effect of this zone on the adjacent rooms.

4. a building was selected as a sample when more than 50% of its occupants are considered to be educated people, that to be sure they will corporate and response to the field survey work.
5. the construction materials is concrete and three types of construction considered for case studies;
   - Low thermal mass. Doors and windows: timber frame with hard wood finish, and single glazing 3mm used for windows.
   - Medium thermal mass ('traditional' construction). External walls: medium-weight concrete block with plaster board finish, 200mm, internal walls: concrete plaster board 100mm.
   - High thermal mass. Precast concrete floor slabs _ Concrete ceilings and roof. Floors tiled (also carpeted by the occupants). Synthetic slate tiled roof.
   - No Insulation or shading devices on windows but there are concrete slab on balconies.

Table 5.4: : existing materials used in case study buildings

Element	Materials	Width mm	fl. to fl. height m	fl. to c. height m	U-value
External wall	- 2 light layers plaster -cavity brick	13.0 each layer 225.0	3.40	3.00	1.63
Internal wall	- 2 light layers plaster -cavity brick	10.0 each 120.0	3.40	3.00	1.05
Floor	-Floor tiles -Cement layer -Sandston -Concrete reinforced -Stone chipping -Clay under-floor	20.0 10.0 100 150 10.0 750	-	-	1.35
Ceiling	-2 light layers plaster -slap concrete	10.0 each 150	-	-	4.55
Roof	-Send cement plaster -concrete reinforced -light layer plaster	15.0 300 10.0	-	-	5.03
External door	Hard wood one layer	50.0	-	-	3.4
Internal doors	Double wood layer _ air between	30.0	-	-	3.00
Windows	Single Glass sheet	3.00	-	-	5.78

Table 5.4 identifies the location and general control scheme for the 12 mixed-mode buildings. The group of mixed-mode buildings that was analysed in the study represents a broad range of building height, sizes, and plans. They range in size from 500 Meters square meters to over 2,500 square meters. The buildings also ranged in number of occupants; the buildings often had a significant transient occupancy, especially in residential buildings, but we only offered the survey to head of the house (father or mother) and therefore the occupancy numbers in Table 5.5 reflect the average number rather than exact occupants' number. The buildings also represent a variety of different operation mode types or strategies. As seen in Table 5.5, sometimes buildings can combine more than one of these operational strategies.

5.8. Chapter Conclusion

The city has all the features of its classified climate in addition it benefits from the sea breeze which can be used in cross ventilation or night ventilation strategies.

Shading and shelter should be first consideration in design stage as the city climate shows a high level of solar radiation with long hours almost all the year round as well as shelter for hot winds (Ghibli). Next chapter with look at built materials that used in case study buildings in aims of search deep into reasons that might cause the discomfort in these buildings.

Darnah located within the Mediterranean climate region with a very similar to its characteristics. Still the buildings were built without climate consideration and need to be improved to suit this climate, also a new design strategy that copes with the environment need to be established. To prove that there is a need for home design improvement, more data planned to be collected and a field work was intended to do, thus a wide survey carried out in August 2010 for the purpose of data collection. Field work and methodology of this research is presented in the next chapter.

Table 5.5: summarizes some basic characteristics of the case study buildings

*Orientation (long side) start with the direction where the main entrance is located.

No.	**Building Code**	**Picture**	**Orientation** (long side)*	**Number of stories** incl. G Floor	**Number of flat / floor**	**floor area** in m²	**Average number** of people/ floor	**Mode type**	**Building type**	**Dist. from sea** (m)	**Year constructed**
B1	SHANEAB (SH)		E-W	9	4	240	24	Mixed-mode system	Residential apartments	~ 40 m	1980
B2	BORJ ALSHATI (BSH/ South)		SE-NW	9	6	700	36	Mixed-mode system	Residential apartments	~ 60 m	1976
B3	BORJ ALSHATI (BSH/N)		NE-SW	9	6	700	36	Mixed-mode system	Residential apartments	~ 30 m	1975
B4	ALMAJRE1 (MJ1)		W-E	8	4	365	24	natural ventilation	Residential apartments	~ 100 m	1975
B5	ALMAJRE2 (MJ2)		W-E	9	4	380	24	Mixed-mode system	Residential apartments	~ 30 m	1970

Continues

B6	BEN TAHER (BNT)		E-W	9	2	415	12	Mixed-mode system	Residential apartments	~ 30 m	1975
B7	ZATOAT (ZA)		SW-NE	7	3	500	21	Mixed-mode system	Residential apartments	~ 1000 m	1977
B8	ARHEAM (ARH)		W-E	5	5	800	30	natural ventilation	Residential apartments	~ 200 m	1970
B9	BU SETRA (BST)		NE-SW	8	2	270	12	natural ventilation	Residential apartments	~ 50 m	1973
B10	ALAWQAF (WQF)		NE-SW	9	4	650	24	natural ventilation	Residential apartments	~ 500	1980
B11	BU ZED (BZ)		W-S	9	4	500	24	natural ventilation	Residential apartments	~ 800 m	1980
B12	REAA (REA)		E-W	6	2	400	12	natural ventilation	Residential apartments	~ 30 M	1980

RESEARCH & FIELDWORK METHODOLOGY & COMPUTER TOOLS MODELLING (TAS)

CHAPTER 6 : RESEARCH & FIELDWORK METHODOLOGY & COMPUTER TOOLS MODELLING

6.1. INTRODUCTION

This chapter demonstrates the ultimate purpose of the fieldwork which is produce reliable information about the existence of the thermal comfort problems in residential multi-store buildings in Darnah, Libya. It also aims to survey energy consumption parameters in these buildings. This chapter also, addresses the research methodology that employed over the period of this research and introduces the research strategy, methods and author's gained experience that helped the author to select a number of buildings to represent the multi-store buildings in Darnah for further detailed investigation.

The aims of field studies are:

- To check the influence of some parameters previously defined in the literature review on the internal temperature.
- To draw the first conclusions about the performance of thermal comfort in Darnah, Libya.
- To provide data for calibration of the software that will be used in the parametric analyses.
- To obtain information throughout measurements results, regarding thermal performance of the buildings with higher thermal comfort compared with lower ones and its location and orientation.

Face-to-face and paper methods questionnaires were practiced as a main tool to examine the indoor environment conditions in the case buildings. Data related to buildings' locations, their surroundings, and construction materials are gathered through the fieldwork. In addition, indoor observation took place to get close data such as cool method used, internal wall colures and ect; which are crucial input data for the computer model. A clear determination for the tasks, the sequence of procedures, and the survey materials was essential in order to carry out the fieldwork with the least effort and on the determined time. The importance of the timing in this survey is vital due to the fact that this survey is concerned with indoor conditions and human comfort in summer time. Therefore, this survey had to be conducted during August which is the one of the hottest month of the year there. The fieldwork was conducted on two stages discussed below in Figure 6.1.

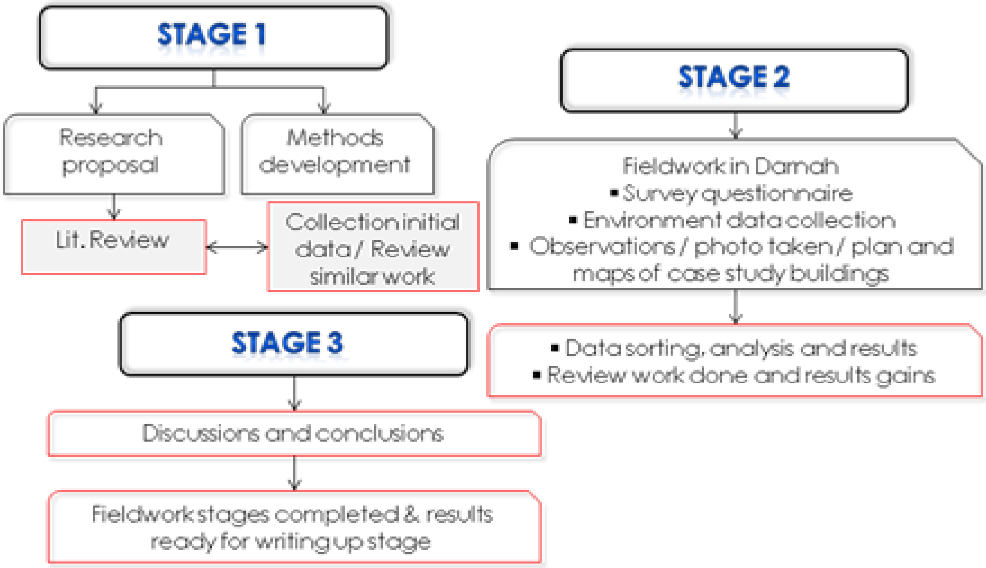


Figure 6.1: Fieldwork flow's diagram

6.2. FIELDWORK PROCEDURE

6.2.1. JUSTIFYING THE SELECTION OF CASE STUDY METHOD

Case study is a useful strategy for converting tacit knowledge into explicit knowledge so practitioners can learn more about the performance of their business systems. It is also particularly appropriate for individual researchers; it gives the opportunity for one aspect of a problem to be studied in depth within a limited time scale (Bell, 1993). Yin (1994) appears to operate from realist ontology when he defends case method against attacks, especially in relation to the 3 forms of validity: construct validity, internal validity, and external validity. A key suggestion for dealing with construct validity is to use multiple sources of evidence; for internal validity Yin (1994) stresses the importance of building cases over time in order to eliminate alternative explanation; and for external validity he points out that case studies rely on analytic rather than statistical generalizations. Sekaran (2003) stated that: "case studies involve in depth, contextual analysis of similar situations in other organisations, where the nature and definition of the problem happens to him the same as experienced in the current situation" and Remenyi et al (1998) as "a detailed investigation of the context and processes that affect a phenomenon within organisations".

Yin (1994) also defines the case study as "an empirical investigation into contemporary phenomenon operating in a real-life context". He states that the case study is the preferred strategy when "how" or "why" questions are being posed. This allows the researcher to determine not only what happened but also why it happened. The case study is excellent as a recorder of decisions, reasons, motivations and structural relationships (Leavy, 1994). The case study is a research strategy, which focuses on understanding the dynamics present within single settings (Amaratunga and Baldry, 2000), and usually refers to relatively intensive analysis of a single instance of a phenomenon being investigated. Case study method is appropriate when a researcher's concern is directed toward a set of issues in a single organisation, or a single department within it, such as development of housing. Bell (1993) develops an argument that the case study approach is particularly appropriate for individual researchers because it gives an opportunity for one aspect of a problem to be studied in depth within a limited time scale. He also indicates the great strength of the case study method is that it allows the researcher to concentrate on a specific instance or situation and to identify, or attempt to identify, the various interactive processes at work. Case study approach is more appropriate when the researcher wants to understand an organisation's phenomena within their real-life contexts (Stake, 1995; Yin, 1994).

It is used if the researcher wishes to gain a rich understanding of the context, and it is a worthwhile way of exploring existing theory (Saunders et al., 2003). Yin (1994) classified case studies into 3 types for research purposes:

- Exploratory case studies: sometimes considered as a prelude to social research;
- Explanatory case studies: may be used for doing causal investigations;
- Descriptive case studies: require a descriptive theory to be developed before starting the project.

Therefore, this research adopted to use questionnaire survey and archival documentation as a source of data within the case studies, for examining the opinion of the householder, and points of view of the professional, about traditional and contemporary housing design.

6.2.2. Case Study Data Collection

Due to the onsite data collection, also the assumptions are as much as possible informed by buildings information, observation and informal interview with the occupants. These data that is presenting in Figure 6.2 have a large influence in results so in TAS simulation when weather data and internal gains were so essential part in this research. There are potential advantages of studying more than one case. Cases can be studied comparatively in order to explore similarities and differences; Table 6.1 summarizes the work done and data gathered of 12 case study buildings while researcher was in field experimental work. Data collected through three stages during summer 2010 and early in 2011, the 3 stages are physical properties of the case study buildings, energy consumption and thermal comfort and user behaviour by using the planning questionnaire.

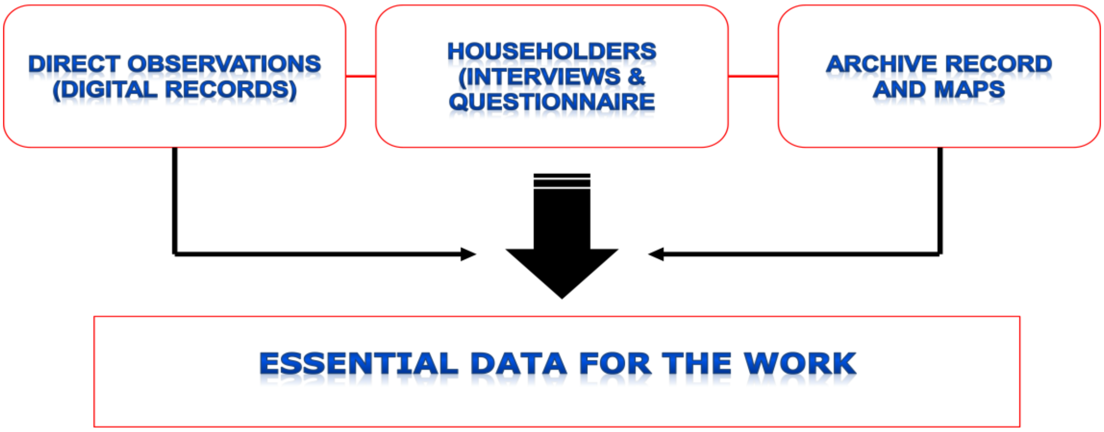


Figure 6.2: The three stages of data collection through a field trip in summer 2010 and early 2011

6.2.3. Difficulties in Conducting Fieldwork

Fieldwork was carried out in Darnah, which is unlike other cities in the world (but many are the same in Libya), the available satellite map for it on the Google Earth is not clear, where this map was an essential material for the field survey. The researcher contacted a Turkish company who is working on housing project in the city in order to get a clear map of the city. Nevertheless, this task was not easy to be done as the company needed many evidence and proofs to make sure the map is for research purpose as the map is copyright by the company and their original work. This map used in located the case study buildings and its layout site. Another issue encountered in the fieldwork was the difficulty of encourage a number of occupants to respond to the questionnaire, even with making it an easy and interesting to answer, and survey team had to do many visits to some flats in order to help occupants to fill in the questionnaire, beside some occupants were not welcoming the observation process where one of the team had to review the size of windows, solar production method, internal surface colour, etc. But, the core dilemma faced the researcher was the absent of weather file of the case study city and has to contact many sources such as US department of energy, METEONORM and Russia’s weather server to purchase the city file, unfortunately, what it is available is Tripoli file which is the capital of Libya, and US department of energy can offer some other cities in Libya. All of these cities were with different altitude or with completely different climate area (Desert climate). Therefore, the researcher obtained a full five years recorded data (2004 to 2009) from the city met office and work out the file using weather tool from Ecotect and Autodesk software, this process took two months to be completed and checked, as this stage was an essential and fundamental in this research.

6.3. The Questionnaire

Prior to the actual assessment process, a questionnaire was designed and tested for clarity and applicability through a pilot study conducted with some occupants who have experience in survey design. Figure 6.3 shows the steps of developing the questionnaire questions which is clearly a linear plan but is also a iterative process.

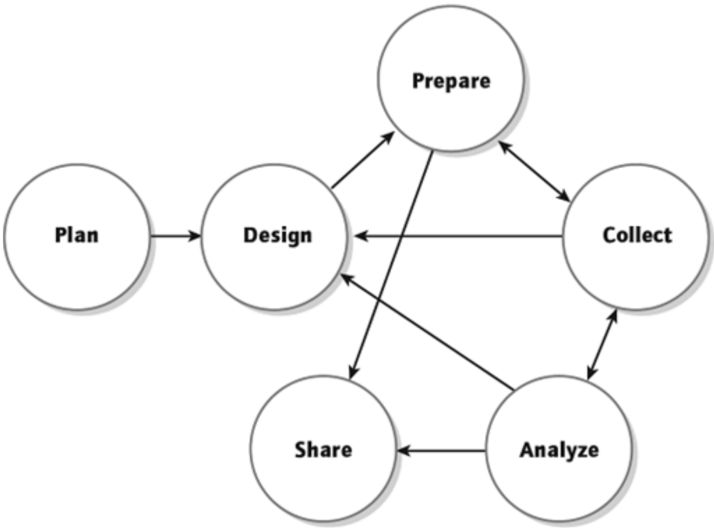


Figure 6.3: process of case study questionnaire

Kidder (1981) has pointed out; "every instrument must pass the validity test either formally or informally. Every researcher who has decided on the instrument must judge whether the test measures the construct he or she wishes to study". Bell, (1993) indicated that "All data gathering instruments should be piloted to test how long it takes recipients to complete them, to check that all questions and instructions are clear and to enable you to removal of any items which do not yield usable data".

6.3.1. Questionnaire Layout

First of all, to make it easier to the respondent to understand the general questions is to classify the questions into a logically coherent sections. This will make the questionnaire more readable and easy to observe. In addition to that grouping the similar questions together will make them easy to the respondent to complete the questionnaire. Furthermore, transition between questions should be smooth. Such points will have a great impact on response rate (WALONICK 2010). Taken into account that some aspects could affect questions" arrangements, such as bringing the difficult and more specific questions at the top of the questionnaire might drop the response rate and instead of that an attempt has been made to go through the questions from general to particular and from easy to difficult. Moreover, even when listing the questions, it would be more convenient to the respondents to fill in closed questions rather than open-ended ones. Considering the points above, this questionnaire, has been designed with divided sections and sub-headings, starting from the easy and more general questions toward the more specific and deep questions. The main headings of the sections are as following:

1. introduction (cover letter) includes researchers information and aims of this survey,
2. occupants general information,
3. flat information,
4. energy consumption,
5. thermal comfort.

7.3.2. Translation of Questionnaires into Arabic

As the questionnaire would be administered in Libya where Arabic is the native language, translation of the questionnaire from English to Arabic was an important issue. Therefore, translation of questionnaires into Arabic language began after the source questionnaire has been finalized in wording and design. In deciding to translate a questionnaire, a major premise is that the source (Qu. English version) and the translated (Qu. Arabic version) questionnaires will ask the same questions. It can be expected that small differences in formulation across languages can affect understanding. For example, the number of categories of PMV scale, which is seven, had to be maintained. However, there is a single expression in Arabic matches the two words "cold" and "cool". In addition, in Arabic, the term that matches the word ''warm'' is used in a different way. The term "warm" in Arabic is used in winter as it means "not cold". Therefore, "cool", "slightly cool", "slightly warm" and "warm" had to be removed from the Arabic scale and were replaced with "cold" "slightly cold", "slightly hot" and "hot" respectively. Subsequently, "hot" and "cold" were replaced with "very cold" and ''very hot" respectively in order to get comparable scale in the two languages.

After the stage of translation, and in order to measure the validity of the questionnaire used in this study, number of procedures had followed in this research:

- A draft version of the questionnaire was presented to supervisor for comment. In the light of his comments some modifications were made.
- A second translation test was done by given to another translator to corroborate the translation and later translated back into English. It was tested by Libyan professional to ensure that it had not lost any of the original meaning and to check this translation again corresponds.

6.3.3. The Pilot Study

A pilot survey was conducted to examine the validity of the questionnaire, (Evens, 1984) stated; "A pilot study serves more than one purpose. In the first place it gives a chance to practice administering the tests. Secondly, it may bring to light any weakness in the procedures of Administration", (Oppenheim, 1992) supports this idea. Accordingly, before the survey was carried out the researcher piloted 15 copies of the questionnaire (Arabic version) with Libyan occupants living in the chosen residential tower buildings. The aim of the pilot survey was to test the questionnaire and to identify the inevitable problems of converting the questionnaire design into reality. This involved comments about the language, suggested modifications to the questions and additional questions as well as obtaining experience of certain aspect of the survey. The pilot survey sample amounted to 5% - 10% of the actual sample studied later. The analyses of comments obtained from the reviewers have been very helpful for improving the design of questionnaire. The following modifications were made to the field study.

- some important questions had been added after reviewing what else the occupants think it is important for their comfort; the design, form and structure of some questions were also changed;
- the pilot survey led to changes in the wording of some questions;
- the length of some questions was found to be undesirable;
- to reveal weaknesses in the questions posed in order to improve their effectiveness;
- order of questions. Useful conclusions were also drawn about the survey procedures and the time needed to conduct the survey.

Table 6.1: summarizes some basic characteristics of the 12 Multi-storey buildings

Case study buildings	
Number of building	12 blocks
Buildings mode	mixed-mode & natural Ventilation
Avg. occupancy/flat	6 individual
Avg. building age	40 years
Avg. building floor area	410 m²
Avg. floor area per person	30 individual
Number of survey sent out	337
Number of survey respondents	260
Avg. response rate	77.1%

Out of 337 families surveyed, 260 questionnaires were successfully filled (details per building is indicated in Table 7.3 below). The average response rate was 77.1%, where it was higher in the cases and normal in some others but never was low at any cases. People respond to the survey was in general good as just 7 flats refused to respond and 14 questionnaire came back empty as some people state they were busy or it is not easy for them to judge their feeling towards comfort, so these copies were left out even with some questions were filled. Furthermore, as stated early in this research that this subject of thermal comfort is new for people in the case study area so data on 9 copies was incorrect, and people show misunderstood the questions despite they have been given explanation and answers from the survey team . In the case of collecting the questionnaire, 42 cases were not in their homes and even with many attempting to reach the occupants; the survey team had not succeed to do so.

Table 6.2: Results of field survey of the 12 case study buildings in details

	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	Total	%
Sent out	24	43	43	21	28	24	21	25	32	32	32	12	337	100
Filled	15	36	33	17	25	20	16	19	24	21	26	8	260	77.1
Empty	3	1	3	1	3	0	1	0	0	0	0	2	14	4.2
Refuse	0	0	0	1	0	2	0	3	0	0	0	1	7	2.0
Not return	4	6	5	0	0	2	4	3	7	4	6	1	42	12.5
Wrong data	2	0	2	2	0	0	0	0	1	2	0	0	9	2.7

An attention have been paid to study one sample of each building groups organized by blocked faces. So there will be 4 groups, (isolated building, 1 side blocked, 2 sides blocked and 3 sides blocked) that are to be simulated in computer model as shown below;

Table 6.3: Selected buildings for further study and examination

Building type	Blocked direction	Building name	Building code
Isolated building	Non	ZATOAT building	B7
One side blocked	North	BURJ ALSHATI, S	B2
One side blocked	South	BEN TAHER	B6
One side blocked	East	ARHEAM building	B8
Two sides blocked	North & south	ALMAJRI 1 building	B4
Two sides blocked	West & south	ALWQAF building	B10
Three sides blocked	South & west & east	BURJ ALSHATI, N	B3

6. 4. Observations

Observation is a technique of data collection in which the situation or the behaviour of research subjects is watched and recorded without any direct contact (Bryman, 2005). This method is used in this study as firsthand information about the features and site layout, forms, construction materials, and social issues. The information of these features is not gathered only since the beginning of this research, but also through living in the case study city for many years. All of these data helped in formulating and defining the problem in this study. In addition, these data drew clear picture about the studied buildings also helped in chosen the case studies buildings besides playing an essential role to find the most appropriate and possible solutions from architecture view.

Table 6.4: Information needed to be collected and their purpose

Information to be collected	Methods of collecting	Aims and purposes
A. Physical properties		
1. Physical size of the building and its flats	Plans from the region municipality and engineering offices.	To find out the building's area and surfaces area in order to know the amount of exposure on the building.
2. Type of buildings' material	Physical observation.	To determine the different types of materials used in order to estimate the building's performance.
3. Buildings' orientation	Plans from the region municipality and engineering offices.	To measure the average of sun exposure received by each direction.
4. Spaces and zones of the flat	Plans and questionnaire	To located the spaces in relation to the sun and calculate their energy consumption.
B. Energy consumption		
1. **Amount of energy that is consumed by each flat in summer & winter**	By reviewing the questionnaire and take in account the number of electric appliances and sources used in each flat.	To calculate the average consumption per flat also to find out the season differs between summer and winter.
2. **Source of energy used in each flat.**	From the questionnaire.	To know the percentage of energy used in cooling or heating with respect to other.
3. **Different cooling or heating systems used in each flats**	From the questionnaire.	To see the different probabilities of energy consumption.
C. Thermal comfort and user behaviour		
1. Number of occupants	From the questionnaire.	To measure the energy consumption with respect to their level of comfort.
2. Level of comfort	From the questionnaire.	To find out the relation between the family size and the energy consumed beside the comfort level.
3. User's behaviour towards using windows and balconies	From the questionnaire.	To see the level of using the natural ventilation.
4. Using natural means	From the questionnaire.	To discover the effect of opining size and orientation.
5. Adapting and using the Air Conditioner (A.C) system	From the questionnaire and observation.	To know the preferable environment to users and weather they are considering about their energy consumptions or not.

6.5. THE SIMULATION SOFTWARE

Developed criteria are applied in choosing the most appropriate thermal modelling programme for this study. These criteria are as follows;

Required Outputs

The first and most important criterion in selecting thermal modelling programme is the capability of the programme to deal with the required application as well as to provide the basic needed outputs. In this study, the selected programme must at least be capable of predicting the internal conditions such as temperature and humidity, estimating the heating and cooling loads, assessing the thermal comfort, and examining the performance of alternative constructions to achieve better indoor thermal environments and lower energy consumption.

Accuracy

As a general strategy, it would seem reasonable to aim for a high level of accuracy. The accuracy of various programmes was checked through; identifying the thermal analysis calculation method on which a programme is based, considering the limitations of each programme, and assessing the level of modelling details demanded by the programme as input data. The levels of details required by various simulation programmes are different. Part of the input data of the simulation is sometimes fixed or hidden from the user. For example, in Hevacomp software some of thermal properties of construction materials which are provided in the fabric data interface are allowed to be edited, while other properties such as thermal conductivity and specific heat are hidden. For the purpose of this study, the main thermal properties of construction materials should be available to be controlled and edited in the data input interface.

Simplicity and Ease of Learn and Use

Building energy simulation tools require a great deal of time to learn (Kim and Stumpf, 2011). The ease of learning a programme is influenced with; the quality of its user's manual, the availability of a support system to answer questions, as well as the complexity of input procedures. After gaining sufficient experience, the need to obtain and enter a complex set of input data into simulation programs continues to consume the time. Many packages can access data libraries which assist in preparing the needed inputs. As several cases (12 buildings) are to be entirely simulated in this study, simplicity to deal with the computer programme should be considered in selecting the appropriate one. However, it is impossible to achieve the optimum level of comprehensiveness and ease of use in the field of building thermal simulation (Clarke, 2001). Consequently, thermal modelling programme has been selected in this study with the intention of finding a balance between ease of application and comprehensiveness with emphasis on the minimum requirements mentioned earlier.

In view of the above, the step of chosen TAS for simulation was based on the availability of this software as well as the complete knowledge of using it. The thermal modelling programs that were available to the researcher were Ecotect and TAS, EDSL and because the researcher had some experience with Ecotect, the first analysis was undertaken using this software. However, it did not reach the required standards as its fundamental approach. Also, it has been found that TAS is more comprehensive in providing the required outputs, particularly estimating heat loss/gain for each component in the building separately. In addition, TAS is based on a calculation method which is more accurate than that of Ecotect and after doing some tests such as solar gain and ventilation, Ecotect revealed some limitations which part of them could be related to the admittance method which the programme is based on. Moreover, TAS database (especially the construction database), is richer than that in Ecotect. On the other hand, input process in TAS is more complex and more time consuming than in Ecotect, and no free student licence is available for TAS and the researcher has to purchase a licence each year. Therefore, although TAS is more complex, it is selected in this study as it is overall more comprehensive, more accurate and because of its ability to simulate the thermal performance of buildings using as fundamental approach dynamic calculation based on the response factor method. The main functions of the software are for the assessment of the environmental performance of the building, prediction of energy consumption, natural ventilation analysis and others more such as Thermal insulation, solar gain, thermal capacity (thermal mass) and built form and orientation. The program output is a series of hourly shots of the thermal state of the building throughout a typical year based on weather data selected by the user. It allows the testing of the influence of many thermal processes that may occur in the building and presents a comprehensive picture of the way it is likely to perform. Also, the software is divided into 2 parts, the TAS 3D Modeller and the TAS Building Simulator. The building's geometry is modelled in the first part then exported to the simulator, which simulates the thermal performance of the building by assessing;

- Conduction in the building's fabric using a method derived from ASHRAE response technique,
- Convection at the building's surfaces using a combination of empirical and theoretical relationships taken into account temperature difference, surface orientation and wind speed,
- Long-wave radiation using the Stephan-Boltzman low using the surface's emissivities from the materials database,
- Solar radiation (direct and diffuse) absorbed, reflected and transmitted using the solar data in the weather file,
- Internal conditions including gain from light, equipment and occupants as well as infiltration rates and plant operation,
- Gain considering radiant on the surface and convective into the zone's air portions,
- Infiltration, ventilation and air movement between zones and respective thermal transfers, taken into account air flow rising from wind and stack pressures,

- Solar radiation through transparent components considering absorption, reflection and transmission,
- Heating and cooling plants with radiant and convective portions.

Equations combine all these variables and are then solved to determine the sensible heat balance for each zone, considering internal gains and the energy balance at the external surfaces. The latent heat balance is solved by taken into account latent gains, moisture transfer by air movement and operation of humidification and dehumidification plant. Simulations were run for each building beside many simulations were repeated to exam the building performance on the hottest day of the year also a whole year simulation to find out the annual loads demands of each building between the 12 ones. TAS software provides output in graphical and tabular form showing the effects of these factors on:

- Air temperature
- Mean radiant temperature
- Resultant temperature
- Surface temperatures
- Humidity
- Condensation risk
- Sensible and latent loads
- Energy consumption
- Required plant size

Although TAS was chosen for its accuracy in thermal calculation it is understood by the researcher that no simulation can predict exactly the real conditions, which are not just influenced by climate but also by people's actions and judgements. And so TAS is selected in this study as it is more comprehensive and more accurate, despite that it is more complex.

Analysis, Discussion on Survey Data and Results

Chapter 7 : Analysis, Discussion on Survey Data and Triangulation of Survey Result with Sites Micro-Climate

7.1. Introduction:

In order to gain actual statistical data of the case study buildings, a survey was carried out to collect this information. The survey was conducted on 337 samples in 12 buildings located in the city centre of Darnah. Other general information was collected by observation during the survey time, including information such as heights, areas and construction materials, all of which was useful in drawing a clear background about the studied buildings. The data collected in the fieldwork was sorted out in Excel sheets and AutoCAD drawings in order to be used as input data for the thermal simulation computer modelling. This information was also used as essential parameters in analysing indoor environment conditions and in drawing a sample for thermal simulation. The first section of the questionnaire was utilized to gather this general data which comprised the flats' area, number of rooms and number of occupants and families. Besides, the construction materials used in the flats were observed, along with exploring the integration of courtyards in these buildings. The results and findings are provided in the following subsections.

7.2. Occupants' Information

A cold environment is defined by conditions that cause greater than normal body heat losses. In this context, "normal" refers to what people experience in everyday life under comfortable, often indoor, conditions, but this may vary due to age, social, economic or natural climatic conditions. In addition, a physiological point of view shows that all three major cold defences which include shivering, vasoconstriction and thermal perception of cold, get compromised with ageing (Kenney, 2011). This would imply that older people would either like to keep warmer or will rate warmer environments more favourably (see Figure 7.1). However, the age effect on thermal comfort was not an essential issue in this study, since the study wanted to get an idea about basic states of residential conditions which includes occupants' health too, so they have been asked to express their feeling towards the cooling and heating means from a health point (see Figure 8.2). 45% of the responses indicate that the means used have good effects on the occupants, especially in summer time, and 30% of occupants cannot judge and say they do not know, whereas the rest are divided equally between bad effects and no effects at all. It is essential to confirm that the data in Figure 7.2 is based on the health state of each person in terms of their use of cool or heat conditions because observation shows that similar flats in size, level and orientation have different individual judgements. For example, case B10, which has the highest percentage of occupants over 40, reveals also the highest rate of "good effect" chosen when it came to heat means (see Figures7.7 and 7.8 for illustration of the type of cool and heat means).

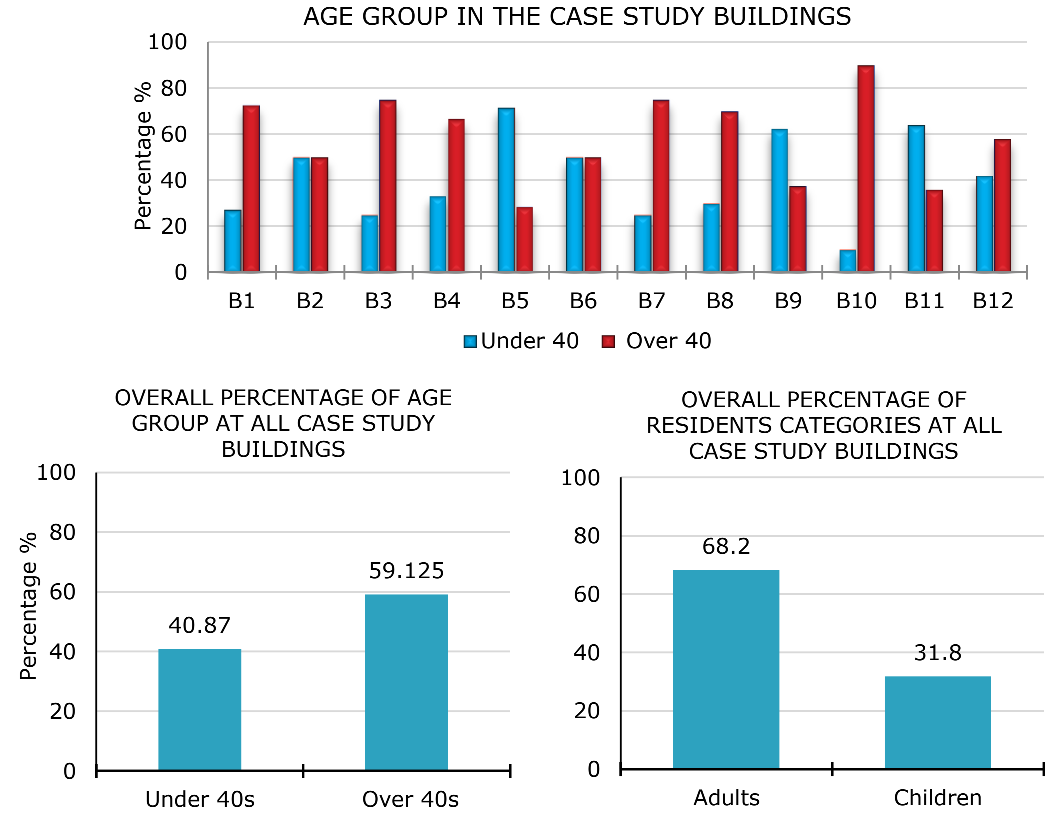


Figure 7.1: a) Age groups in a. each case b) overall percentage and c) type of residents in the case study buildings

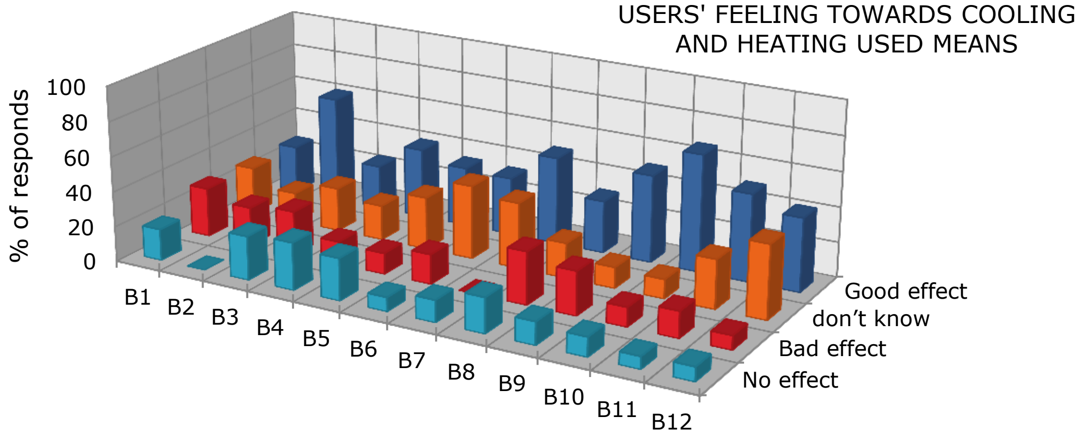


Figure 7.2: Feeling towards the used thermal means from health point measures by the case studies' residential

Table 7.1 shows that the longest period of living in 8 buildings was more than 15 years. This was recorded by occupants due to many reasons such as: very low rent, where these buildings are owned by the government and they pay low rent comparing with private rent (less by 75%); social reasons (e.g. their children used to go to the local school) even though the survey noticed that, in some cases, the size of flat was not suitable for a family size (see Table 7.2). In the case of building 2, there are many flats that used to be used as a Commercial office or an agency and just recently the city council changed the whole building to be a residential one as a part of re-organise the city plan. Other buildings 4, 5 and 9 used to be private owned by one family then 30 years ago those building were taken from the owners to be a government property. Figure 8.3 presents the number of flats in each building categorized by living period. Flats in these buildings are 87% rented and just owned by 13% of occupants.

Table 7.1: Period of living in the flat presented in percentage

	B1	B2	B3	B4	B 5	B6	B7	B8	B9	B10	B 11	B12
< 5 Y	18.2	33.3	37.5	50	45	30	12	40	3	3	23	9
5 to 10	27.3	38.9	12	40.8	14.3	25	5	40	60	20	20	33
11 to 15	9	16.7	10.5	2	10	3	10	10	12	10	2	16
> 15 Y	45.5	11.1	48	7	16	42	72	50	25	67	55	42

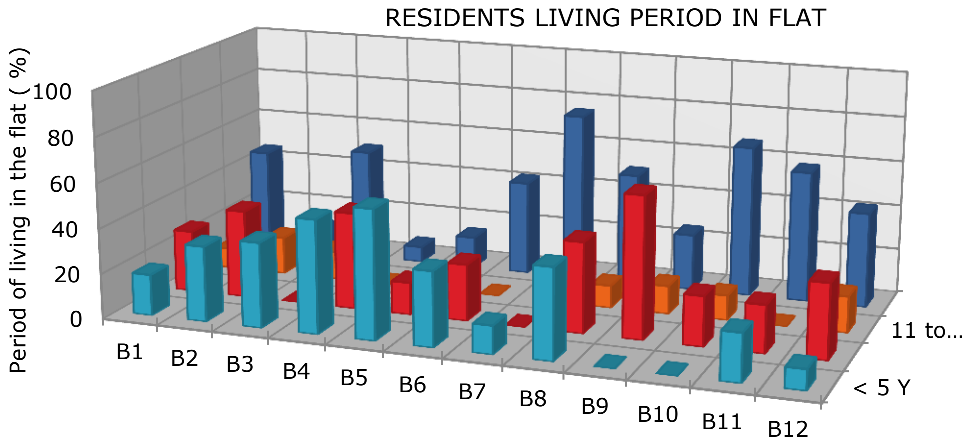


Figure 7.3: number of years living at case study flats

7.3. FLAT INFORMATION

7.3.1. FLATS SIZE

The area of surveyed flats ranged between 101-150 m² and 151-200 m² as presented in Figure 7.4, only in some buildings especially these flats owned by their occupants are designed to be more than 200 m² from the beginning to be as a family flat and the rest of block will be used as rented flats. Some buildings as building 1 were designed to have all size of flats to suit different size of family. Observably, issues related to design and early standard are not suitable with the average of family size in this country should be considered in order to offer more comfort environment.

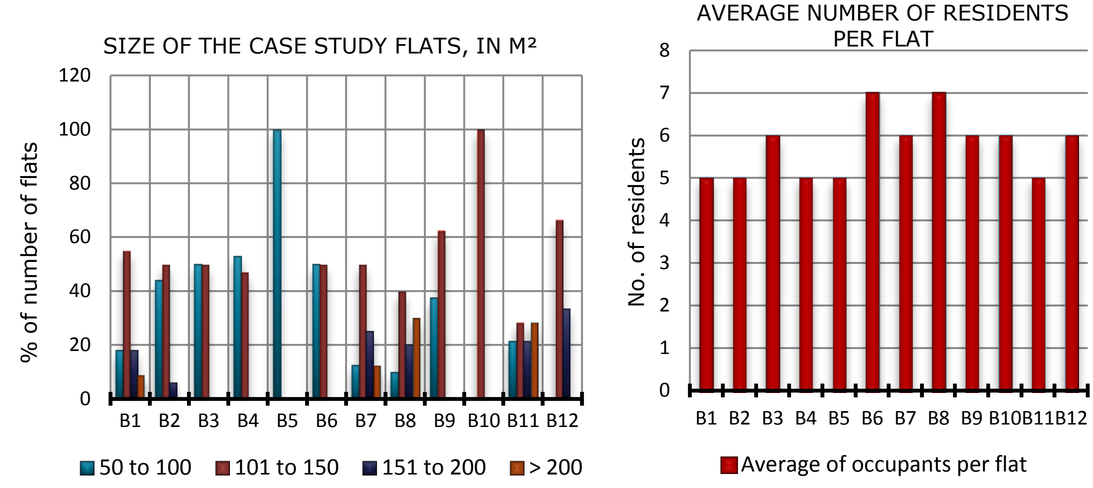


Figure 7.4: a. size of case study flats in meter square and b. average of people per flat

7.3.2. FLAT ZONES

Counting the number of occupants was essentially in this work because of importance of known about heat emitted by them, divided here by age (adult & children) to know the average use of their frequent use of space and appliances. As well as seen if the size of the flat suite their comfort or not. Case study buildings share same number of living room, guest room and kitchen, the difference was in the number of bedroom which depends on the size of the flat itself.

Table 7.2: general information collected about occupants and their homes

	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12
Number of residents living in the flat												
Adults	37	42	35	54	20	53	36	55	27	46	53	48
Children	20	44	9	24	13	31	14	12	18	9	19	23
Average people per flat	5	5	6	5	5	7	6	7	6	6	5	6
Number of rooms per flat (average No.)												
Living rooms	1	1	1	1	1	1	1	1	1	1	1	1
Guest rooms	1	1	1	1	1	1	1	1	1	1	1	1
Bedrooms	2	2	2	1	2	1	3	3	2	3	3	2
Kitchen	1	1	1	1	1	1	1	1	1	1	1	1
Average of last time painting the flat's walls (%)												
< 1 Y	18	28	37	33	57	42	50	0	0	12	28.6	16.5
1 to 3	46	39	38	40	0	33	12	20	25	22	37	50
3 to 5	18	22	25	20	14	8.5	0	40	62.5	36	35	18
> 5 Y	18	11	0	7	29	16.5	38	40	12.5	30	0	16
Average of last time refurbish (%)												
< 1 Y	18.2	5.5	0	20	28.6	8.3	37.5	10	0	11	7	8.3
1 to 3	9.1	5.5	12.5	0	0	0	25	0	0	0	7	8.3
3 to 5	9.1	5.5	0	6.6	42.8	8.3	12.5	10	0	0	21.5	8.3
> 5 Y	18.2	0	0	26.7	0	16.6	12.5	40	50	44.5	21.5	41.6
No change	45.4	83.5	87.5	46.7	28.6	66.8	12.5	40	50	44.5	43	33.5

Other data such as the average of painting or refurbish were needed to see the effort that people make their flats work efficiency with its environment, and if there is any efforts made to use new type of environment friendly materials. Many occupants did paint their walls on an average of 1 to 3 years and many of them have painted the external walls with bright colour to help minimize the overheating indoors. However, almost all of them did not change anything in their flats regarding to buildings' materials. The reason was that many of them are not the owners and so they cannot do any changes (Table 7.2 above).

7.4. Energy consumption

7.4.1. Energy resources

In this survey occupants were assumed to either be at home on normal day which start from 8:00 am to 10:00 pm where occupants are active and using most of the appliances whereas the other times they are assumed to be in bed where is the use of the energy is at its minimize and therefore the same period has been used in simulation using TAS software. Energy use was calculated within these times only as the rest of the time most of people will be in bed and energy use is at minimum level. The main energy resource that used daily for heating and cooling has been found to be the electricity and that also includes some appliances operation. The second source is the gas where is mainly used for cooking purpose, and a small percent are using it as a heating mean (4%). Variety in average values in Figure 7.5 is due to building size but the overall trend percentages are similar in all buildings. The other sources are not anymore used or the amount of use is really small and can be neglected even though these sources are cheaper than the other two resources (Electricity and gas) from the point of cost and charge.

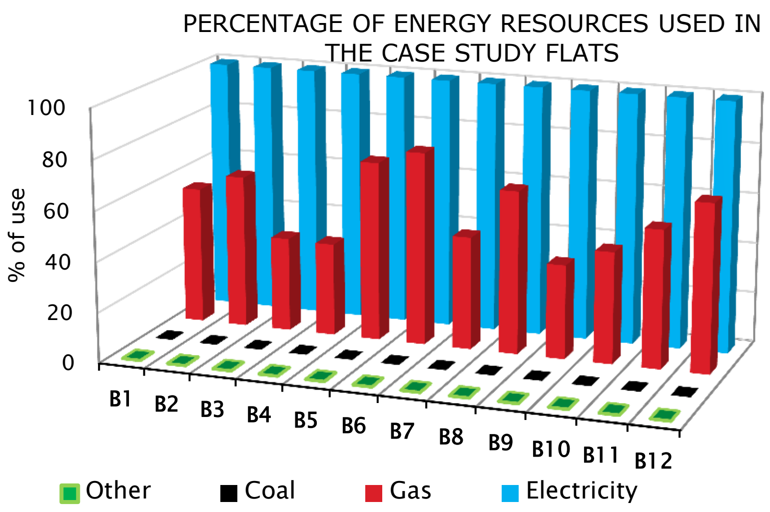


Figure 7.5: proportion of properties with different types of energy sources

7.4.2. Numbers of appliances

In order to get an overview about the level of energy consumed in these case study apartments, the number of appliances was included in the survey. The result is illustrated in Figure 8.6. Almost all the occupants are using the necessary appliances where the percentages of owning a TV, a Fridge or a washing machine are the highest in all the case study flats. Also, the amount of using gas resource in cooking is more far from using electricity in cooking that is because in general, gas is cheaper than electric for cooking in Libya, about 86% using gas cookers and just around 14% using electric cookers. The proportion of using cooling mean such as an A.C and a fan ranges between 69% and 26% respectively even with their knowledge of that the air condition is a high energy-consuming device. According to US department of energy (online source) air condition uses an amount of wattage at 2000 to 5000 watts where a stand fan uses between 100 and 500 watts. Percentage regarding to the use of heat means representing in the electric fires was a low value of about 31% in winter comparing with the use of air condition in summer that might as a result of the warm winter there also as shown in people responds where they state that they feel more comfortable in winter than summer months.

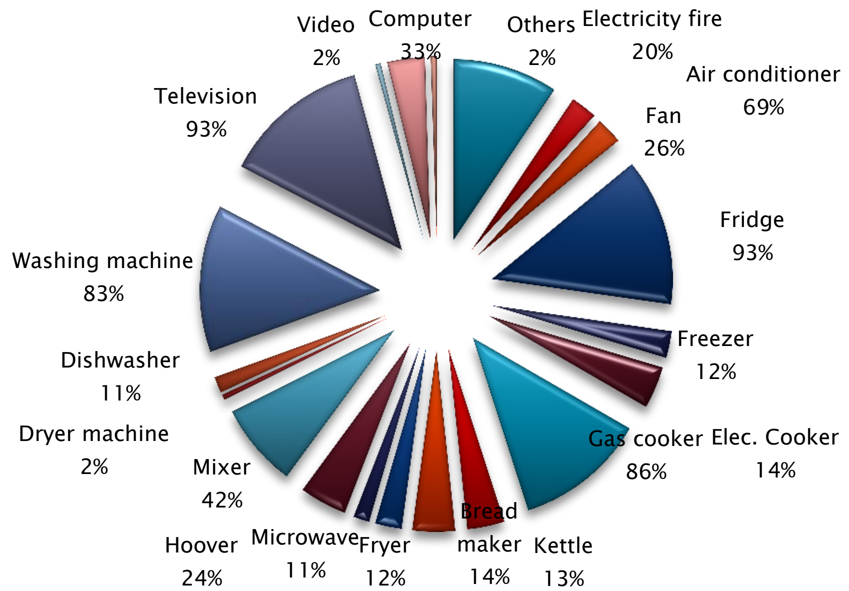


Figure 7.6: Percentage own and use of domestic appliances as an average percentage of Appliances per building

7.4.3. Level of Energy Consumptions Used

The level of energy consumptions were recording to the occupants nearly reasonable for all flats that have been surveyed. Figure 7.7 shows the results for all buildings regarding energy consumption in their homes. Spending level was found to present severe overlap with those stating their use as reasonable or low. Observing the responds these was a strong connection between household with air condition use and high energy consumption which led to that almost all energy consumption come from electric source.

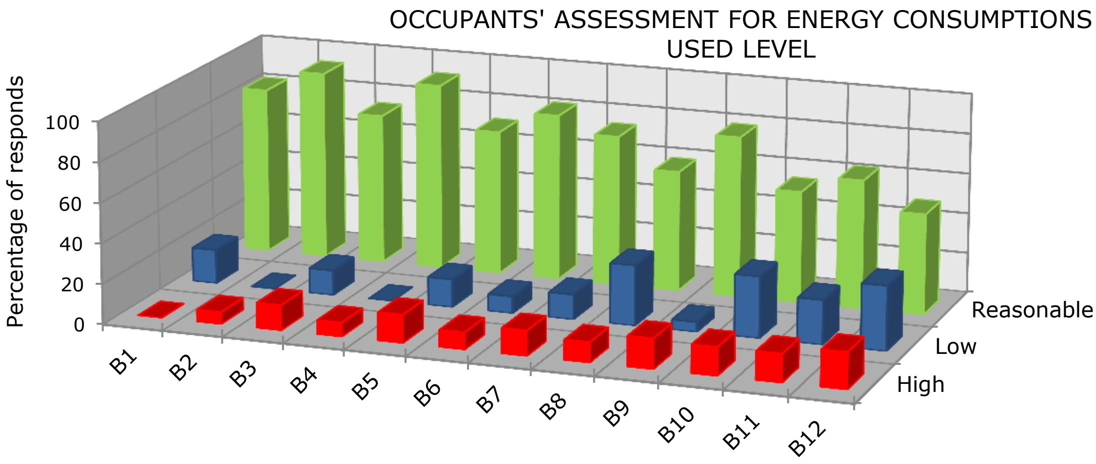


Figure 7.7: Perception of respondent to the level of energy consumptions used in their property

However, simply this measuring of the occupants may not necessarily provide the reality and thus have consequences of been not able to know the real level of consumptions because of some barriers faced this survey such as people did not welcome given their electricity bills, some people who are using the air condition system admit having a high bill during heat season.

7.4.4. COOLING AND HEATING SYSTEMS

Several types of cooling methods are used in different spaced within the flat. People use these different types to maintain comfortable during summer days where in most of them the intense heat (especially in July, August and early September) makes activity and relaxation are impossible. For this reason, recently people adapt air condition to be their first choose and not surprise to find that 80% of people use air condition in living and guest spaces as these are the main rooms in the house where just 20% are still using portable fan and these cases fund to be in the buildings located just few meters from the sea. Another thing highly recognised is the use of natural ventilation which widely used in utility areas and also with rooms which have balcony or window that are facing the north or northwest. The survey, as presented in Figure 7.8, shows that an intensive use of cooling systems in hot season which related to the poor thermal performance of the building materials and lack of insulations. On the other hand, the survey related to heating means observed that almost all people stopped using some means of heating such as coal fire and gas radiators and just few still using the ones operated by kerosene. Figure 8.8 also indicates that the high level of use is the electricity means between artificial sources which used by 80% of them almost in all parts of their flats that because people think it is harmless to their health and with new technology it becomes safer to use too.

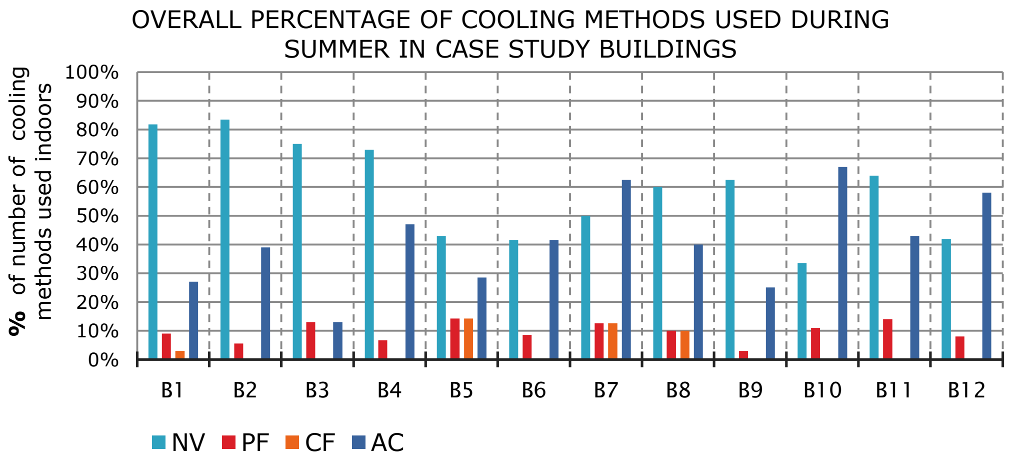


Figure 7.8: Percentage of cooling methods used during winter in case study buildings _ more details Figure at appendix 1.
A.C: air condition_ NV: Natural vent._ PF: Portable Fan_ CF: Ceiling fan

Figure 7.9 compares the percentage use of heating methods used during winter in each case; in general, the most used one was seen to be the electric fire. Some other are using air condition system for heat purpose and generally use it in living and guest rooms. In kitchen area occupants do not use any type of means as they rank it a warm place even in winter. In relation to space orientation, 85% of occupants do not use heat means in rooms that facing south and only use it in areas which blocked from south or east. Generally, people stated that they do not use their heaters all the time during the winter that because of the changeable weather where is cold in some days and not in others.

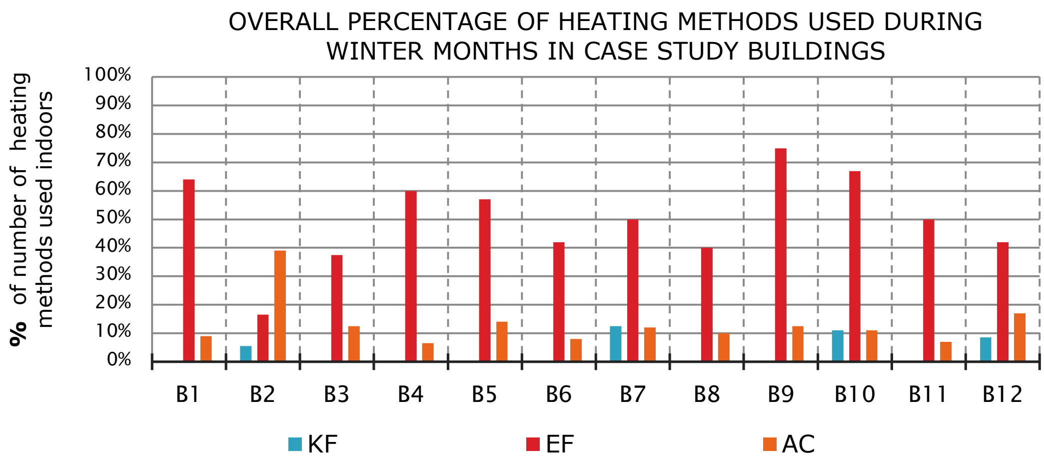


Figure 7.9: Percentage of heating methods used during winter in case study buildings _ more details Figure at appendix 1.
A.C: air condition_ KF: kerosene fire_ EF: elect. Fire

7.5. THERMAL COMFORT

7.5.1. SOLAR CONTROL

The hottest period of the day during summer is at late afternoon (13:00 to 15:00 hours) _ as stated by meteorological station of the city and explained early in chapter 5 of this research _ and since walls and roof stores the heat of all day time and as most of people are at home, basically occupied the space and gathering for lunch beside other daily activities. These reasons make the responds, as tabulated in Figure 7.10, show a lot of discomfort in this space especially if the space has a south or west window. Nearly 85% prefer to use curtains to prevent the heat and unwanted daylight from entering the space as illustrated in Figure 7.10. Investigation this high level of using curtains showed main reasons for that; it is fashionable, cheaper to install, easy for users to control for more privacy. However, some other means are also used such as climbed plants, horizontal and vertical blinds.

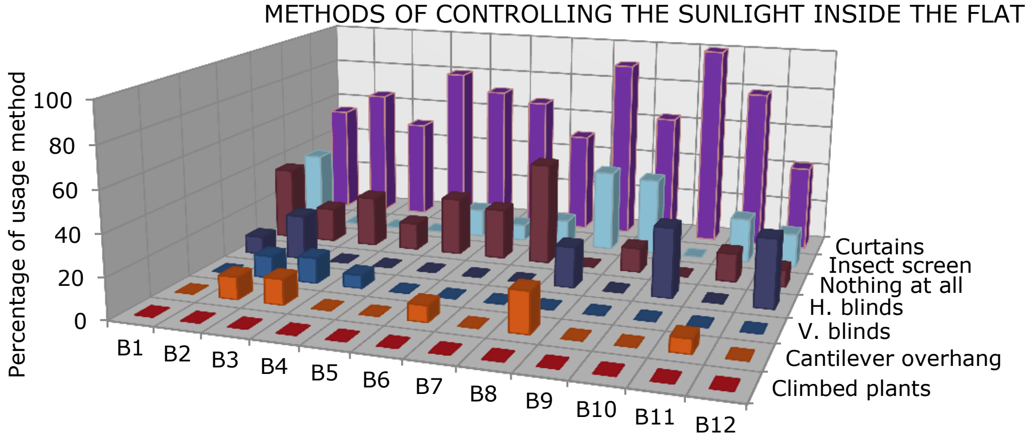


Figure 7.10: Methods of controlling the sunlight inside the flat

Although, the survey observed that few people know about the benefit of using curtains as a thermal mean also noted the lack of using external device in building design which are the most efficient thermally because they intercept the solar energy before it has entered the room. Thus, even if energy is absorbed by them, it is not trapped behind the glass. They carry the disadvantage of having to be weatherproof and are more difficult to control from inside.

7.5.2. THERMAL COMFORT ESTIMATION

Thermal environment, the main focus of this study plays the major role among the other indoor conditions in human comfort and has the greatest effect on energy consumption. Thermal comfort in flats was investigated, and reasons of discomfort in summer and winter were explored as well. Energy consumption for heating and cooling purposes was also inspected. And to test the sense of people towards thermal comfort, they have been asked to rate on scale of ASHRAE; hot, warm, slightly warm, comfort, slightly cool, cool, and cold. Occupants were advised to express their feeling away from their feeling with cool and heat means such as air condition or radiator. However, some mixed result came out and a close percentage appeared, for example in summer time the condition ranged between warm, slightly warm and comfort while in winter people felt even warm in some cases and specify the warm space to be the kitchen, conspicuously, this space in these case fund to be located on courtyard that is possible because of courtyards during winter can receive sunshine and less direct wind. Significantly, not all the spaces near the courtyards have recorded a similar condition. The reason is the orientation of courtyard which makes a big difference for the entry of both sun and wind (previously explained in ch2 & 3). Other reasons have been noticed of the mixed rate which related to buildings location and surroundings as well as the buildings materials and unavailability of insulations to help thermal performance of buildings beside the absent of shading devices. Consequently of these reasons the majority judged their flats uncomfortable warm and see that they could not cope with the long hot summer, which last from May to early October, without using a cool mean such as fan or air condition. General results of this question are discussed as follows;

In building B1 (fully exposed from north and east sides, and few meters from the sea) occupants in summer show a fluctuated rating of thermal comfort, their rating depended on the orientation of each space and weather it has a window opening on the sea or not, generally the survey marked hot to slightly warm feeling without using cool means. While the occupants feel cool, comfort and some rated their flats spaces to be cold. Figure 7.11 indicate that thermal comfort is not any easy issue to rate as people from same building rated their feeling in summer as feeling hot as well as felling cool. Whereas in winter a considerable number of people think that they are comfortable but at same building, particularly in kitchen zone, they never felt hot.

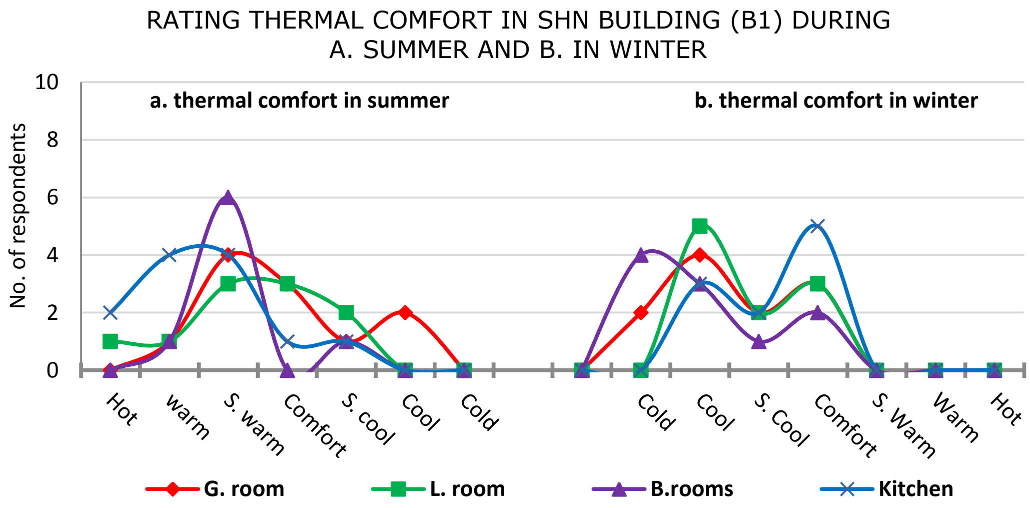


Figure 7.11: Thermal comfort at different spaces in a dwelling as rated by occupants in a. summer and in b. winter in the case B1 (SHA Building)

Building B2 has an external surface that is partly cover with mosaic, people rated their flats to be warm or comfort in summer and half of them rated the kitchen space to be hot where in winter they felt comfortable in general (Fig 7.12). This building (code: B2) is located just few meters away from the cost but blocked by building B3 from the north and open to south direction and yet there is some responds informing that they fell hot during summer time, spaces where they record they are uncomfortably hot is kitchen area. Observation uncovers that the kitchen in this building is located on inside atrium not more than 3m^2 and has a window with small vertical sliding (0.80 cm wide) with just small part open from the top part designed for privacy purpose, but unfortunately this window failed to provide a good ventilation or air circulation in the zone especially with the use of oven and cooker, whereas kitchen zone is shown the highest comfortable rate during winter. Figure 7.12 illustrates the occupants respond to thermal comfort through summer and winter.

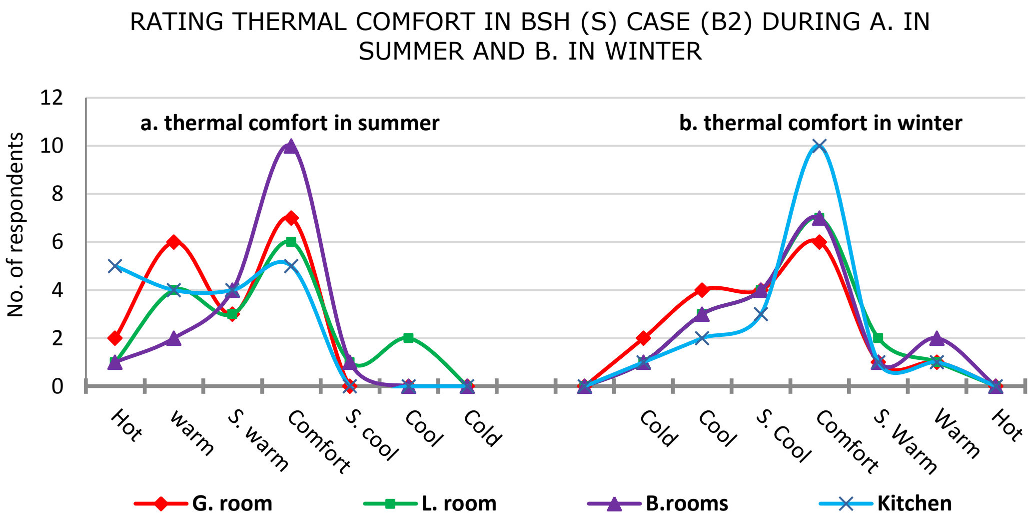


Figure 7.12: Thermal comfort at different spaces in a dwelling as rated by occupants in a. summer and in b. winter in the case B2 (BSH_S)

Result of building 3 which is adjacent to building 2 from the north and blocked from the east and the west by other buildings, shows little comfort signs in winter and occupants felt cool instead while in the summer they feel warm/slightly warm and in some places comfortable but never they felt hot unless its *Giable* wind (hot wind coming from Sahara).

As indicated in Figure 8.13 the rate of been comfortable during summer months is the highest among other buildings as might be as a result of this building located opposite to the sea and there is just a highway street between this building and the coast. In winter, unexpectedly most people rated that better comfort feeling as comfortable when it was predictable that the sea breeze would worm the ambient nearby and subsequently that will influence the winter temperature to rise a bit. In Figure 7.13 comfort feeling in winter fund in kitchen and bedrooms areas while in summer times comfort recorded in gust room and bedrooms as well, these bedrooms are located north and northeast directions. Occupants of building 4 rated their spaces to be warm, slightly warm and comfort during winter, while in summer occupants considered same spaces to be cool, slightly cool and other spaces like living area to be comfortable, living rooms of this building are located on a courtyard. Once more, variety in comfortable rhythm is shown in Figure 7.14 which proof the comfort depends on physical and emotional factors such as age, cloths, feeling and that explain the movement in comfort contour within a building.

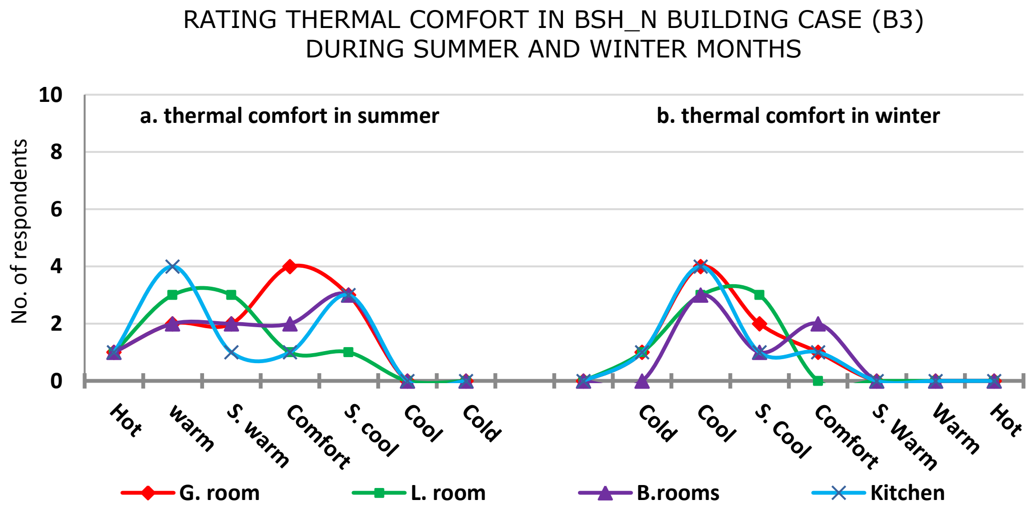


Figure 7.13: Thermal comfort at different spaces in a dwelling as rated by occupants in a. summer and in b. winter in Block No. 3 (BSH_N)

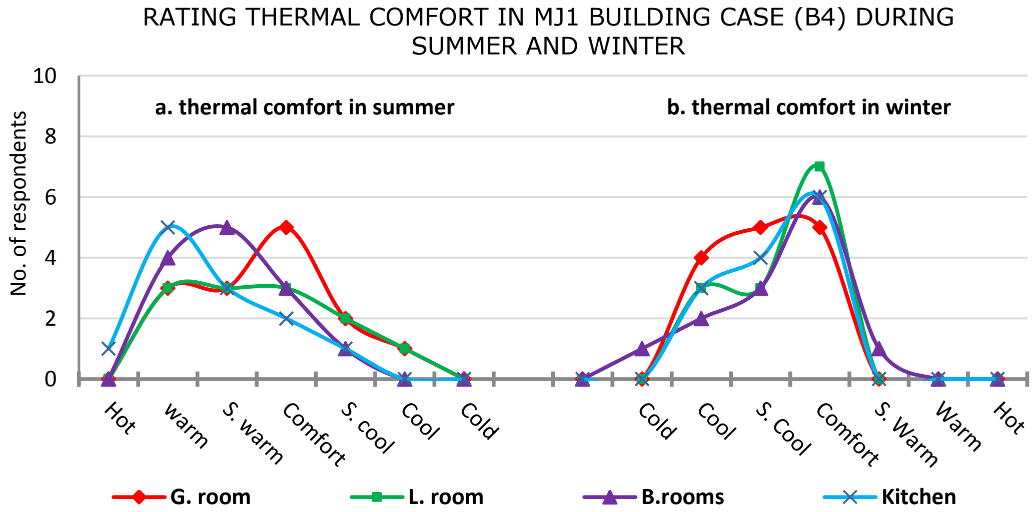


Figure 7.14: Thermal comfort at different spaces in a dwelling as rated by occupants in a. summer and in b. winter in Block No. 4 (MAJ1)

Regarding side blocked of buildings and here the example of a building which is blocked from 2 sides, building 5, the assessment of thermal comfort was little different even with the blocked sides are the south and the west where people find these directions the hottest one with reference to sun heat. People in this case building feel hot, warm and in some places comfort while in winter some spaces showed to be slightly warm in living rooms that are located on south side and kitchen zones are leaning between been a comfy to cool zone in this building due to its location on narrow street behind the building which work as wind channel and helps to drop the temperature slightly or considerably depending on wind speed (Fig 7.15).

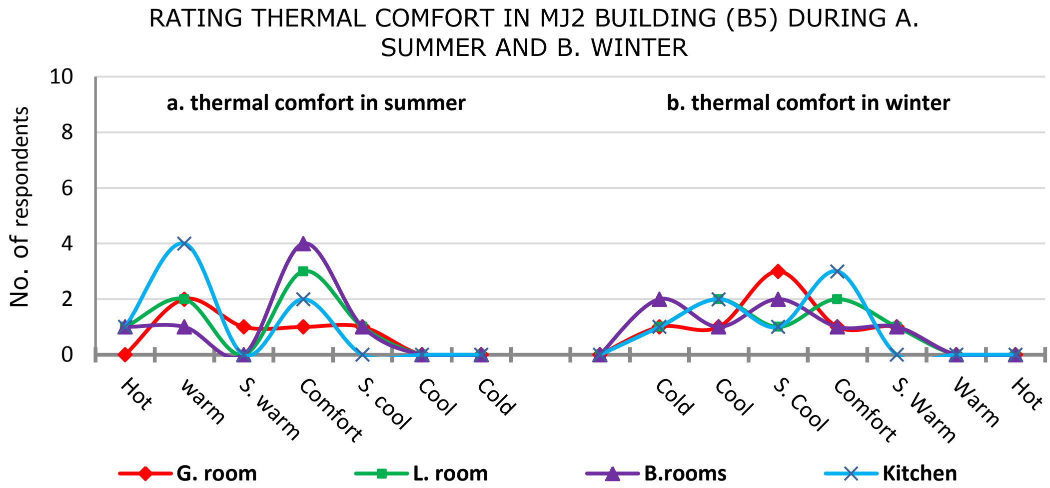


Figure 7.15: Thermal comfort at different spaces in a dwelling as rated by occupants in a. summer and in b. winter in case B5 (MAJ2)

Building 6 is also a similar case to building 1, except its surroundings are much lower than the building 6 itself. Thermal rate shows a general discomfort level in summer where in the living rooms for example show a high rank of warm were as reported by the occupants also same zones described as a cool zone during winter time. Observation finds that, the living rooms are located west and blocked by other nearby building from the north side. Building case 6 show a small level of comfort during winter when just cool; slightly cool and few feel slightly warm are claimed by occupants of this building during winter months. (See Fig 7.16)

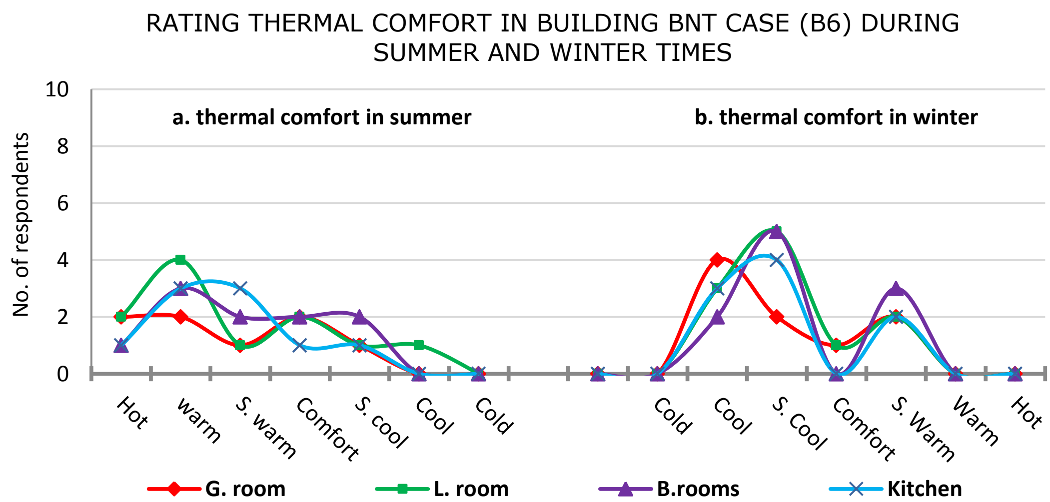


Figure 7.16: Thermal comfort at different spaces in a dwelling as rated by occupants in a. summer and in b. winter in Block No. 6 (BNT)

Figure 7.17 presents the thermal rate of an isolated building, occupants there rated their thermal to be fluctuated from hot to comfort in some areas such as guest rooms which generally located near the main corridor of the building with 3 internal surfaces whereas they feel cool and slightly cool in winter beside some rated the kitchen area to be a comfort zone.

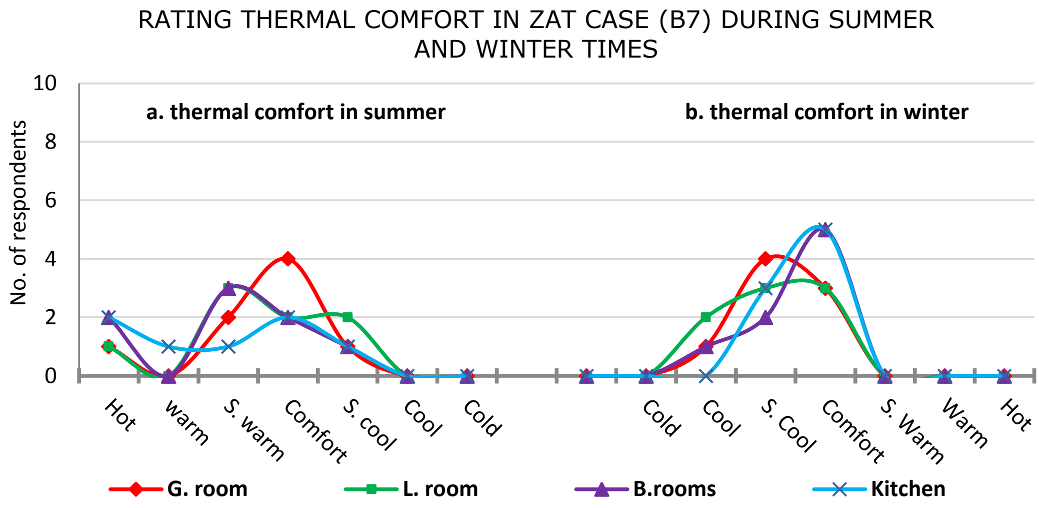


Figure 7.17: Thermal comfort at different spaces in a dwelling as rated by occupants in a. summer and in b. winter in building No. 7 (ZAT)

Other 2 blocked buildings from 2 sides one is building 8 (Fig 7.18) which is blocked from the east and south and the second is block 10 (Fig 7.19).blocked from south and west here people rated their spaces almost the same; slightly warm while in winter they felt cold or slightly cool in some areas but still rate the kitchen in building 8 as a comfort area.

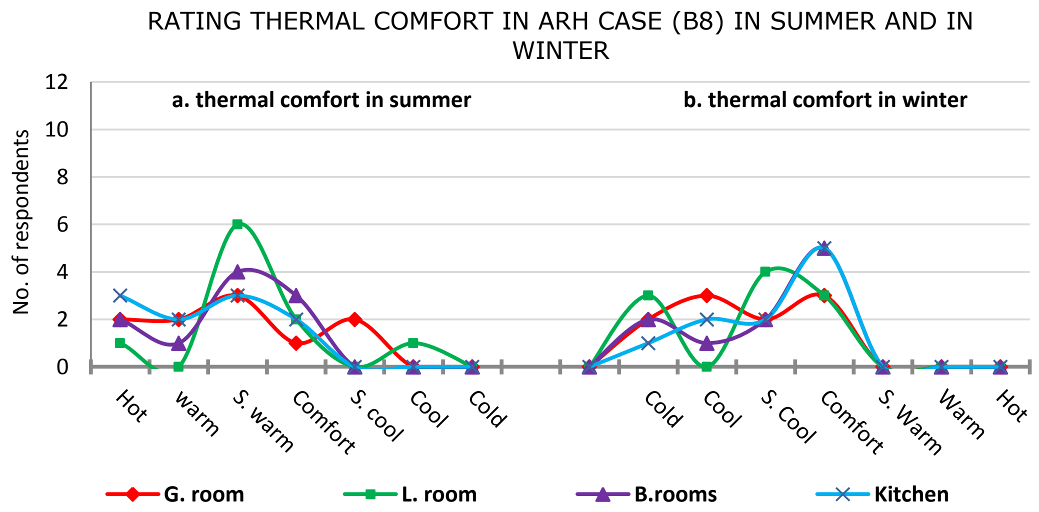


Figure 7.18: Thermal comfort at different spaces in a dwelling as rated by occupants in a. summer and in b. winter in building No. 8 (ARH)

Figure 7.19 shows the results for building B10 regarding comfort in main rooms of the flat, this is building the one it has a row of long tress blocked the southeast side. The majority of occupants here find that almost all rooms are comfortable and just minority number feel hot/warm in some spaces such as kitchens and living rooms that located on other side away from the tree sides, while, this building was found to be as a generally cool in such spaces during winter time.

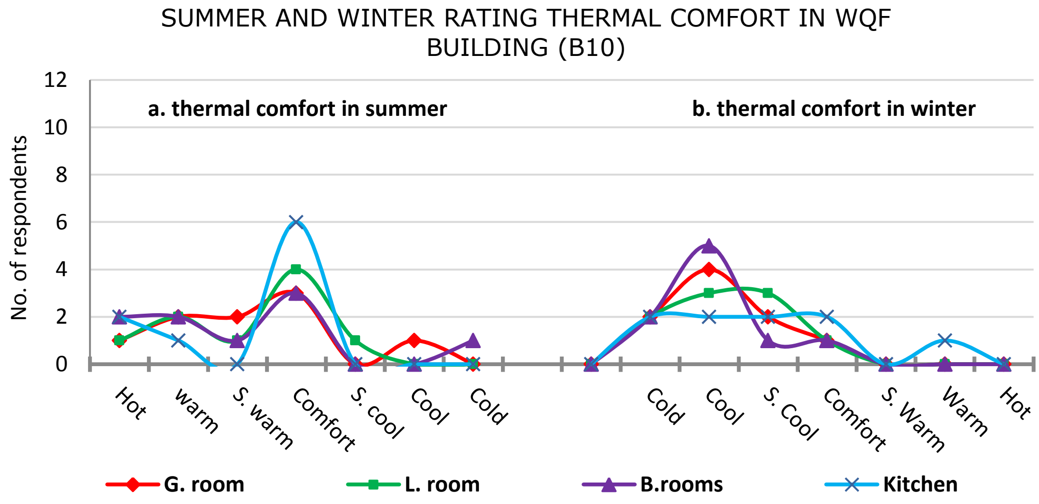


Figure 7.19: Thermal comfort at different spaces in a dwelling as rated by occupants in a. summer and in b. winter in building No. 10 (WQF)

The other three buildings are blocked from one side that is the south (Buildings 9, 11, 12) people here share the feeling of been hot or warm in summer and cold to slightly cold in winter however in buildings 9 and 11 there were few people who rated some areas as a warm or even a hot places during the winter, these areas were mostly the kitchen. However, in buildings 11 and 12 many people put some other spaces in comfort zone such as living room and kitchen areas. Figure 7.20 shows that the level of comfort drops in winter and people feel more comfortable in summer; for example, guestroom is a comfortable zone in summer but it is a slightly cool during winter.

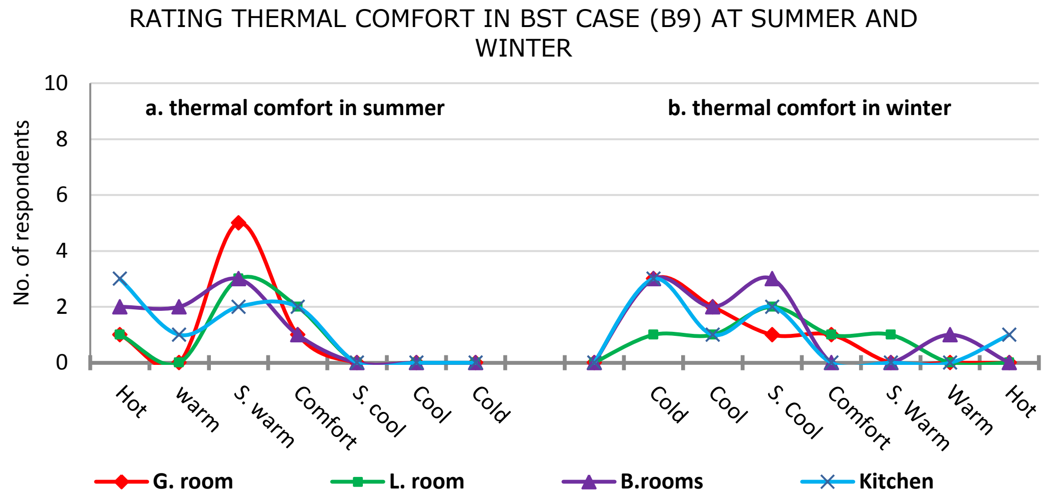


Figure 7.20: Thermal comfort at different spaces in a dwelling as rated by occupants in a. summer and in b. winter in building No. 9 (BST)

Similar trend here in Figure 7.21 in relation with building B11 and comfortable feeling even with more people feeling comfortable all through the year in summer and winter. All rooms shown that a high level of comfortable. This building is blocked from south side and has a narrow street on west side.

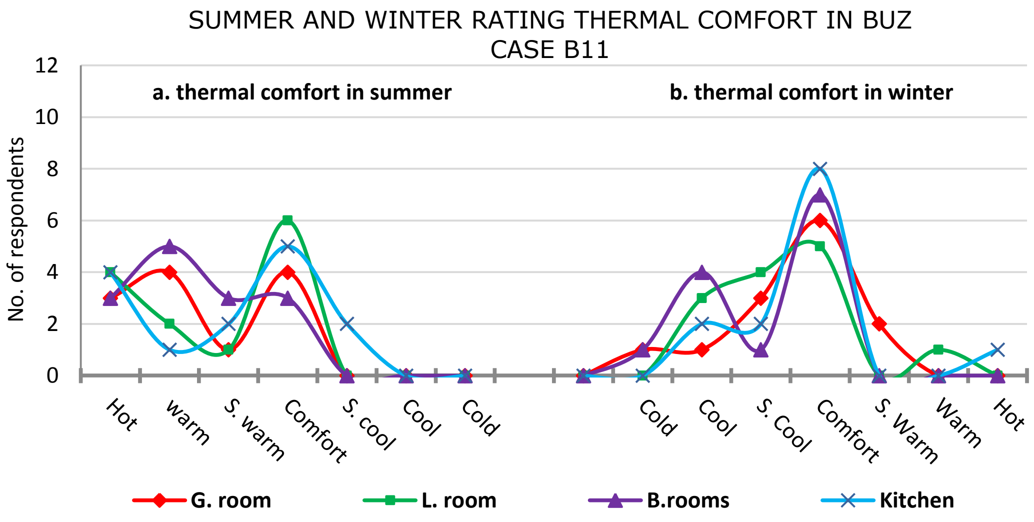


Figure 7.21: Thermal comfort at different spaces in a dwelling as rated by occupants in a. summer and in b. winter in building No. 11 (BUZ)

The last case study B12 has similar curve movement in both summer and winter. The building located in an open square in the city of Darnah and attached to exact high building from south side. In general occupants of this building rated their level of comfort as a comfortable one. Exploring the Figure, the only different will be that bedrooms in summer is warm than other rooms also occupants in summer will never feel cool or cold as they will never feel war or hot during winter as illustrated in Figure 7.22 below.

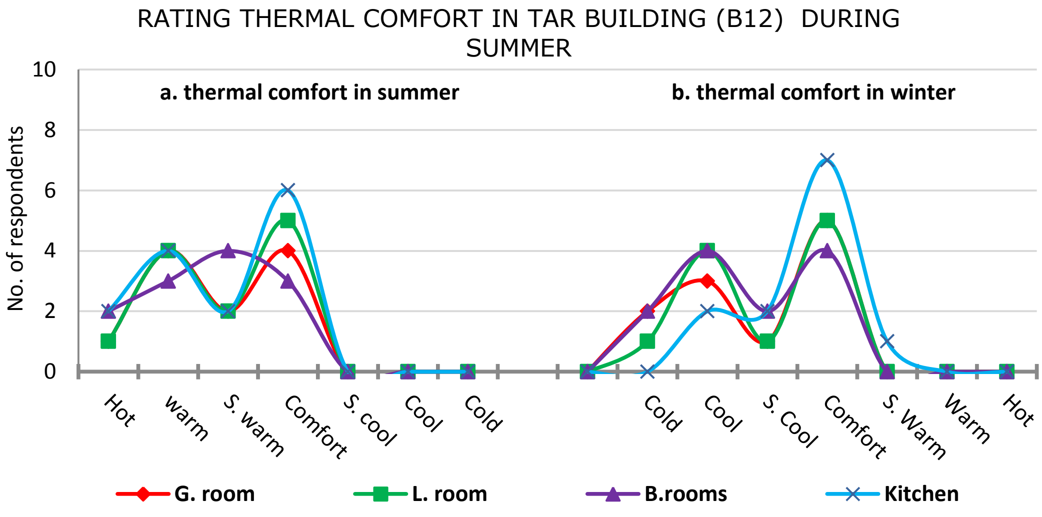


Figure 7.22: Thermal comfort at different spaces in a dwelling as rated by occupants in a. summer and in b. winter in building No. 12 (TAR)

The answer of a question that have been asked to occupants of top floor SE flat, (in your flat, which is the warmest room in the summer?), was at bedrooms and kitchen zones. Simulation results show that, the average temperature in these zones between 10 am and 18 pm is 31.1°C in living rooms, guest rooms and bedrooms while in kitchen is 30.4°C. To conclude, the above occupants' measurement showed that achieving a comfort condition is far complicated and do not depending only on orientation or building's surrounding the problem seems to be also related to the performance of building's envelope, materials, insulations and shading devices.

7.5.3. Cross Ventilation

Windows design and their using have great effect on indoor environment including thermal, visual, and acoustic environments along with their influence on building security and indoor air quality. In many areas, you can save money on cooling bills by opening up your windows in early mornings and evenings, when the temperatures are typically more pleasant. The survey detected a common use of cross ventilation in utility spaces (kitchen and bathroom); even in some cases people complaint about the lack of air circulation. The key, of course, is to have open windows (or voids) on opposite directions of the structure to allowing winds to circulate freely which is unavailable in almost all flats as the survey observed. Ignoring some designing details in early stage resulted in less benefit from natural ventilation; consideration must be given to apertures direction and the effect of air flows on the occupants. Figure 7.23 Shows also the use of other techniques in some buildings such as window fans which used just where the kitchen located on courtyard or alley to allow more air circulation, beside few use of ceiling fan and zero use of air condition because of that people believe it is expansive too use this system in a utility place.

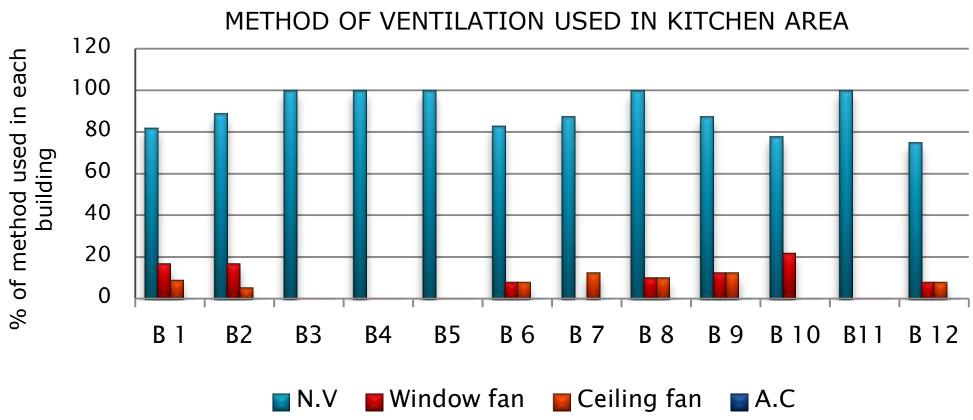


Figure 7.23: Percentage of ventilation technique uses in kitchen area

Figure 7.24 shows the use of cross ventilation, almost all people use their windows for cross ventilation during morning period and the number goes less towards night time. Occupants see that during the night it becomes cold even in summer time and they prefer to keep the windows close. In fact, the average diurnal temperature swing very quickly during the night and especially before sunrise and the building must have a good thermal mass performance to be able to use night ventilation without been discomfort in the occupied space.

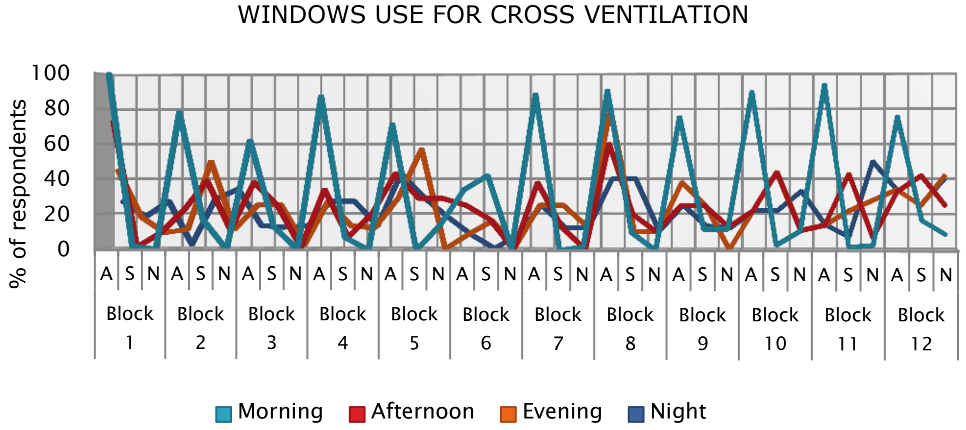


Figure 7.24: Percentage of cross ventilation use at different time of the day

7.5.4. Size of Windows

Windows are obviously one of the most important aspects of passive design as they control most of the solar gain, daylight and ventilation aspects of any design. And, so a large window can provide a better source of ventilation but can also be a source of hot air access. When considering the size of a window someone must takes into account the climate. In hot climate, large windows are preferable, but they should be shaded using overhangs, awnings, trees, shrubs…etc,. Relatively small and well located windows are better in strategies involving high levels of insulation. In the case of this survey, observations have been recorder such as missing of some insulation within the window itself such as weather-strips and a proper exterior shading devices. In the case study buildings, times and reasons of opening and closing windows in case study buildings were examined and analysed. Firstly, occupants were asked about the size of their flats windows. As presented in Figure 7.25 almost all people are satisfied with the size of their windows.

Figure 7.25: Proportion of people vote about preferable windows' size in relation with its orientation

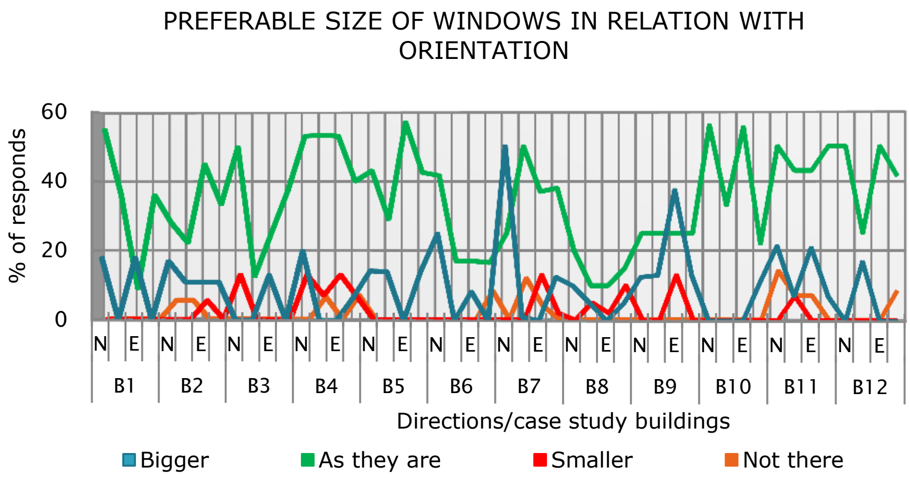
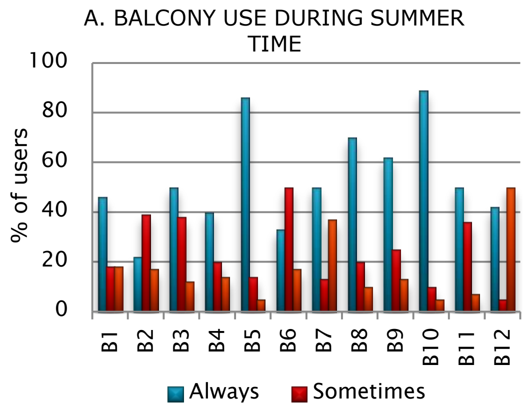


Figure 7.25 shows that only occupants of building 7 (isolated building) like to have bigger windows on the north side. Few people in buildings 2 & 11 wanted these north windows if its not there at all, there reason was that these windows is located on courtyard of these buildings and it affect their privacy. Occupants of building 10

show a complete satisfied with their windows' size despite the location of their buildings in the heart of the city with the high level of street noise. The survey noticed that people are not fully aware of the essential role of windows on their thermal comfort that because they ignore renovate or refurbish and many windows are not fully sealed. Old windows lose large amounts of heat to the outside during the heating season and gain too unwanted heat during the cooling season. According to USA Energy Department, over 25% of the heating and cooling energy bills in a typical home are due to inefficient windows.

7.5.5. Balcony Use

Balconies can be an effectively part in multi-store buildings that is because they help improve the uniformity of the indoor vertical air distribution in the middle and lower parts of most rooms (0–2 m level), which in turn is of great help in creating a comfortable environment. However, Balcony depth has a different effect on the heating loads for the various balcony orientations. South-oriented balconies have disadvantages in terms of limiting the heat for south facades that could be potentially entering the main living area especially in winter time (i.e. there are shading effects associated with these cases). On the other hand, north facades receive significantly less solar radiation than the south facades and for north-oriented balconies the thermal characteristics of the constructions are more important (i.e. to limit heat losses through them) than the shading effect that balconies may have on the main living area.



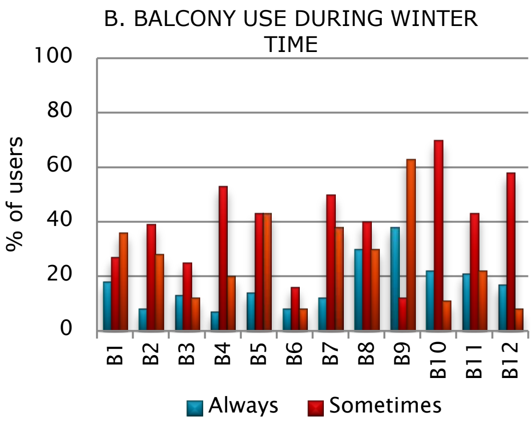


Figure 7.26: a. Balcony use during the summer, b. using the balcony during winter

In this study the majority of people use their balcony during summer time and almost all the day, just in buildings 2 and 6 the majority were using their balcony from time to time and not always their reason was having an A.C in the same room and prefer to use the A.C system then having a heat wind coming from the balcony usually these balconies are in south orientation. Whereas in building 12 many people are not using their balcony for different reason which is the noise that is coming come the close port on the north side. On the other hand, in winter as shown in Figure 7.26 above people are still using the balcony but less than summer days with some changes in how often, for example in building 10 the level of usage changed from all day to some hours during the day their reason is to block the cold wind coming from the balconies also to manage the speed of the air in their flat. The numbers of never opening are higher than those in summer time as seen in buildings 9 and 5, also it has been noticed the opening level in building 12 people are use their balcony more in winter because of slow traffic motion in the nearby port. From the point of thermal comfort, people tell that they use their balcony for air exchange especially in early morning and almost all of them (even those with A.C system) prefer to open their balcony on a hot summer night to enjoy the comfy breeze if there is any.

7.5.6. Air Condition Use

The use of air-conditioners has increased many folds over the last few decades in the country in general, this use is mostly confined to window or split units. Such buildings may be considered to be a type of mixed-mode building in their operation. The cooling systems are under direct occupant control instead of any automated controls. They have further observed that even among mixed-mode buildings, those buildings had more occupant satisfaction which provided greater degrees of direct control to the user. For occupants in these buildings, switching the A.C on/off is taken as just one more adaptive behaviour. And it does seem to have similar usage pattern as any other adaptive behaviour. What acts in favour of using air conditioning is its ease and effectiveness and what acts against it are the costs involved. Concerns for energy expense mean that an A.C is either used less, or maintained at a high temperature or used only when temperatures are too high for other adaptive measures. Observation finds that people in their homes used air conditioning intermittent and their first preference was opening windows. At the same time, there were a few replays of the survey where occupants rating their thermal sensation as slightly cool as they use the system more than 8 hours a day. In order to identify the use level of A.C system, the study asked occupants to specify whether they have A.C or not and if they have it for how long and what time of day they usually use it. Figure 7.24 shows the period of owning an A.C system, the result was that even the system is very popular in the city but surprisely, there is a respect number of people (36%) who do not have one when asked about the reason, recording to them that was due to many reasons, such as cannot meet the expense of it use; plan to buy it in next few months or year; its unhealthy to use it; my flat is facing the sea and not need it; or it is simply puts an extra load on their electric bills.

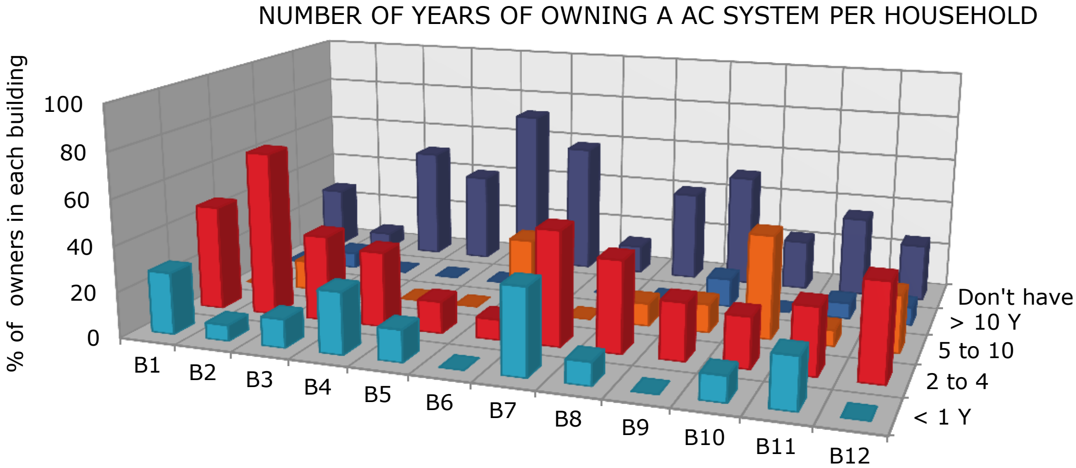


Figure 7.27: Percentage of people with no A.C system and other with different time of owning A.C system

The rest have the system for different period that shown on Figure 7.27 _ 14%, 35%, 12% and 3% respectively. Figure 8.28 shows the most operated hours and it seems that people rely heavily on A.C to reach the state of comfort during peak heat hours (13:00_17:00) where the temperature rise up to 32°C also, there are nearly 24 hours use on some summer days i.e. during the holy fasting month of Ramadan and during the hot prevailing winds season. Figure 7.28 shows the average use in summer time.

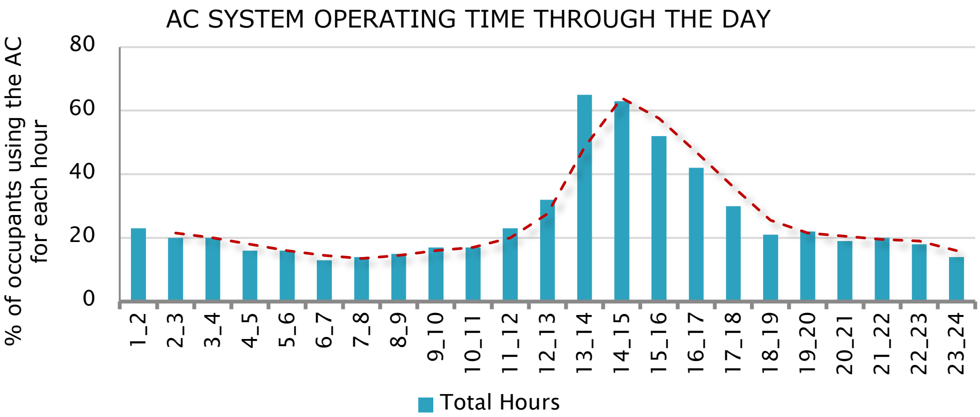
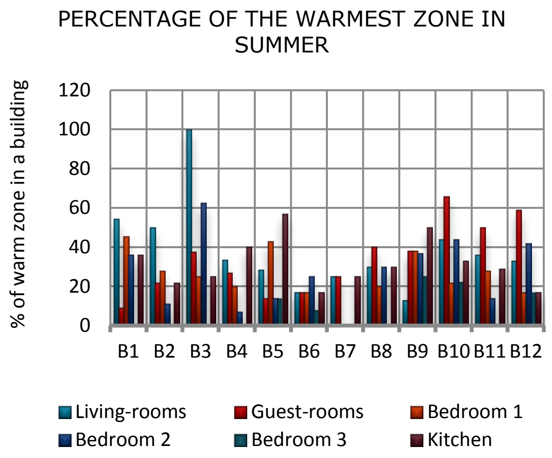


Figure 7.28: A.C use through the day in case study flats

7.5.7. THERMAL COMFORT IN DIFFERENT ZONES

Many reasons have been observed from been the warmest (or coldest) room in the flat by considering the location of these buildings, some of these reasons are south orientation; most of warm spaces are located on the south, but there were other spaces which located on east or west sides this leads to the next reasons which are inefficient building materials, absent of sun-shading devices also the size of windows or openings and its materials. These arrangement or improvements may not provide 100% climatic control, but they substantially reduce the task of the active systems in order to reach the comfort level in these spaces. For example living room in buildings 1, 2 and 3 located on south side but the guest room in building 10 located on east side and both of these spaces shown to be the warmest area in Figure 7.29 The living room in building 2 is the coldest in winter even its located on south side which is clearly shown the need for insulation and material's upgrading.



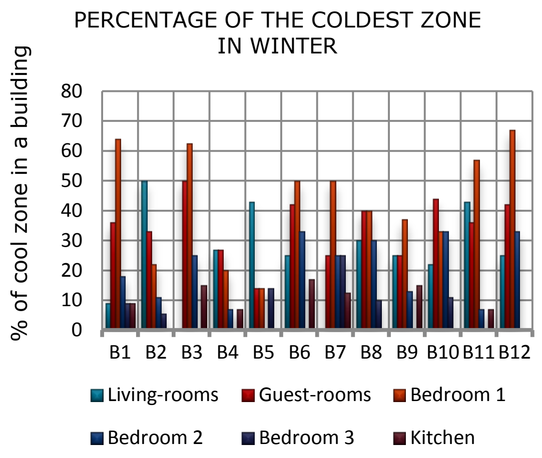


Figure 7.29: a. Warmest and b. coldest room in flat ranked by occupants during summer and winter times

The bedrooms revealed to be the coldest areas in winter in almost all buildings. Another reason for different ranking was floor height, where rooms in upper flats show more warm zones in one flat comparing with those in lower floor which they highlighted one or two zones and this was equally in cold season. Kitchen area shows to be a warm zone both in summer and winter that might be a reflection to its function and operated many appliances in same time. Obviously, uncomfortable zones encourage people to use more energy to cool down or heat up the space and this rise up the need for materials upgrade to cope with climate of the building.

7.6. THERMAL COMFORT

Occupants of each building have measured their comfort satisfied level inside their flats during summer time. Following is their answer in relation with blocked directions, height from the ground and number of family also the size of flats. In relation to blocked direction, there are 3 groups of buildings besides one isolated building. Buildings 1 and 10 blocked from one side south and west respectively while building 4 blocked from south and north sides. Figure 7.30 compares these two types of buildings from comfort level side, the estimation was slightly different where 60% of people in buildings 1 & 10 rated their flats to be in the comfort range while the rest are feeling discomfort. In buildings 4, which blocked from south and north, people are feeling more comfort and almost half of the flats are comfortable but there is 30% of the same buildings feel very uncomfortable.

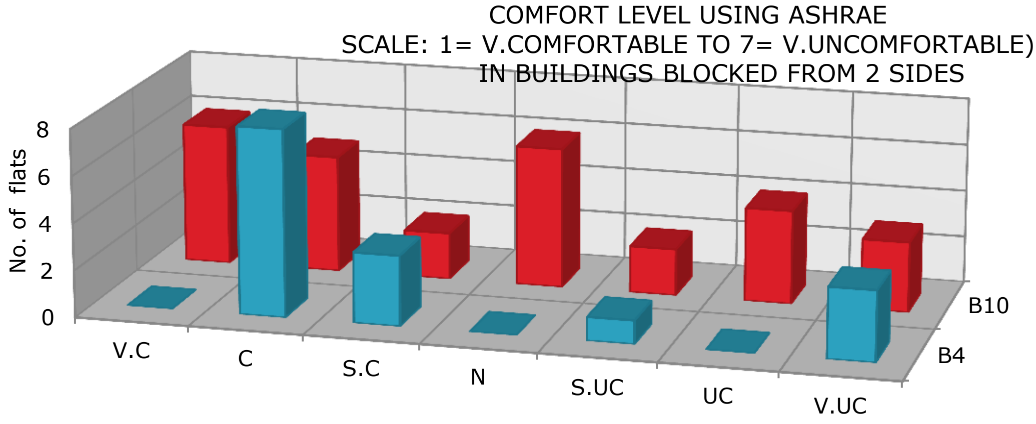


Figure 7.30: Comparison between different orientation buildings blocked from 2 sides from the point of comfort level

On the other hand, buildings that are blocked from three sides (south, east and west) show a similar result except the rate of uncomfortable where it tripled in building 3 as can be seen from Figure 7.31 below, this might be due to the high number of flats per floor comparing with the other building which resulted been located on a deep small courtyard that has no connection with the outside to allow a circulation path in order to promote ventilation inside the courtyard and thus the connected rooms, also it is typically been discomfort because solar gain is less affected here due to shading provided by the deep courtyard and many people will fell little cool although in summer time.

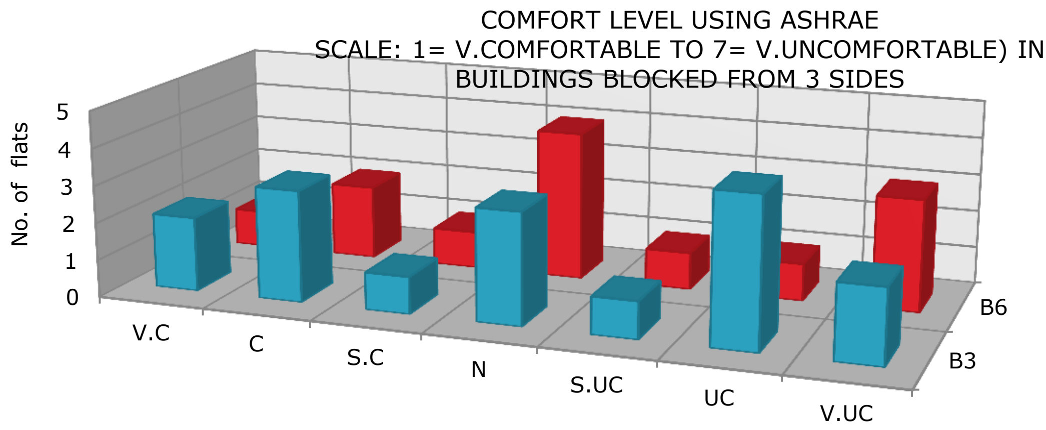


Figure 7.31: Comparison between different orientation buildings blocked from 3 sides from the point of comfort level

Looking at building with one side blocked, from the south, (buildings 2, 5,9,11 and 12) or building 8 that blocked from the east, it can observe that despite the number of responds there is clearly an agreement in level of satisfaction in these buildings. This leads to that orientation does has an effect on people comfort. It is well known that south direction got the most heat in both summer and winter and in these buildings case when this side blocked or shaded a high percentage of people rated their comfort between 1 to 4 (the range of very comfortable to neutral). See Figure 7.32.

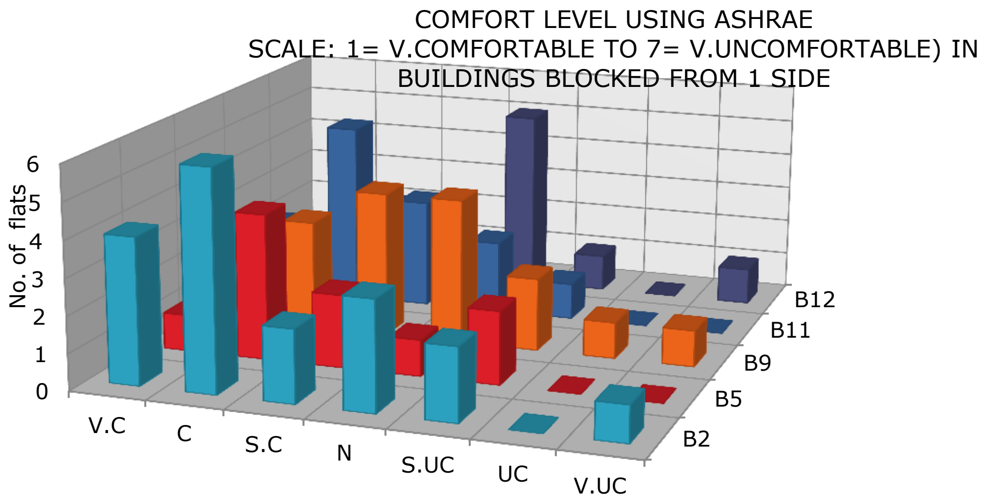


Figure 7.32: Comparison between comfort levels at buildings that blocked from one side

The isolated building which is building B7 shows a trend that shift slightly to be neural or comfort more than been very discomfort as seen in Figure 7.33. Observation show that, building B7 surrounds from west and southwest by a green land which improved little reflecting the heat coming from the sun and winds also work as shading device to lower floors (see Figure 7.34).

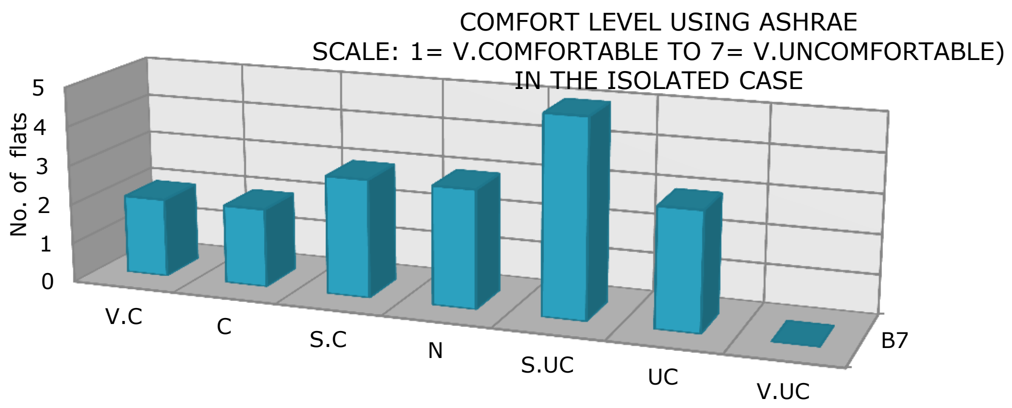


Figure 7.33: Comparison between comfort levels at isolated building

Figure 7.34: Photo taken from Google Earth shown the isolated case building also shown plan of the same case _ building case 7 code: B7

All of all, there are many elements that play a significant role on human comfort in these buildings, these are; orientation of the building and here it means the level of shading devices that needed in each direction also insulations in wall and roof especially for those in top flats which exposed directly to the sun without any material protection. Poor thermal performance of the building envelope normally affected the internal temperatures to react quickly to the variation of external temperature and lead to indoors discomfort. Table 7.3 summarize the result of occupants respond in relation with their satisfied level of comfort arranged by two groups; majority and minority.

Table 7.3: result of thermal comfort indoors in relation with blocked direction of the building

	Thermal comfort in flats as a whole		
blocked side	**Exposed side**	**Majority**	**Minority**
Non	4	Neutral	Slightly uncomfortable
One (south)	3	Comfortable	Uncomfortable
One (east)	3	Very comfortable	Neutral
Two (south & north)	2	Comfortable	Slightly uncomfortable
Two (south & west)	2	Neutral	Slightly comfortable
Three (south, east & west)	1	Neutral	Uncomfortable

7.7. Analysis of Discomfort

Effect of cross ventilation on discomfort

The survey showed that the majority use cross ventilation in kitchen area only and less than 20% use this method to cool their flats. Figure 8.35 shows the effect of cross ventilation on people's comfort, a correlation between been discomfort and using cross ventilation has been created using SPSS programme. Many of respondents open their windows in one area such as bedrooms to exchange the air during the morning period and they state that they close the doors in order to control air violence because of shutting doors. Obviously that will effect cross ventilation because this method improved when openings are well distributed horizontally or vertically and this cause air to flow between two openings at different pressure, even if they are both at a positive pressure. Results shown in Figure below indicated that buildings with high level of use the cross ventilation method (such as B1, B4 and B8) are the higher occupants that felt never uncomfortable during summer, however, some cases such as B2, B11 and B12 that have more of no use of cross ventilation than use of that method show also a higher percentage of never uncomfortable than those who fell definitely uncomfortable. This will lead to a second investigation in order to see if these responding are affected by the use of A.C. system.

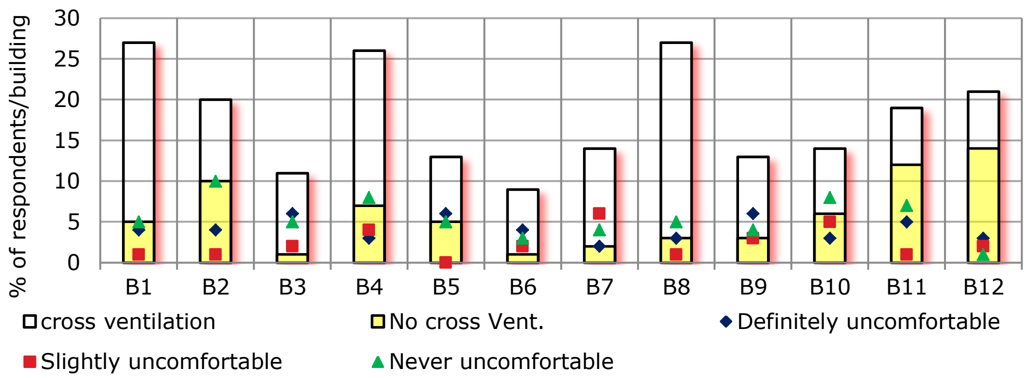


Figure 7.35: Percentage of respondents to the question of cross ventilation on discomfort

A second investigation in relation to A.C system and discomfort feeling was carried out. It has been clear that B2 has shown a small percentage of occupants without A.C and therefore people are relying on air conditioner and think they are never uncomfortable because of the present of this system. In general, case study buildings are found to be a heavily relying on A.C system during summer months where the highest percentage of flat with no A.C shown to be in case B6 at just 58.6% between the selected test sample of 15 flats per building mainly on ground and top floors.

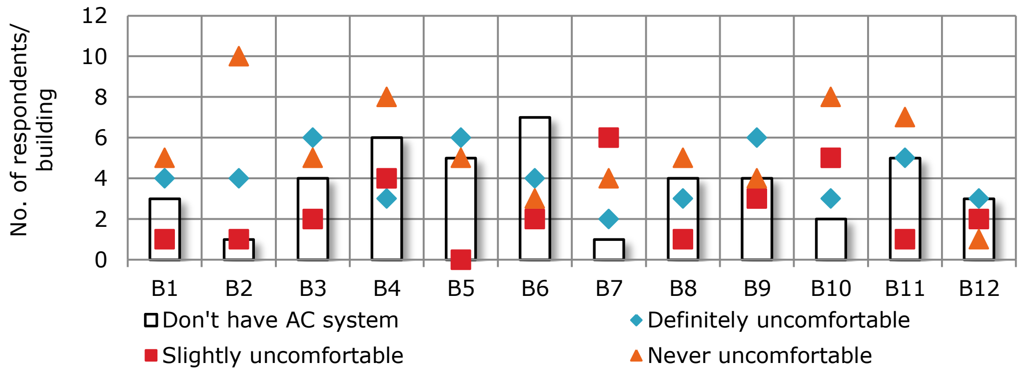


Figure 7.36: Number of respondents to the question of cross ventilation on discomfort in selected test sample of 15 flats per building

7.8. CHAPTER CONCLUSION

The main purpose of field survey was to answer these questions that related to the part of field work of this research as stated early in section 1.3 of research questions;

- What do people feel about their home?
- Which level of comfort is preferred by inhabitants and why?

Among numerous variables affecting thermal comfort, only outdoor temperature is considered in this research. Moreover, the experiment was not done during extremely hot or cold outdoor temperature. Nevertheless, outdoor temperature has an effect on thermal sensation. Even though, thermal comfort is a difficult issue to measure especially in place like the case study city of where people do not use to hear or talk about this term of environment (actually some people preferred to use "just right" instead of comfortable). Therefore, some responds cannot rely on their accurate answer and for this reason a question was address to occupants to tell how sure they are from their answer that regarding to thermal comfort and a need for simulation as satisfying all occupants is depend on personal characteristics.

Some important survey results are summarized below;

- Although, the occupants of the case study buildings cooling means in summer such as air condition a good number of them still think that these means have a bad effect on their health but they need it to feel more comfortable in their home.
- Aspects such as flat size and number of rooms show an essential effect on people responds where occupants with bigger flats tend to be more comfortable in summer than those in small ones similar to room numbers aspect.
- Regarding to internal heat source; apart from light and people, people use of appliances tend to take a very reasonable level when almost all flats use the main appliances such as TV, Fridge and gas cooker.
- The first source of energy is shown to be electricity, however, almost all of responds state that they use gas as their first choose for cooking purpose. High electricity cost come from A.C system as people using this cooling method tell that their energy consumption is quite high comparing with those how do not have A.C. Beside, people who use Air Conditioner are 64% from all the chosen sample and 62% of those are using the system in a normal summer days up to 8 hours a day, and almost all of them are using the A.C between 13:00_14:00 hours up to 17:00_18:00 hours continuously.
- 95% of occupants use internal materials curtains to control solar, other methods such as shading devices; vertical or horizontal are rarely used. Also almost all occupants are happy with their size and orientations of flat's windows and balconies.
- Same survey data were blotted using PMV Tool to exam the effect of the use of natural ventilation and thermal comfort. An impressive result as shown in Figure 7.36 show that the use of the natural ventilation method during the peak hours will increase the comfort percentage significantly. For example, in August almost there is no record for comfort however if the NV is in place the percentage will shot up to 40%. Even it is remarkable result but also these results show that the use of NV can certainly improve the comfort level but another solution is needed in order to maximal the percentage as previous definition of ASHRAE shows that "the thermal comfort state is where at least 80% of people agree that it is comfort".

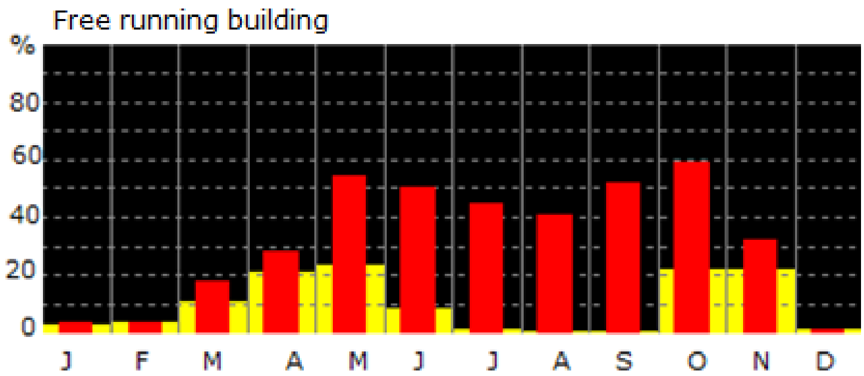


Figure 7.37: Comfort percentage indicated in yellow before NV and comfort percentage indicated in red bars after NV use _ weather Tool, Ecotect

- Although, Cross ventilation is a great method of supplying more comfort feeling actually in the case study buildings is fail to improve the discomfort situation as many occupants declare that they close the doors in order to control air violence causing shutting doors, which therefore effect cross ventilation method which works effectively when openings are well distributed horizontally or vertically and this cause air to flow between two openings at different pressure, even if they are both at a positive pressure
- Thermal comfort is measured in relation with buildings' blocked sides, height from the ground (floor height) and number of family beside the size of flats. In relation to blocked direction, the table below summarize the result of occupants respond in relation with their satisfied level of comfort also buildings have arranged in four groups (blocked from 0, 1, 2 and 3 sides).

Table 7.4: result of thermal comfort in different spaces in relation with blocked direction of the building

		Summer		**Winter**	
blocked side	Exposed side	Majority	Minority	Majority	Minority
Non	4	Slightly warm	Hot	Comfort	Cool
One (south)	3	Comfort	Cool	Slightly cool	Cold
One (east)	3	Warm	Hot	Comfort	Cold
Two (south & north)	2	Slightly warm	Cool	Cold	Comfort
Two (south & west)	2	Slightly warm	Comfort	Slightly cool	Comfort
Three (south, east & west)	1	Comfort	Slightly warm	Cool	Comfort

- There are many elements that play a significant role on human comfort in these buildings, these are; orientation of the building and here it means the level of shading devices that needed in each direction also insulations in wall and roof especially for those in top flats which exposed directly to the sun without any material protection. Poor thermal performance of the building envelope normally affected the internal temperatures to react quickly to the variation of external temperature and lead to indoors discomfort, refer to Table 7.4 above.
- Thermal comfort occupants' measurement showed that achieving a comfort condition is far complicated and do not depending only on orientation or building's surrounding the problem seems to be also related to the performance of building's envelope, materials, insulations and shading devices

also, observation show that it is clearly building's envelope plays an important role on thermal comfort as most of top flats' occupants recorded more discomfort than those in ground flats, and therefore a need for computer simulation inspection is necessary.

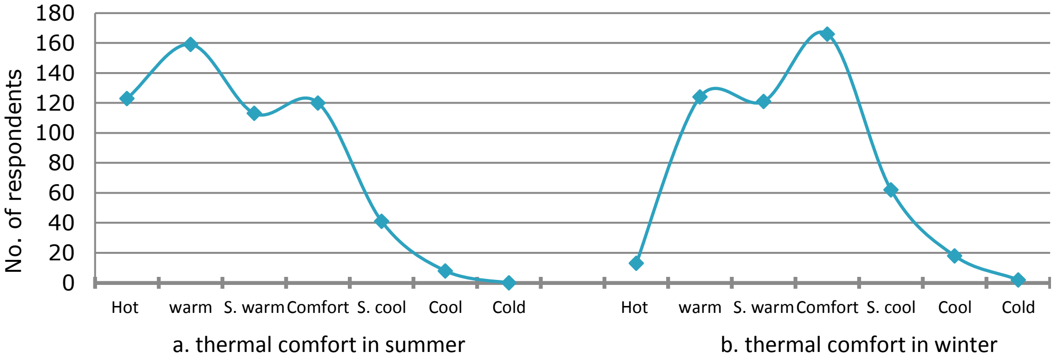


Figure 7.38: Rating thermal comfort in the 12 case study buildings during summer and winter times

RESULT OF TAS MODELLING ANALYSIS AND FINDINGS

CHAPTER 8 : RESULT OF COMPUTER MODELLING (TAS)

8.1. INTRODUCTION

TAS is a suite software product, which simulates the dynamic thermal performance of buildings and their system. The programme has the unique capability of accurately modelling non-conventional, energy efficient and creative design solutions. In this study, TAS the energy simulation program was utilized to examine the effectiveness of the passive climate control methods which were adapted in multi-storey residential buildings from the energy consumption aspect. The simulation models were built in TAS based on the form, orientation, spatial layout, architectural features, finishes, and construction material of the buildings in which the field work was conducted in summer 2009. Process of simulation is explained in Figure 8.1.

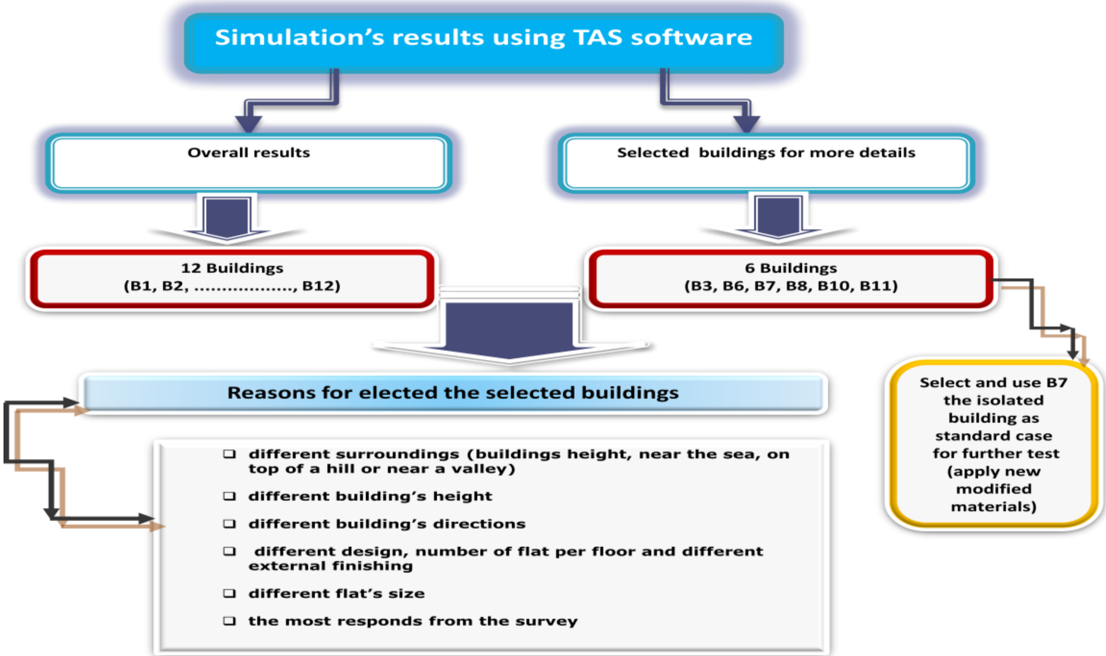


Figure 8.1: Steps of simulation work using TAS software

Uses of TAS indicated that most of energy consumed by the building during summer time is due to the huge heat gained through external walls, windows and roofs. Less sources heat gain were from occupants, appliances and infiltration, however, these sources have a small impact on thermal performance and comfort temperature as well as these heat gains are controlled by the occupants and managed by them in order to suit their life style, reverse of building envelope that is authority and monitory by the government. The above reasons boost this study to concentrates on improving the building envelope, namely walls, roofs and glazing which included in building regulations low.

The software of TAS (building designer) has been used to analysis and simulates a sample of the case study buildings. First, a 3D file was created for each example as shown in Figures 1 and 2. The file then exported to TBD file where the weather file attached and the construction materials identified to each building elements. Other data such as schedules, internal conditions and aperture types were also identified. After that, we came to the stage of TAS result reviewer where we got the output of these two previous stages, at some stages a use of Excel programme took place to clear some of these charts that produced by TAS.

This chapter is designed to include three parts of results and findings; general results created after investigate the all 12 cases as coded by letter B following by number (B1, B2, B3,.......,B12) in order to get an overall idea about these buildings behaviours and Characters in relation with indoor temperature specifically at summer time. Second part is demonstrates deep simulation findings by examine 6 buildings from the 12 which selected according to many parameters such as height, floor size, orientation and surroundings. The last part comprises one building (B7) with many examination that include material, surfaces and many more. This building will be the one which further examination, convert and modified will took place on it using TAS software in order to find right materials and insulations that will work perfectly with the climate of the case study area.

8.2. Energy Loads in All Case Study Buildings

Cooling Loads:

As the Load is the measure of energy (Btu/h) needed to be added or removed from a space by the HVAC system to provide the desired level of comfort within a space, and the cooling load is that gains from the outside environment such as solar gains beside internal gains (sensible and latent components), see Figure 9.2. The case studies buildings show that even with the same internal conditions and climate, a significant difference in cool and heat loads is exists. An example from Figure 8.3 is building case 8 demonstrates the top gain. Reasons for that are;

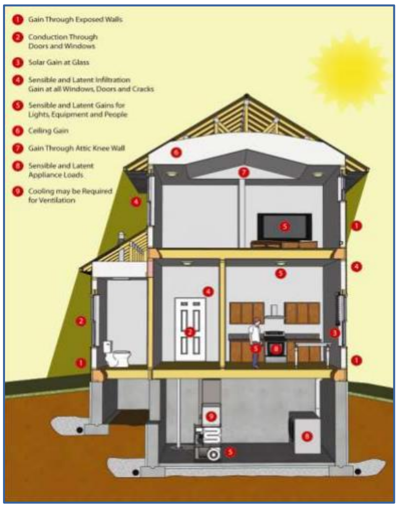


Figure 8.2: Cooling loads
Source: IBACOS

- Building’s orientation trend to north and south which allow massive east and west walls’ surface to face sun all the day. Also, the south wall is free and unattached in this building helped to increase the exposed time to sun heat.
- This is the case that has 3 big courtyards (more details in section; the effect of courtyard on indoor temperatures).
- Due to its shape and design with big balconies help to increase ventilation around it and in summer time the air is quite hot coming from south and

southwest winds, furthermore due to the large surface area that exposed to sun all day.

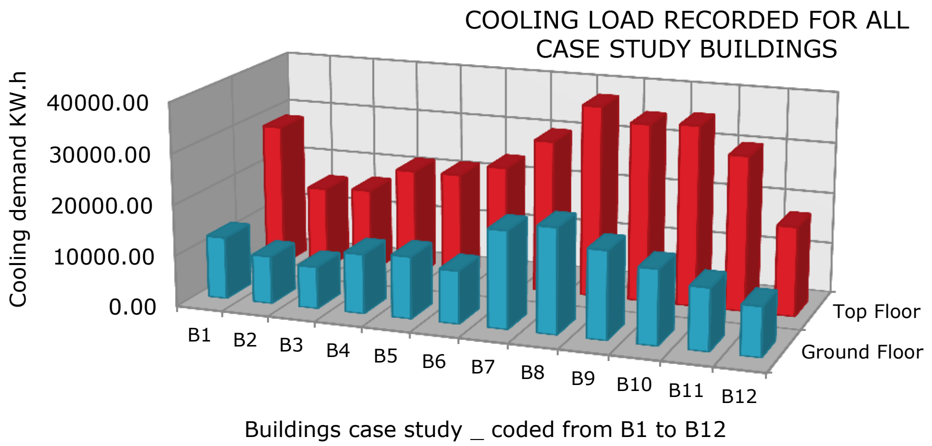


Figure 8.3: Yearly cooling load (heat gain) at case study buildings

HEATING LOADS

Heating loads is the loss to the outside environment and with no credit is taken for solar gains or internal loads because the peak heat loss occurs at night during periods of occupant inactivity, (see Figure 8.4) related to the warm land breeze coming from the near deep valley located on the south-east side of case B7. Back to the case study buildings and with same factors that presented above, the case B8 shows high demand for heating loads.

Figure 8.4: Heating loads
Source: IBACOS

The results in Figure 8.5 reveal a close number of heating loads between case B7 and case B8 and that might be Mainly, the top floors are shown higher demand of both heating and cooling loads and that is due to the high solar gain in summer and earth effect on ground floor in winter, but also when it comes to buildings that are located near the sea it is clear that the warm breeze help to warm the atmosphere and thus reduce heat demand. Examples on these cases are case B2, B3 and B12 which are the nearest one to the sea.

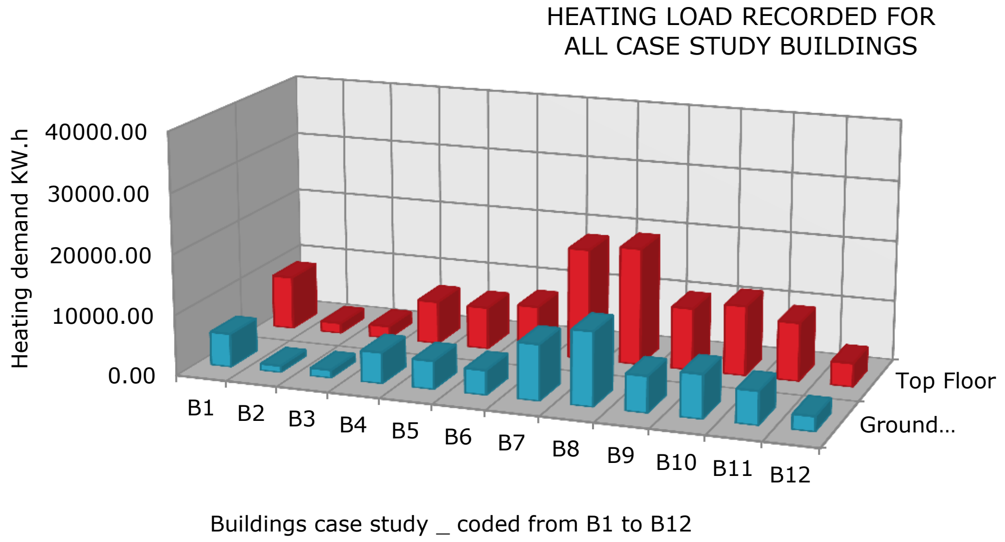


Figure 8.5: Yearly heat loss at case study buildings

8.3. ROOM TEMPERATURE RECORDED IN ALL CASE BUILDINGS

Room temperature is quite high during summer time on top floor and the average shows values that exceed the comfort level (28°C) at almost all buildings. The case at ground floor is just at the high limit of the comfort level which is between 27 and 28°C and it is clear that the level of comfort is far better at ground floors then top floors. While in winter (Figure 8.7), the temperature is not as unacceptable as in summer time. But still the ground floor's occupants feel more comfortable than those at top floor. Buildings such as B4, B10 and B11 have higher temperatures because they have 3 sides blocked which give them a better shelter from the cool wind during winter. (see Figure 8.6)

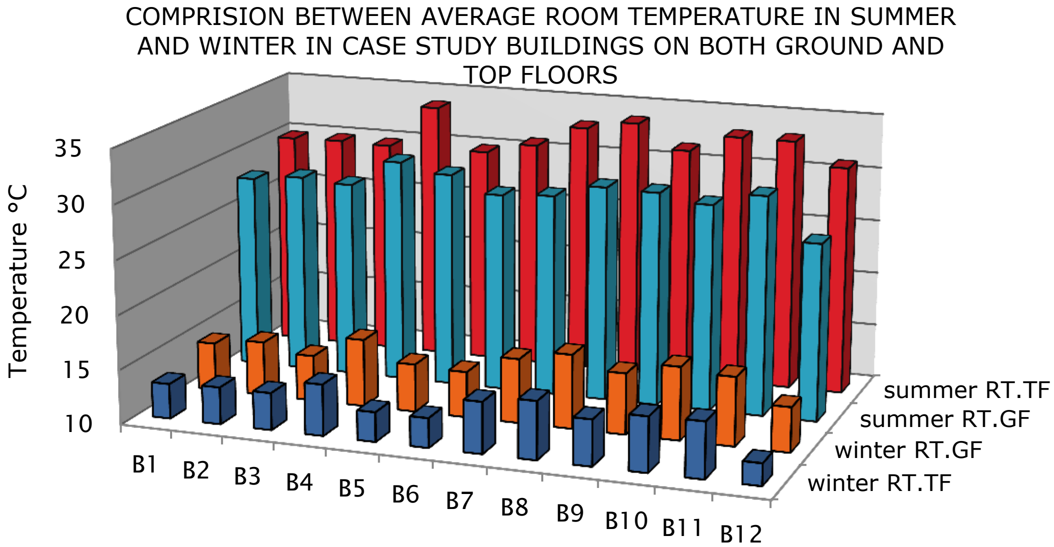


Figure 8.6: Room temperature in case buildings simulated on 21/December for winter and on 21/Jun for summer using TAS

The above simulation results came compatible with the responses of the buildings' occupancies. Certainly, there was a complete agreement between survey results and simulation on this point, where the analyses of people responds indicated that people living on ground floors are feeling warm in winter and less hot then those living on top floors during summer time. The survey results compared here was of the above simulation result and the survey questions of;

<u>In winter overall, How satisfied are you with the temperature in your flay?</u>
<u>In summer overall, How satisfied are you with the temperature in your flay?</u>

8.4. Predicted Mean Vote PMV (PMV)

Predicted mean vote (PMV) was calculated for the main spaces in the buildings using TAS. The parameters of metabolic rate, air velocities, and clothing are required to be entered by the user of the programme for calculating the PMV, where other parameters such as temperature and humidity are calculated by the TAS itself. A single value is required to be set for metabolic rate and a range of two values are required to be set for air velocities and clothing. It is worth noting that in estimating PMV by TAS, two PMV values are calculated (one using the lower air speed and upper clothing value, the other using the upper air speed and the lower clothing value) and the better of the two in terms of thermal comfort is provided as outputs. This means that the lower clothing value and the upper air speed are used to calculate PMV in summer while the upper clothing value and the lower air speed are used to calculate PMV in winter. Figure (8.7) provides hourly PMV through a year in the main spaces of top floor of building B7. The inputs were as that; a metabolic rate of 1.6 met (which is the value for home light activity) was set to calculate PMV in the studied flats. The lower clothing value was set 0.5 clo (which is for light summer ensemble), and the upper clothing value was set 1.4 clo (which is for thermal indoor winter ensemble). As the studied flats are located not far from a coast, internal air speed was set 0.5 to 0.75 m/s, where 0.5 *mls* is classified as "pleasant" and 0.75 *mls* is classified as "light breeze" (Natural Frequency, 1994).

As indicated in the Figure, the maximum PMV is overall estimated in summer when in some hours reached to maximum discomfort (+3), while the minimum PMV is estimated in winter (up to -1). PMV ranges from (-0.8 to +0.8) in almost two third of the total hours through the year. Besides, spaces on average are estimated to be comfort ($-1 \leqq$ PMV $\leqq 1$) during about 70 % of the year; with the greatest number of hours is estimated for the three bedrooms and the lowest is for guestroom on same floor. Due to internal equipment gains in kitchen, PMV in kitchen is almost higher than PMV in other rooms through the whole year, where kitchen is generally warm in summer and slightly cool in winter. For second PMV calculation another small software called predicted Mean Vote were used (Square One software as shown in Figure (8.8), an investigations was carried out to find the satisfaction level of flats users and compare these results with the questionnaire ones. Exact data were inputted using B7 case, cases compared in both ground and top flats.

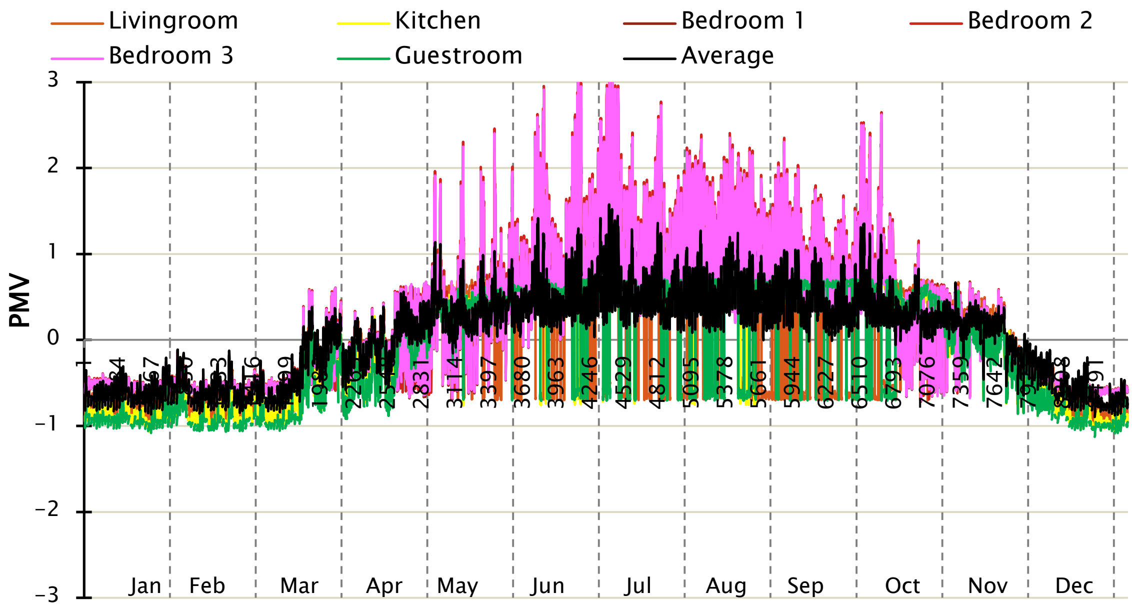


Figure 8.7: Hourly predicted mean vote PMV for building case B7, top floor

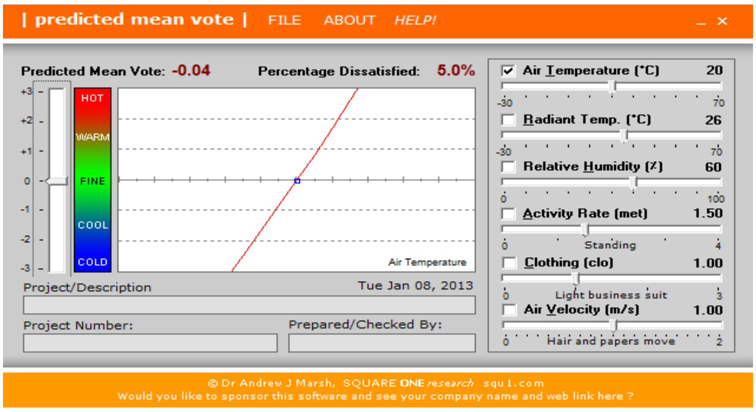
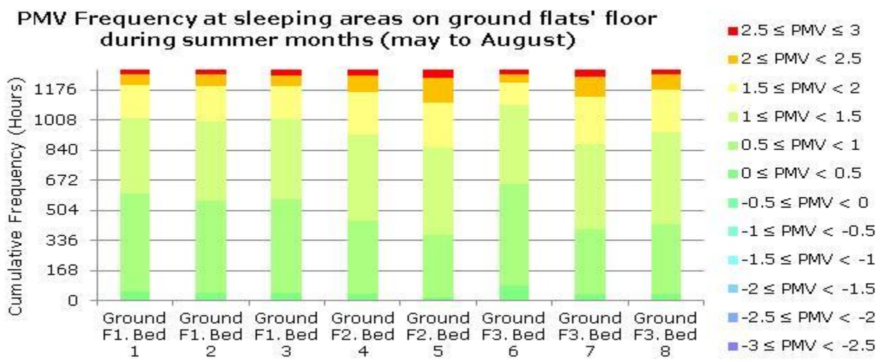
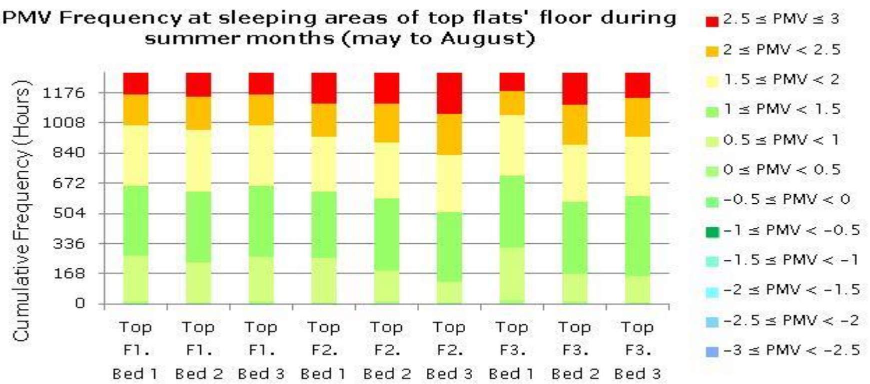


Figure 8.8: PMV Software_ Square one research, Dr. Andrew J Marsh. www.squ1.com

A similar result has been recorded as these obtained from the survey results where the survey show that top flats' occupants feel less comfortable than ground floor occupied. The majority top ones feel neutral during the night and slightly uncomfortable at noon time, while people on ground floor feel comfortable at noon. Figures 8.9 (a, b) show the results produced by using PMV software. It can be seen that number of people feels very warm to hot is lots more in top flats than on ground flats (shown in red colour in both Figures).



a.



b.

Figure 8.9: PMV recorded at bedrooms located on a). ground floor of case study B7 for summer, b). top floor_ Create Report option in TAS and PMV Tools are used here.

Looking at discomfort from another aspect, the radiant temperature, Figure 8.10 verifies the most discomfort time of the day which is 15.00 to 17:00 pm hours when the temperature rise up to 32°C on most days during summer time. Chosen 2ed of August to be the selected examination day as it is the hottest day in the case study city and those radiant temperatures shown in the Figure 8.10 below were used in order to observe the level of discomfort during these hours.

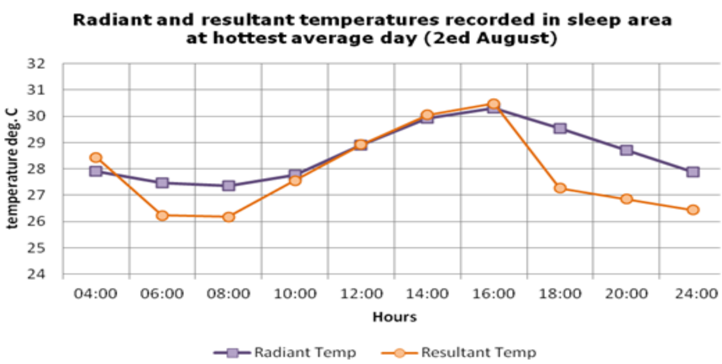


Figure 8.10: RMT and RT recorded in case study building case B7 at all bedrooms zones_ results using TAS version 9.2.1.3

Besides using PMV Tool with set the air temperature, RH, activity, clothing and air movement percentages of dissatisfied during these hours similar to data collected by the field survey. The coming out results are presented in the below Table 8.1.

Table 8.1: percentage of dissatisfied hours at bedroom zones created by PMV Tool

Hours	10:00	12:00	14:00	16:00	18:00
Percentage of dissatisfied %	79.3	99.4	99.7	99.0	97.3
PMV (-3 to +3)	2.06	3	3	3	2.75
Hours	20:00	22:00	00:00	04:00	06:00
Percentage of dissatisfied %	74.8	50.8	29.0	7.4	5.0
PMV (-3 to +3)	1.96	1.50	1.07	0.34	0.01

Table 8.1 demonstrates that within the sleeping time at night the percentage of discomfort drop down a little. For instance, at midnight only 29% of people feel uncomfortable in their beds while taking a nap at 2 pm seems real difficult with very hot temperature and at a vote of mark +3 (Hot). Furthermore, even though temperatures in bedrooms drop at night, they are still higher than limits suggested by CIBSE in summer times, for this reason further investigation using Ecotect software was carried out to find out more about discomfort by chosen two different orientation bedrooms with a random choose from case B7, in order to count how many hours of discomfort that the zone spent outside the comfort band during a year. These zones are; Bedroom 1 _ used by parents, Bedroom 2 _ used by children. Bedroom 1: located on two directions south and east occupied by 2 adults usually used during night. Results of zone 1 investigation are shown in Figure 8.11 and Table 8.2.

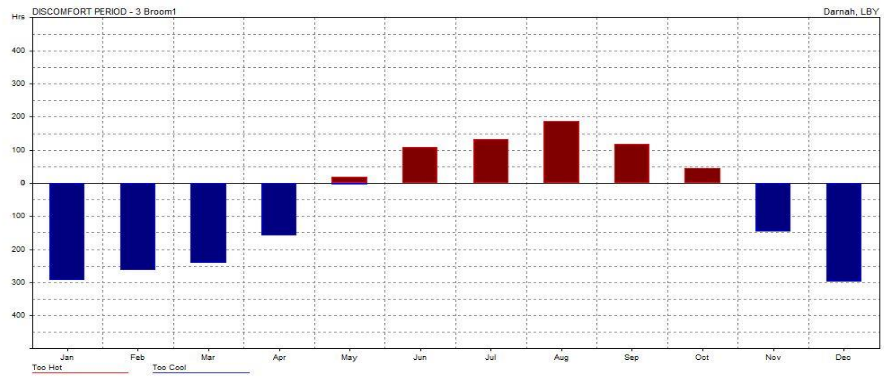


Figure 8.11: Annually discomfort hours recorded in bedroom 1 using Ecotect software_ red: too hot & blue: too cool

Table 8.2: Discomfort hours presented in numbers as shown in Figure 9.13 for bedroom 1.

Zone name: Bedroom 1
Occupancy: Weekdays 00-07,
Weekends 00-10
Zone 1 is not air conditioned
Comfort: Band = 18.0 - 28.0 C

MONTH	too hot (Hrs)	too cool (Hrs)	Total (Hrs)
Jan	0.00	294.00	294.00
Feb	0.00	262.00	262.00
Mar	0.00	241.00	241.00
Apr	0.00	159.00	159.00
May	18.00	5.00	23.00
Jun	109.00	0.00	109.00
Jul	133.00	0.00	133.00
Aug	186.00	0.00	186.00
Sep	119.00	0.00	119.00
Oct	46.00	0.00	46.00
Nov	0.00	146.00	146.00
Dec	0.00	299.00	299.00
TOTAL	**611.0**	**1406.0**	**2017.0**

The second zone is bedroom 2 the south-east zone, occupied by 3 children and used as a sleep area during night and play area during day. Analysis shows that this area is in the comfort zone range only 1850 hrs annually or in other word nearly 77 days (21.0% of a year). Therefore, this zone if under the required average of been a comfortable zone as for example, during August this zone is too hot 260 hours (equal to ~ 11 days), more Figures of each months are presenting in Table 8.3 and Figure 8.12.

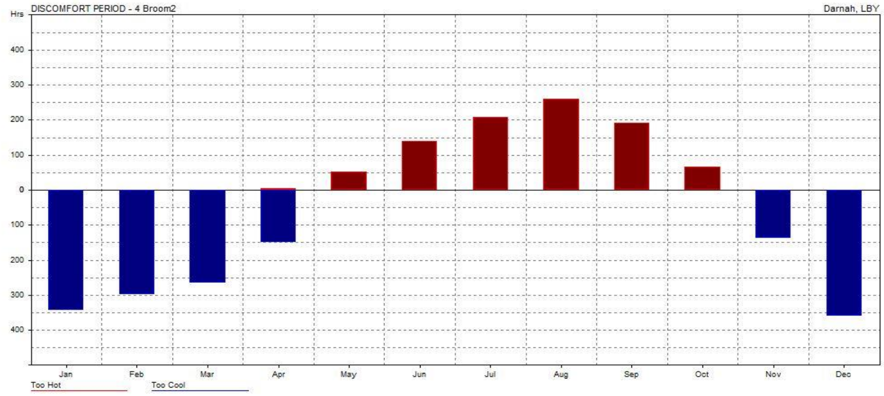


Figure 8.12: Annually discomfort hours recorded in bedroom 2 using Ecotect software_ red: too hot & blue: too cool

Table 8.3: Discomfort hours presented in numbers as shown in Figure 9.14 for south bedroom.

	MONTH	**too hot (Hrs)**	**too cool (Hrs)**	**Total (Hrs)**
Zone name: Bedroom 2 Zone is not air conditioned. Occupancy: Weekdays 00-07 Weekends 00-17 Comfort: Band = 18.0 - 28.0 C	Jan	0.00	343.00	343.00
	Feb	0.00	298.00	298.00
	Mar	0.00	264.00	264.00
	Apr	5.00	150.00	155.00
	May	51.00	0.00	51.00
	Jun	139.00	0.00	139.00
	Jul	207.00	0.00	207.00
	Aug	260.00	0.00	260.00
	Sep	192.00	0.00	192.00
	Oct	67.00	0.00	67.00
	Nov	0.00	138.00	138.00
	Dec	0.00	359.00	359.00
	TOTAL	**921.0**	**1552.0**	**2473.0**

An equivalent examination was carried out using TAS software on same bedrooms but on both top and ground floors shows a close result. The result shows exceeded comfort temperatures during summer months (May to Aug), Figure 8.13 shows that temperature difference between ground floor and top one, even the trend is the same but number of hours of been discomfort are different. For instance, the ground bedroom 3 recorded a temperature of 32°C for duration of 200 hours during May to August while the same room on top floor recorded 900 hours at same temperature.

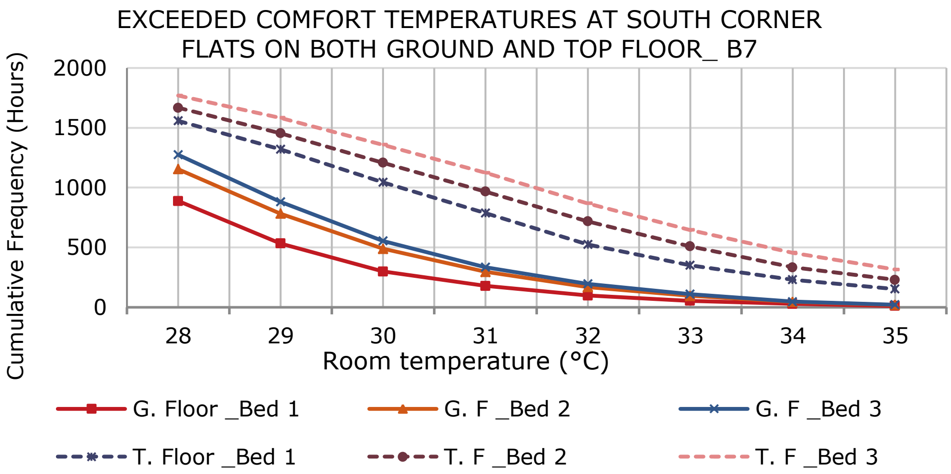


Figure 8.13: Exceeded comfort temperatures at south corner flats on both ground and top floors _ schedule applied at bedtime (10pm to 7am) during summer months_ TAS result

8.5. FURTHER EXAMINATION FROM MANY ASPECTS ON SELECTED BUILDINGS

8.5.1 ASPECT OF BUILDING'S HIGH

Figure 8.14 shows that at peak time of the day the higher the floor is the higher the temperature reach. At the case of 8 floors building the temperature recoded at the top floor reached nearly 35° C while in the case of 5 floors the highest temperature is 32.5° C on fifth floor. Also, it can be observed from the Figure below that temperature degree gradually increase from lower to upper floors because of the effect of the heat gains that absorbed by the roof. For example, in building case 7 the amount of heat gains on top floor at peak hour is 14.2 KW where on ground floor the amount recorded is 7.9 KW. That lead to say the lower buildings are more suitable to cope with a climate like the city study one. Also, a glance back on Figure 8.14 shows that on top zones more hours go beyond comfort temperature than that recorded on ground zones.

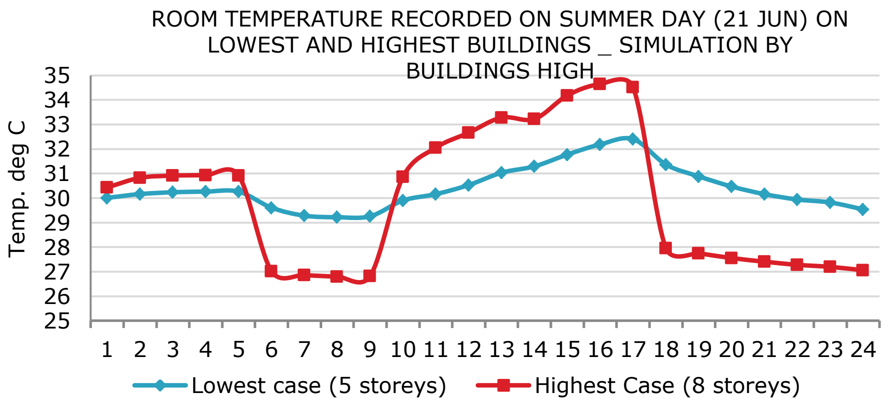


Figure 8.14: room temperature at different high buildings

8.5.2 ASPECT OF DISTANT FROM THE SEA

It is obvious that the nearest building from the sea has lower indoor temperature than others. Even though, Figure 8.15 shown difference as only 1 degree on hottest average but that is depending on how far the other buildings are, in this case the far building is around 1000 meter far from the sea and the nearest is 60 meter, so B7 still as well considered not that far from the sea since this the case in the city which located on a coast. However, during night hours difference between the two cases was noticeable clear (4 degrees). A further aspect is that, the effect of sea breeze on comfort which is considerable important and openness to the sea which could explain the low temperature in case B3 where the reason B7 case is warmer than B3 ones, might depend on the fact that it is relatively far from the coast and might be less affected by the sea breeze.

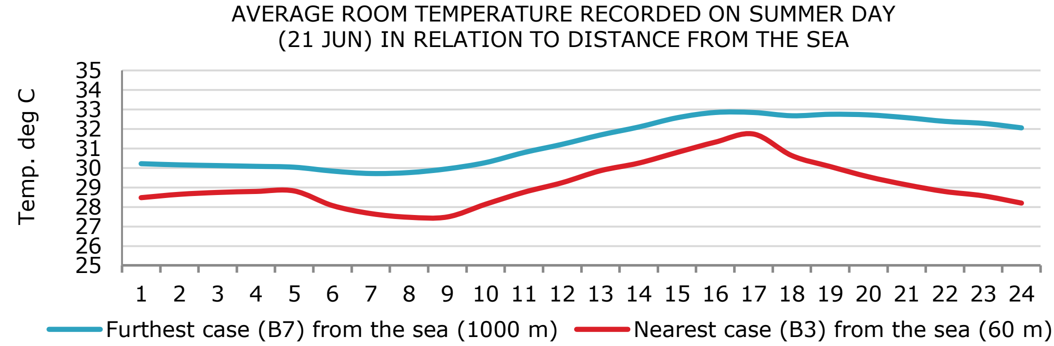


Figure 8.15: Room temperature recorded on a summer day in relation with distant from the coast

8.5.3 Aspect of Present of Vegetation

Vegetation reduces building energy use by shading buildings during the summer and consequently lowering temperatures also help to block cool winds in winter. But, they can increase energy use by shading buildings in winter, and may increase or decrease energy use by blocking summer breezes. Thus, proper tree placement near buildings is critical to achieve maximum building energy conservation benefits. Figure 9.18 illustrates the situation of same building (case B10), investigated once with a trees row that present in reality just 3 meters away on southeast side from B10 and second time was run without the existing of those trees using TAS simulation. The effect of tree shading shows a significant impact on room temperature. It has a shading screen on ground floor between 8:00 am to noon nevertheless the external temperatures still expectable and relatively lower than those of mid-day temperatures where the shading moves to the opposite direction. Figure 8.16 shows variable results, noticing that this result is for same building with and without the trees, it is a remarkable change in temperatures during early hours of the day up to noon time. Figure 8.18 also shows a sector of energy gain recorded in both cases on 21st of June.

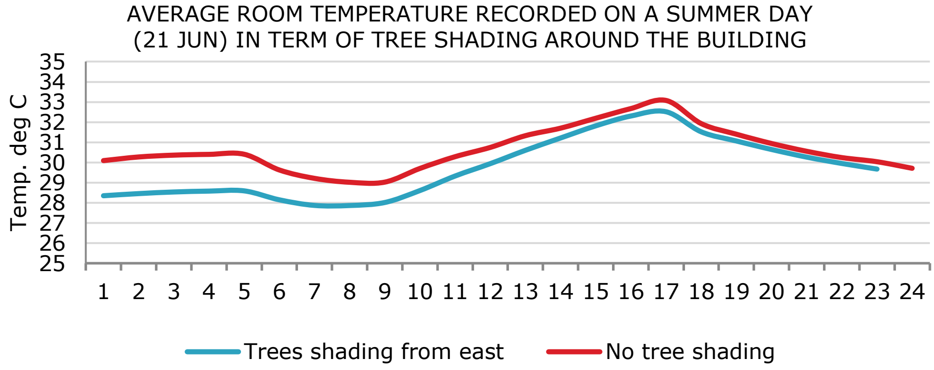


Figure 8.16: Room temperature recorded on a summer day in relation with tree shading near the building _ examination carried on case B10

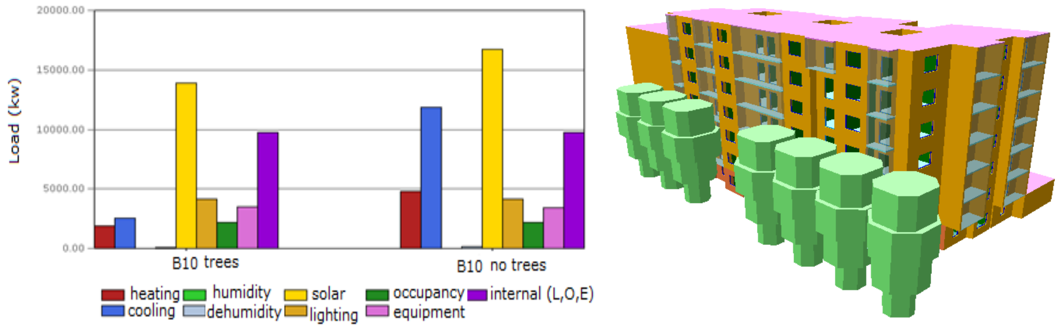


Figure 8.17: Energy loads recorded at 21/Jun in relation with tree shading near B10 building as shown in TAS 3D drawing on right

Table 8.4: Energy loads recorded at 21st Jun in relation with tree shading near B10 building

Building	KW/H	Heat	Cool	Hum.	Dehum.	Solar	Light	Occup.	Equip.
B10 WITH TREES SHADE		1886.3	2541.0	0.0	26.2	13898.2	4140.7	2180.1	3468.4
B10 NO TREES		4824.4	11893.5	0.0	119.7	16757.0	4140.7	2180.1	3446.1

8.5.4 ASPECT OF BUILDING'S SIZE

Two cases were chosen to exam the aspect of building's size on room temperature from parameters such as dense, orientations, number of occupants and building's plan. Finding depict that the peak hour was similar in both cases at 17:00 O'clock on 2ed of August when the sunset is around 20:00 O'clock; even though small building recorded higher room temperature; the explanation to this is depending widely on building design and number of apertures. Where the plan of the small building is built mainly on a narrow close corridor with flat on each end of it in two opposite directions, while the big building has a square corridor that consists 6 flats in all directions and has many windows in it which work with the flats window when the doors are open as a cross ventilation machine. Figure 8.18 shows the different in room temperatures of 1 degree between the two cases.

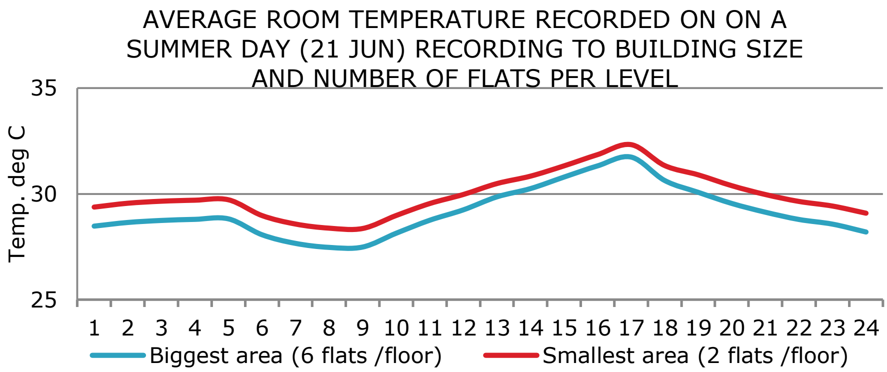


Figure 8.18: Room temperature recorded on a summer day in relation with building's floor size and number of flats per floor

8.6. FURTHER INVESTIGATION ON 6 FILTERED BUILDINGS (B3, B6, B7, B8, B10 & B11) FROM THE 12 CASE STUDY

Following a general simulation on all case study buildings, six buildings the same ones that were selected at survey stage for further inspection. These buildings were selected in favour of variety of blocked directions by other buildings (see Table 8.5 for more details). The results at survey stage show a different altitude in comfort level between these buildings; therefore, more work using TAS was needed to investigate these results.

8.6.1 MEAN RADIANT TEMPERATURE DURING SUMMER MONTHS

Figure 8.19 reveals that the isolated building (B7) witnesses the highest temperature on all floors which reached nearly 40°C at top floor and still quite high even on ground floor at 34.5 °C, it seems that isolated building receives solar heat on all its surfaces at all time, this led to increasing in heat gain consequently rising the indoor temperatures. Following case B7 in high temperature is B8 that block from one side (east) than B10, B6, B3 and B11 respectively. All previous cases are blocked from 2 sides, (south &west or south &east), except B11 where it is blocked from west, south and east. So, even at top floor B11 case shows the lowest temperature (32° C) as an effect of higher surrounding buildings that supply a shading cover for the roof at peak time (noon hours).

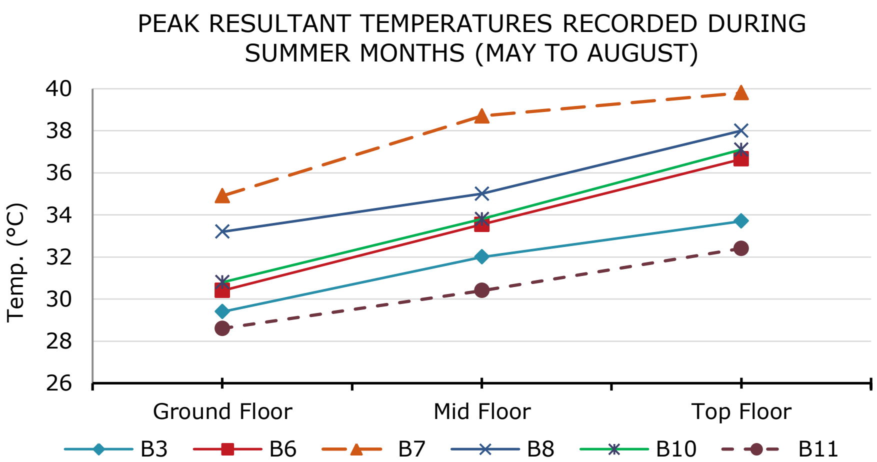


Figure 8.19: peak temperatures measured at different storeys of different buildings during summer months using TAS software.

After that, Figures 8.20 (a & b) show peak temperatures of ground and top floors on equinoxes and solstices days of the year, again B7 shown the highest trend through summer days up to early autumn days while in December the same building is the lowest temperature shown in both Figures, this low result in winter may be explained by the effect of the cold wind blowing on all external walls (isolated building) as well as located near a valley. Whereas, B10 case recorded a far low temperature at spring time (21st March) on ground floor which highly likely as a result of the present of trees on southeast side and its shading effect on temperature. The other buildings show comparable temperature behaviour. Noticeable, temperatures on both ground and top floors are relatively close and the variety average is no more than 3° C as shown in Figures 9.20 (a & b).

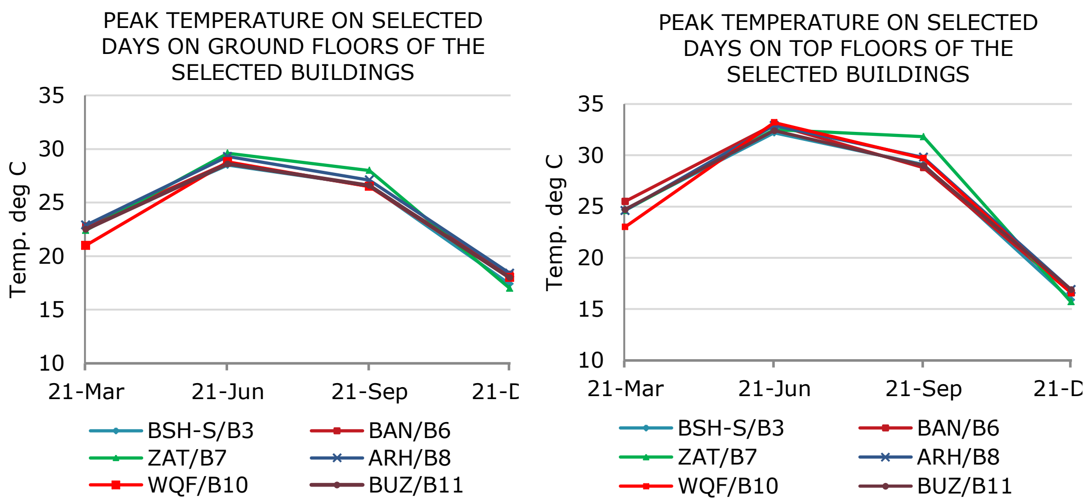


Figure 8.20: Mean radiant temperature on equinoxes and solstices days at a) Ground floors & b) Top floors

8.6.2 RESULTANT TEMPERATURE DURING SUMMER MONTHS IN THE 6 PREVIOUS BUILDINGS

Clearly is that the higher floor is the highest temperature occurs. Here are some examples presenting the TAS simulation results that perform peak mean radiant temperature on selected days of the year on chosen floors as demonstrated in Figures 8.21 (a, b & c). Apparently, top floor shown the highest temperature during June and lowest temperature during December at all presented cases while the ground floor is the comfort zone in hot months and warmest one in cold ones, making the ground level as an ideally level for thermal comfort seekers. What needs to be stressed is that results of case B7 the isolated building show little distinction between top floor and mid floor in temperature where at other cases the temperature of mid floors show more variability.

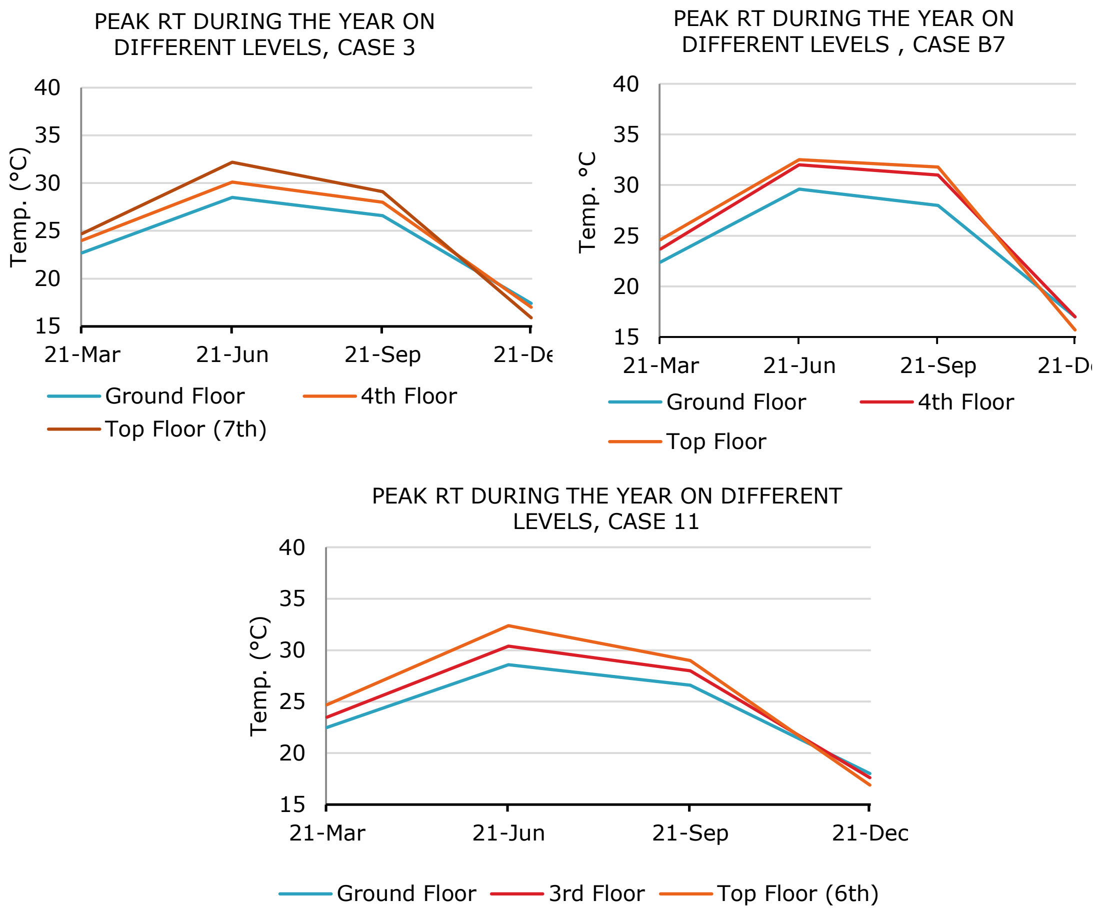


Figure 8.21: Peak RT through the year at different floors in a) case B3 & b) case B7 & c) case B11 _ produced using TAS software

8.6.3 ANALYSIS OF VARIOUS DIRECTIONS OF FLATS

Repeatedly, perform a TAS simulation on the 6 chosen buildings in order to investigate the effect of orientation on room temperature (results shown here are only for two buildings the other results' Figures are presented in appendix 5 as all results show same trends). Analysis process includes all the occupant zones excluding bathrooms and toilets as well as other service areas of the building such as staircase, stories, corridor and lifts, Figure 8.22 shows building (B3) plan and in advance pages Figure 8.28 shows building (B8) which are the two chosen buildings to present their results in this section.

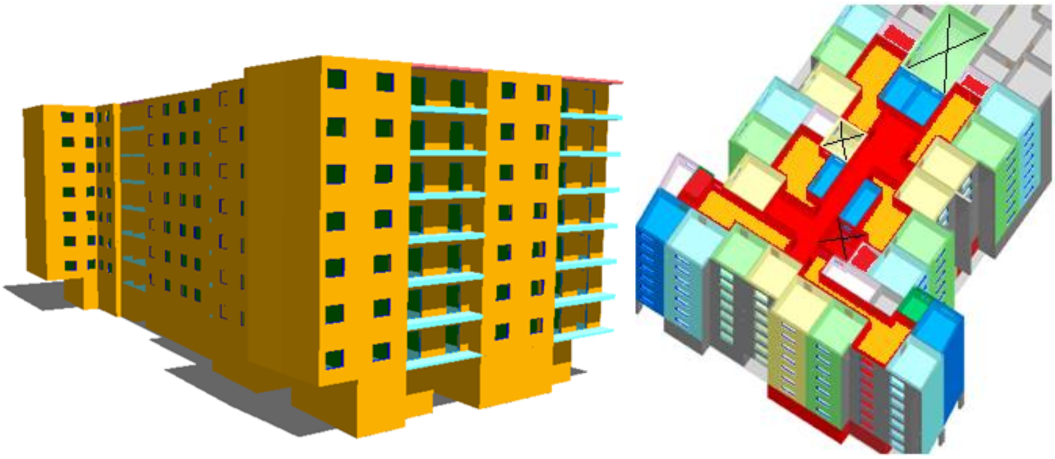


Figure 8.22: Plan of B3 drawn in TAS 3D modeller_ picture on left shows building storeys and courtyards & on right simulation zones shown in blue, green, white, orange and yellow colours (red zones are excluded from simulation)

Case B3 flats have been grouped according to their various directions then a simulation runs on both top and ground flats, these floors were the most differentiable ones among other floors from temperature point. Building B3 contains 3 different flat positions; south-east, south-west and north-west. Figures 8.23, 8.24 and 8.25 exemplify the result of TAS simulation runs on 21st of June as the longest day of the year with longest exposed to sun heat shown that in respect of peak indoor temperature at top and ground flats. Findings of TAS simulation show that temperature at peak hour were in southwest and southeast top flats (33.6°C and 32.2°C respectively) these temperatures were higher than northwest (30.7°C) even so the temperature in this direction still higher than expected, probably effected by hot westerns wind. On other hands, ground flats show similar results according to directions but with lower temperatures. Figure 8.23 states that the highest temperature recorded on top floor was in living room at 33.6 °C and the lowest temperature on same floor was in kitchen at 31.4 °C. The trend on ground flats were slightly lower in bedroom zones recorded as 31.3 °C. However, again lower temperature was in kitchen as same result of what has happened on top floor, kitchen temperature was 29.0 °C, it can be observed that this area is benefits from been located on courtyard that allowing cross ventilation.

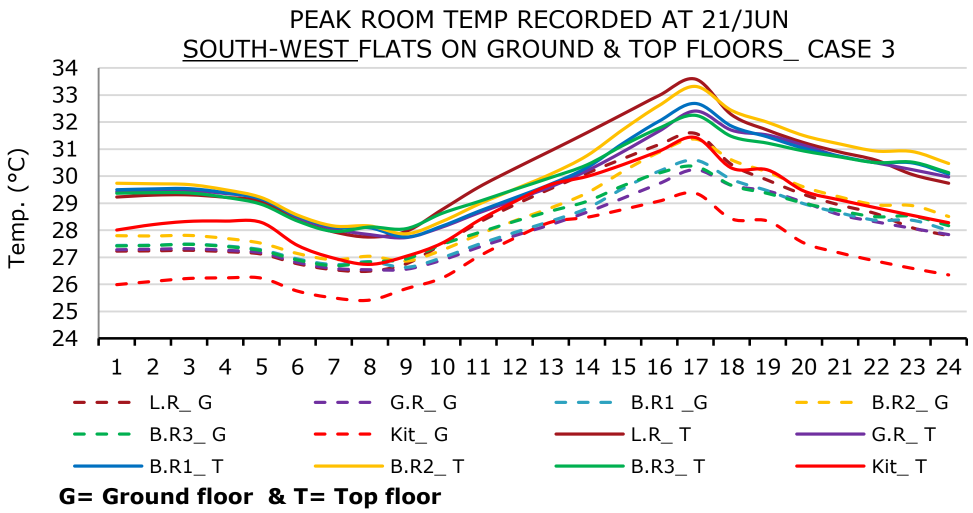


Figure 8.23: Peak room temperature simulated on 21st of Jun for top and ground flats B3 using TAS software and fieldwork collected data

Figure 8.24 shows peak temperatures on southeast flats both on ground and top flats. Indeed, temperatures are shown to be high at this direction almost all day hours as a record of 32.6 °C at 17:00 hour indicated on top floor's living room and the lowest temperature on this floor was in kitchen at 30.6 °C whereas on ground floor's flats the highest and lowest temperatures at same zones were 28.5 °C and 27.3 °C respectively.

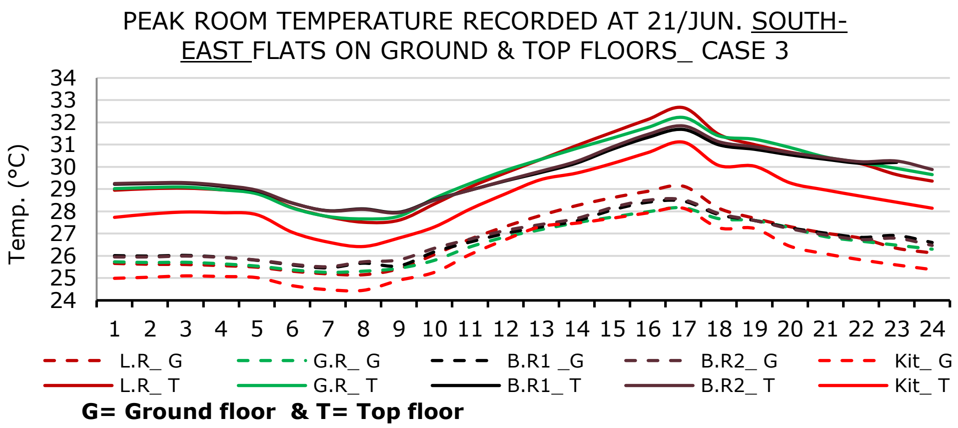


Figure 8.24: Peak room temperature simulated on 21st of Jun for top and ground flats B3 using TAS software and fieldwork collected data.

A significant finding was that temperatures of southwest direction have a merging zone between lower top temperatures and highest ground temperatures whereas south-east top flats temperatures are separated from ground flats temperatures. Figure 8.25 shows the temperature on northwest been somewhat high even it is on north side but clearly the effect of west sun and wind are playing great part on increasing these temperatures. In regards to northwest top flats higher temperature was in bedrooms at 32.6 °C and the lower zone is the kitchen at 31.2 °C and on ground flats the highest temperature is 30.4 °C recorded in bedrooms zone and 29.3 °C in kitchen zone as lowest temperature on ground flats on peak hour.

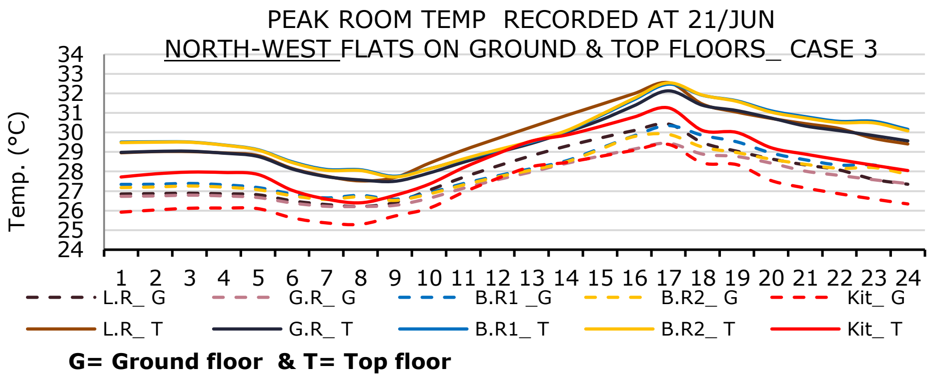


Figure 8.25: Peak room temperature simulated on 21st of Jun for top and ground flats B3 using TAS software and fieldwork collected data

Result at first part of Figure 8.26 (a) shows the peak temperatures on different flats direction in case study B3 as have been obtained from TAS, the Figure shows that temperatures at peak hour were in south-east and south-west flats (32.5° C and 34.4 °C respectively) higher than north-west flat (30.7 °C). It can be observed that the indoor temperature of southern and western flats is hot and worm whereas warm and comfort for northern flats. The second part of Figure 8.26 (b) compares the above findings with a study of Alsoasi, (carried out in Gaza 2005 and examined indoor thermal comfort), it seems that both results support each other as similar trade is certainty shown in both Figures. Even though, Alsoasi study shows less temperatures and that is due to the weather variation of the case study in this study and the city of Gaza in the situation of the second study.

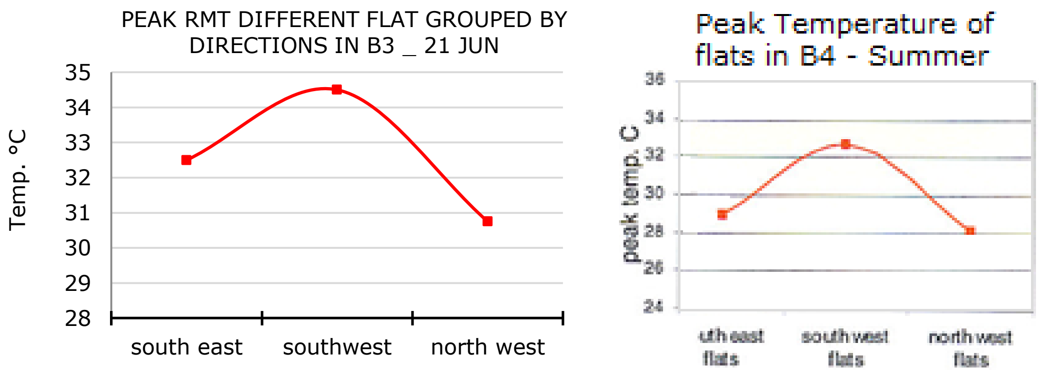


Figure 8.26: Peak temperature recorded a) at different flat directions on 21st Jun in B3 & b) Peak temperature at different flat directions on 21st Jun as shown in Alsoasi, 2005 study, Author here used HevaCopm software

The second case to show is case B8 and its simulation results (Figure 8.27); this building was selected for its different tendency to north and south which is different from the above case. Flats of case B8 that have been grouped according to their various directions, simulation runs on both top and ground flats. This building contains 3 different flat positions; west, east and north.

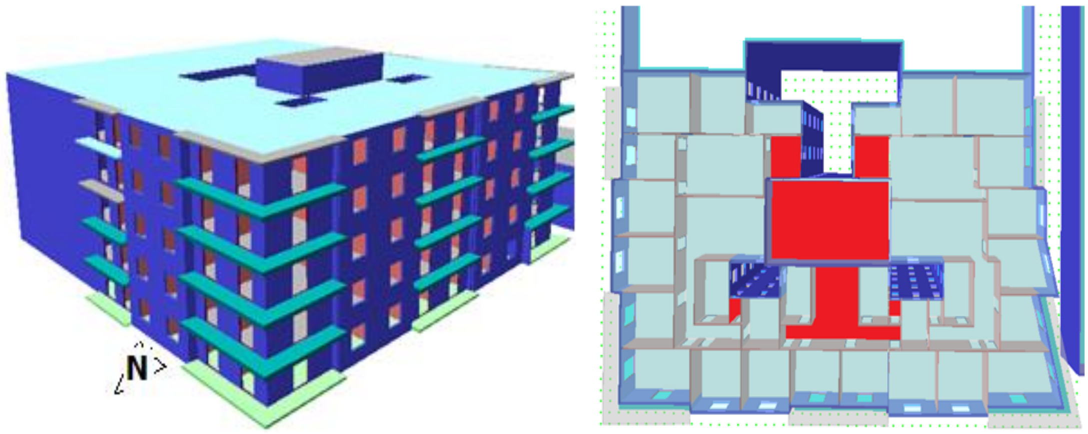


Figure 8.27: Plan of B8 drawn in TAS 3D modeller_ picture on left shows building storeys and courtyards & on right simulation zones, notice red zones are excluded from simulation

As indicated in Figures 8.28, 8.29 & 8.30, results of TAS simulation show that temperature at peak hour (17:00 O'clock) was in west flats (Figure 9.28). On top flats the highest temperature witnessed in bedrooms area (34.0 °C) and on ground flats the temperature for same area was 31.1 ° C. Lower temperatures at peak hour at this direction were as follows; 32.0 °C recorded in kitchen of top flats and on ground the lower temperature found to be in kitchen as well at 28.2 °C.

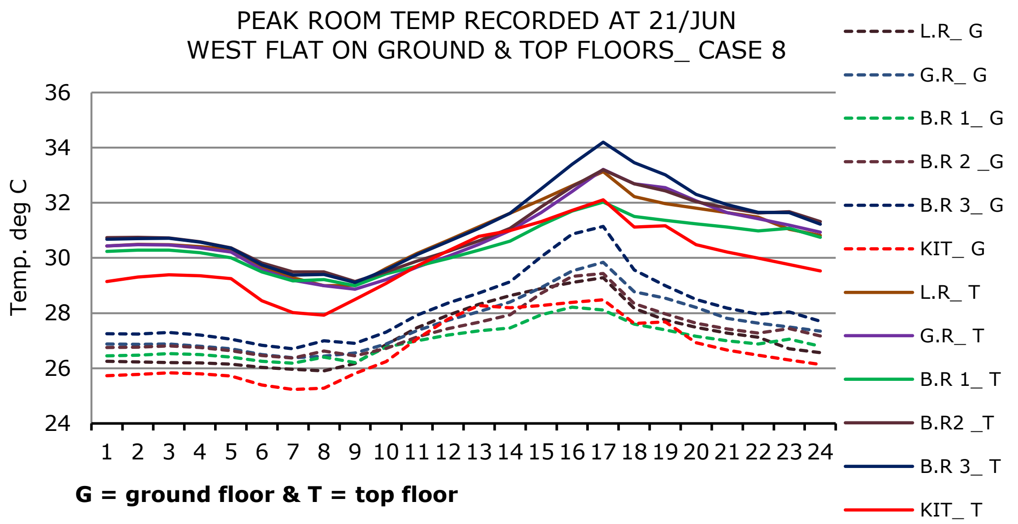


Figure 8.28: Peak room temperature simulated on 21st of Jun for top and ground west flats of B8 using TAS software and fieldwork collected data

Furthermore, Figure 8.29 shows peak temperatures on east flats at top and ground flats. Temperatures still high at this direction recorded 33.1 °C at 17:00 hour in bedroom top flat and the lowest one at this time were in kitchen at 32.4 °C whilst on ground flats the highest and lowest temperatures at peak hour were 30.1 °C and 28.3 °C respectively. Most likely, temperature on east side is high as a result of balcony and window present on east wall.

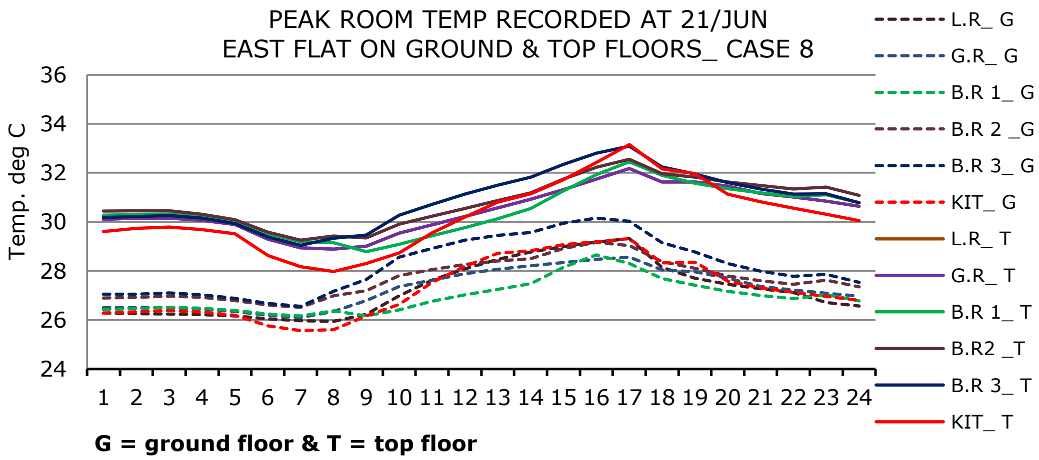


Figure 8.29: Peak room temperature simulated on 21st of Jun for top and ground east flats of B8 using TAS software and fieldwork collected data

In regards to north flats to some extent lower temperatures were shown on ground floor where the highest temperature at peak hour was 29.3 °C and the lower temperature at same hour 28.0 °C and on top flats the highest temperature at 17:00 hour was 32.7 °C recorded in bedrooms zone and 31.9 °C in kitchen zone as lowest temperature on peak hour, results shown in Figure 8.30.

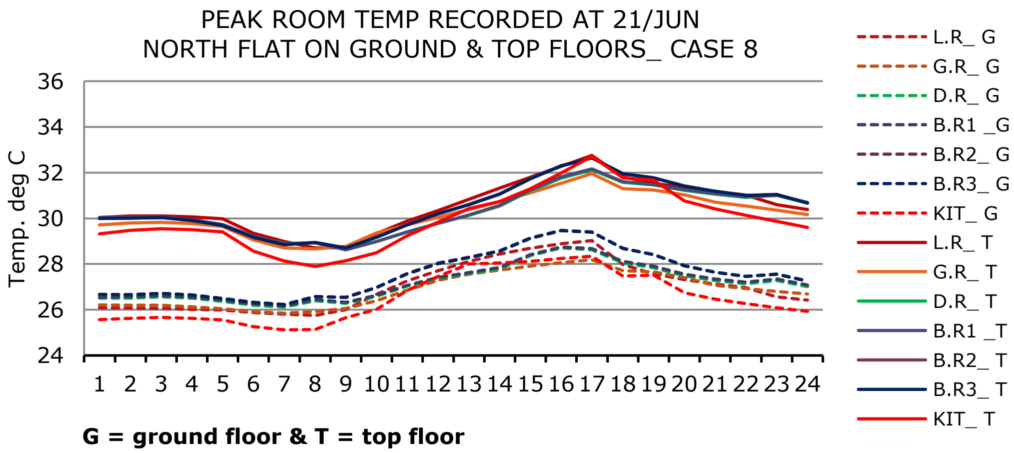
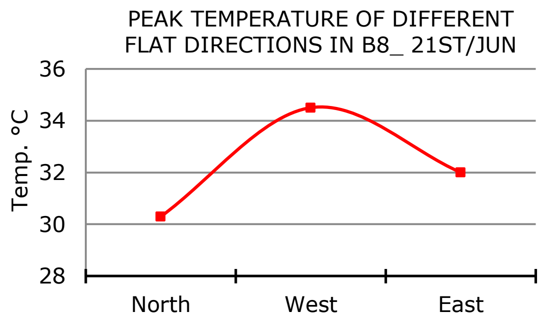


Figure 8.30: Peak room temperature simulated on 21st of Jun for top and ground north flats of B8 using TAS software and fieldwork collected data

Findings depict that the peak hour is at 16:00 O'clock; was 30.2 °C in north flats which mean that occupants of northern spaces at this time of the day feel warm, whereas the highest temperature degree was 34.3 °C in southern flats, that also meat that occupants of these flats fell hot and discomfort (Figure 8.31, a) it can be observed that west direction flats has a lower temperature degree than the south (32 °C); this can be as a result of the presence of openings on this side of the building. Yet again, the above results were compared with results in Alsoasi, 2005 study; Figure 8.31 (b) shows a similar result recorded on different directions.



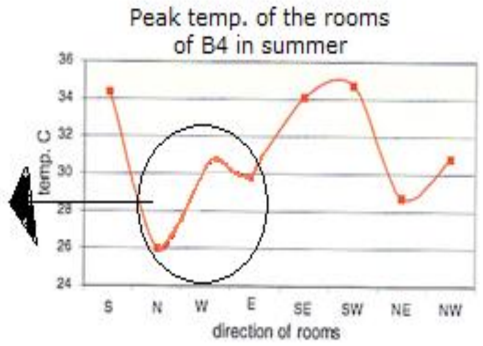


Figure 8.31: a) Peak temperature of different flat directions in B8_ 21st Jun
b) Peak temperature at different flat directions on 21st Jun as shown in Alsoasi, 2005 study, Author here used HevaCopm software

8.6.4. Analysis of different heights of floor's

Another examination took place on the above 6 selected buildings in order to exam the effect of floor heights within a building on temperature range. Three buildings are chosen from the six above buildings, each one chose to be with different distance from the sea. Figure 8.32 shows that temperature degree gradually increases from lower to upper floors.

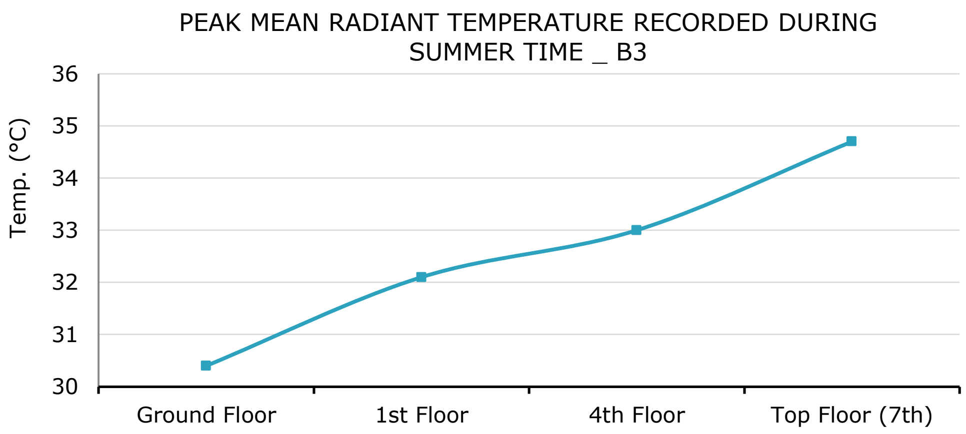
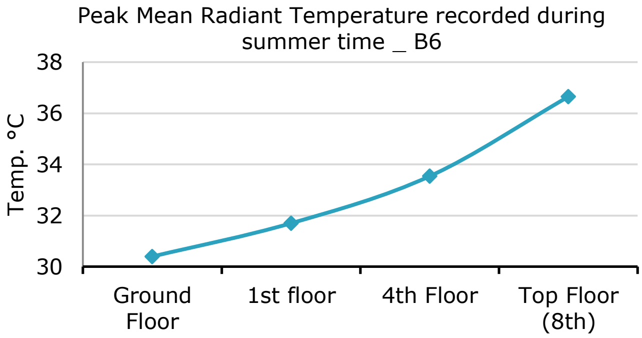


Figure 8.32: Peak summer temperature in different heights of floors on 21/Jun_ B3

In B3 building peak hour shows to be at 16:00 O'clock in these cases. Temperature at ground floor is 30.4 °C; on other hand temperature at top floor is 34.5 °C. Figure 8.33 shows that high temperature in top floor at B6 case is 36.3 °C and on ground floor is 30.4 °C. It can be observed that these two buildings are close by the sea and not far as the following case however there are differences between temperatures on top floors that can be due to building surrounding where B3 has a surrounding buildings with same heights floors (7 storeys) while B6 is surrounding by lower buildings (1 and 3 storeys).



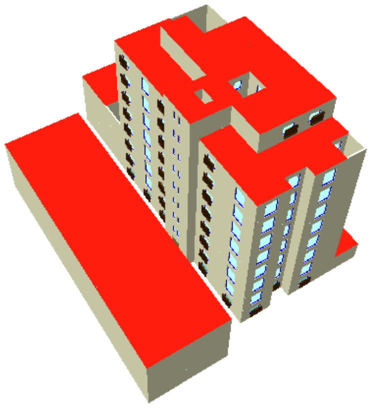


Figure 8.33: Peak summer temperature in different heights of floors of B6 case on 21/Jun beside shown a 3D drawing of B6 building

Peak temperatures at case B10 which is the case study with trees row blocking the east side up to third floor show high temperature at all floors. Multi-parameters result in this increase such as direct open to the south and west directions with wide windows and balconies also north direction is blocked by another high building also the size of courtyards in B10 are small and do not help in cross ventilation process to ease the exchange of indoor temperature since this building is a destines one from the sea, Figure 8.34.

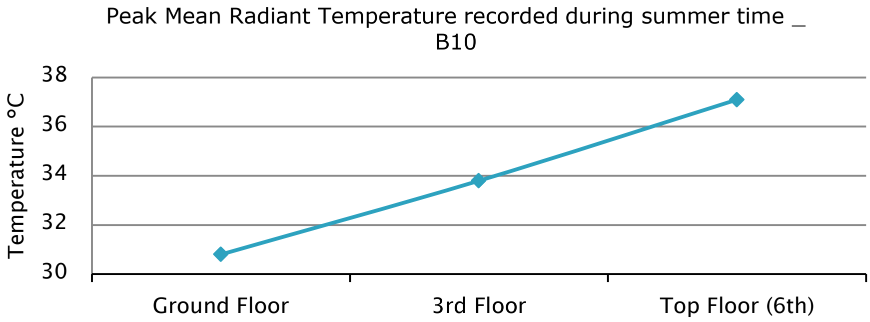


Figure 8.34: Peak summer temperature in different heights of floors on 21/Jun_ B10

8.6.5. Analysis of Energy Loads

Sizing heating and cooling loads is an important function of TAS Building Designer. It can be used to compare the relative merits of different heating and cooling strategies. The graph below was created in Excel through an automatic data export from TAS. It shows total energy on annual base for ground and top flats with a natural ventilation system. Also, maximum load of the B3 and b8 buildings is found at 17.00 hours. Considering the results in Figure 8.35, it is clearly that internal heat gains as obtained from fieldwork are similar at ground and top flats also each sector is relatively equal as people tend to minimize their consumption as possible as they can due to electrics price according to them (usually £75 to £120 per month) also it should be noticing that occupants of this building tend to reduce A.C use to minimum as they do benefit from sea breeze (cross ventilation) during summer time (internal heat gain is 1.30 KW.h in total). Although, two sectors of heat caused by cooling loads and solar heat are shown to be the higher heat sources in both floors.

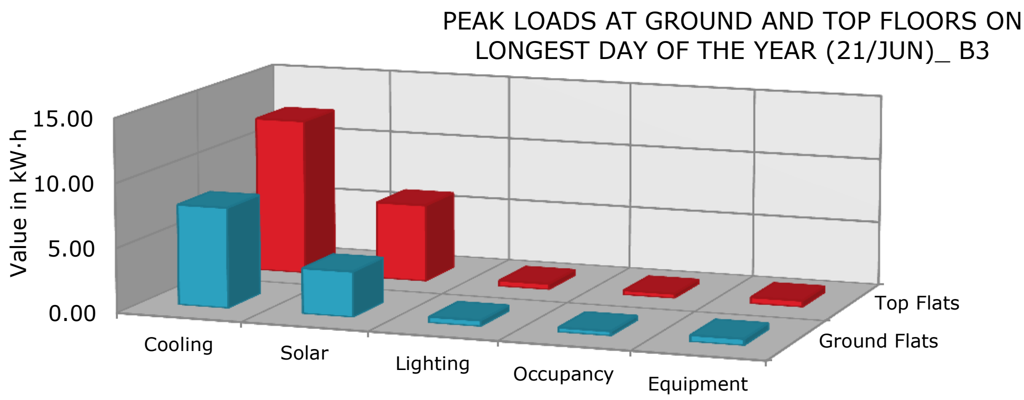


Figure 8.35: Different heat sources on ground and top floors at peak day of the year_ B3

As it is well known that cooling loads is the hourly amount of heat that must be removed from a building to maintain indoor comfort, it seems that top flats are less comfortable than ground ones since the heat that needs to be removed on top flats is 12.23 kW.h while on ground ones it is 7.80 kW.h. Figure 8.35 above shows an example from case study buildings that is one of the closest cases to the sea. Whereas solar loads which produced by sun radiation entering the building and converted into heat by absorption it becomes an additional heat load that leads to overheating of the interior in summer.

Figure 8.36 shows a high sum at top floor due to the exposed roof (6.07 KW.h) and less effect on ground floor at 3.51 KW.h. The solar loads are depending on the following building design aspects: glazing fraction / fenestration, shading devices, orientation, shading from external surrounding, specific heat storage capacity of the building and geometry of the room; and can be minimized if the surface is shielded from the direct rays of the sun or glazing fraction sun-shading on the outside of the facade but if this is not possible, painting the surface a light colour and adding insulation should be considered that because heat from the sun must be considered when identifying the total heat load on any system should be used. Figure 9.36 gives explanation for higher cooling load at top floor caused by high outside temperature that heating the external surfaces and allow heat to transfer through them to inside zones practically these ones just beneath exposed roofs.

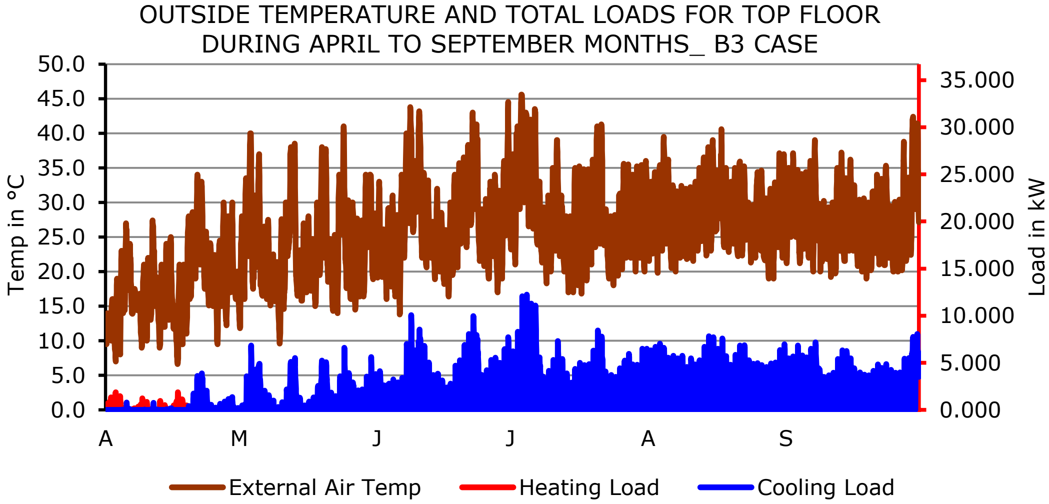


Figure 8.36: Hourly heating and cooling loads (in kW) and the summer temperature (in degrees C) for the entire project for the period from April to September.

The next case is one little far from the sea and blocked from north direction by other buildings. although internal heat gain show a higher trend in this case too but it is found to be higher than B3 case, from observation it seems to be caused by more frequently use of A.C system (6.54KW.h in total) and once more same situation occurs as above where top flats experience higher heat at both sectors (cooling and solar). The hourly amount of heat that must be removed from top and ground floors to maintain indoor comfort as shown in Figure 8.37 is 72.20KW.h and 47.16KW.h respectively; whereas solar loads shown high sum at top floor due to the exposed roof (22.13KW.h) and less effect on ground floor at 12.60KW.h.

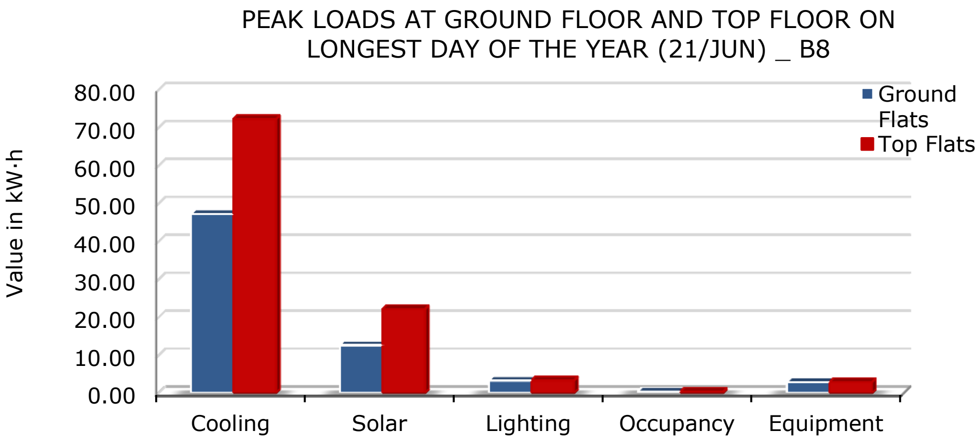


Figure 8.37: Different heat sources on ground and top floors at peak day of the year_ B8

Additionally, Figure 8.38 gives reason for higher cooling load at top floor caused by high outside temperature that reaches 45 °C in some days during summer and do heat the external surfaces in its way inside through that surface.

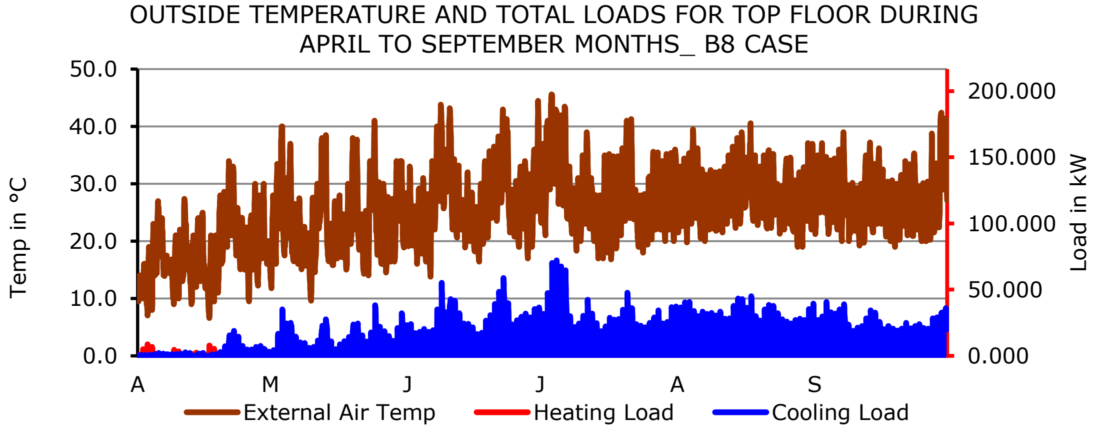


Figure 8.38: Hourly heating and cooling loads (in kW) and the summer temperature (in degrees C) for the entire project for the period from April to September.

However, studying all the above Figures it must be emphasised that there are high degrees of uncertainty in input data required to determine cooling loads. Much of this is due to the unpredictability of occupancy, human behaviour, outdoors weather variations, lack of and variation in heat gain data for modern equipment, and introduction of new HVAC equipment with unknown characteristics. These generate uncertainties that far exceed the errors generated by simple simulation methods compared to more complex methods. Therefore, results obtained from TAS simulation have a reasonable satisfactory level comparing with data that collected by the field survey.

8.7. FURTHER INVESTIGATION ON ISOLATED BUILDING _ BLOCK ZAT (B7).

A computer model has been created as close as possible to the existing building together with a very close to the monitoring work that is took place during the summer of 2010, all the details of those models are given later in the Appendixes, as well as the internal conditions such as lighting, occupancy and equipment gain which have been calculated with CIBSE A guide as a reference or collected during the fieldwork.

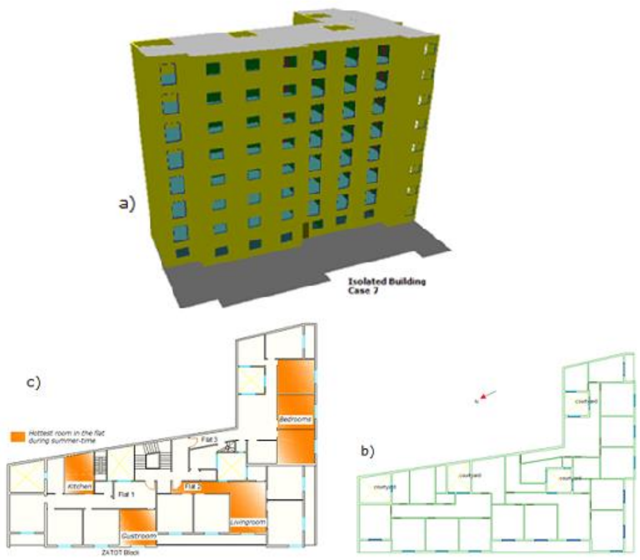
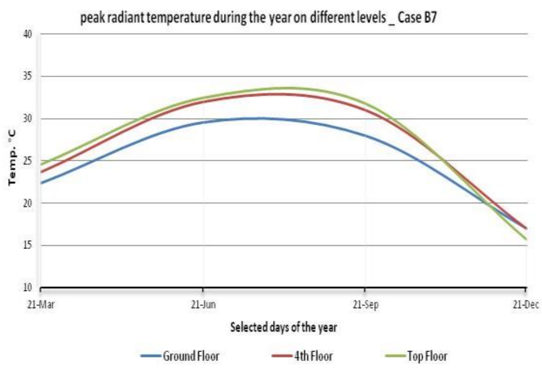


Figure 8.39: TAS work showing; a) perspective of case B7 as isolated building, B) plan of B7 and c) hottest rooms in the building during summer months colour in orange

Following, some analyses that took place on case B7 in order to exam the comfort level on difference flats' direction and highest, three floors have been chosen from ground, 4th and top floors. Figure 8.40 shows the average temperature during selected days of the year. The result is shown for three floors; ground, forth and top floors. Result shows that there is a close trend between 4th and top floors whereas ground floor demonstrates less high temperatures on the same selected days. Where the temperature during summer on ground floor reach up to 30°C and on same time of the year the fourth and top floors shown a close temperature of around 34 °C. Also the results reveal that on the day of 21st of December the temperatures on all floors are lower particularly on fourth floor.



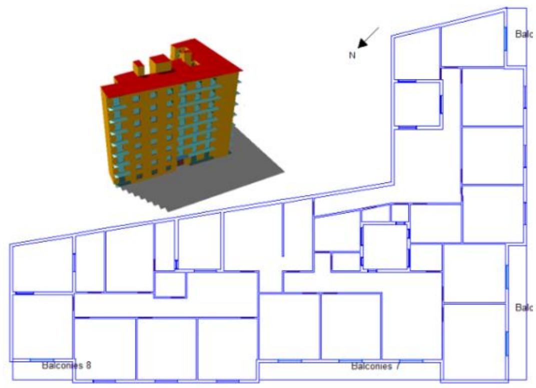


Figure 8.40: Peak RT on selected days of the year on different floors_B7 also below is the 3D and plan of B7 case

8.7.1. Internal zone temperature

Simulations have carried out to measure the existing comfortable temperature during summer months at ground, 4th and top floors. Figure 8.41 shows the number of resultant temperature that recorded on ground southwest flat in order to find number of hours situated within comfort range. For instant, bedroom 2 (southwest zone) with two windows at south and west directed ones, get nearly 200 hours above 32°C at 14:00, 15:00 and 16:00 hours of the day during testing period (91 days) as well as witness almost 600 hours of 28-29°C at 09:00 and 11:00 hours of the day. A similar situation expose in living room 1 (west zone), with little less hours above 32 °C and this is perhaps as a result of one window instead of two located on south direction, these zones are shown as uncomfortable places to be in Only the kitchen zone shows a close level to comfort it might due to it located on internal courtyard.

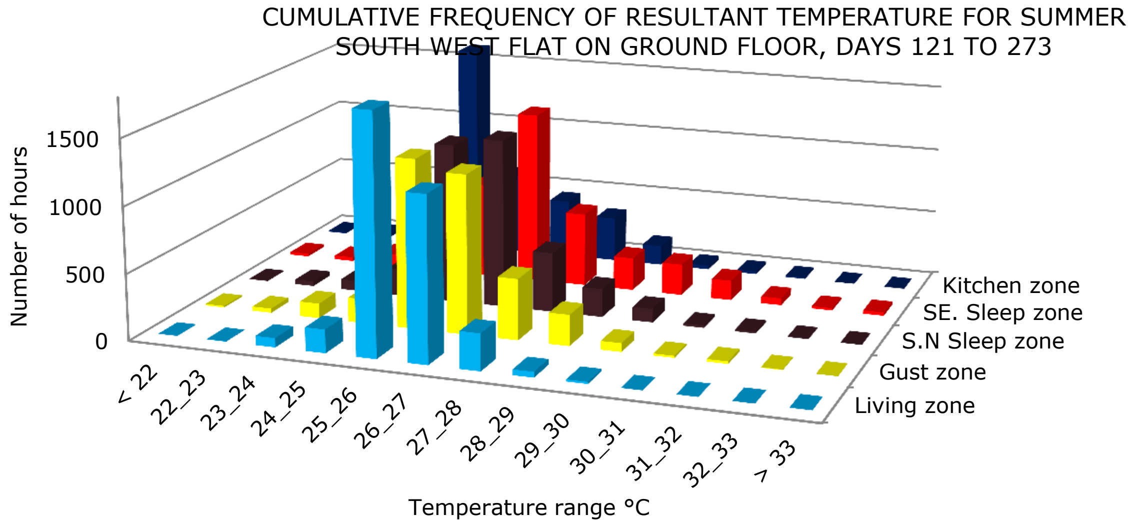


Figure 8.41: number of hours in relation with cumulative frequency of mean radiant temperatures during summer on southwest ground flat

The top floor (Figure 9.42) during summer time shows the result of southwest flat. The result indicated a similar trend line with ground floor but with more hot hours at top floor this is credited to the effect of solar heat gained through roof element.

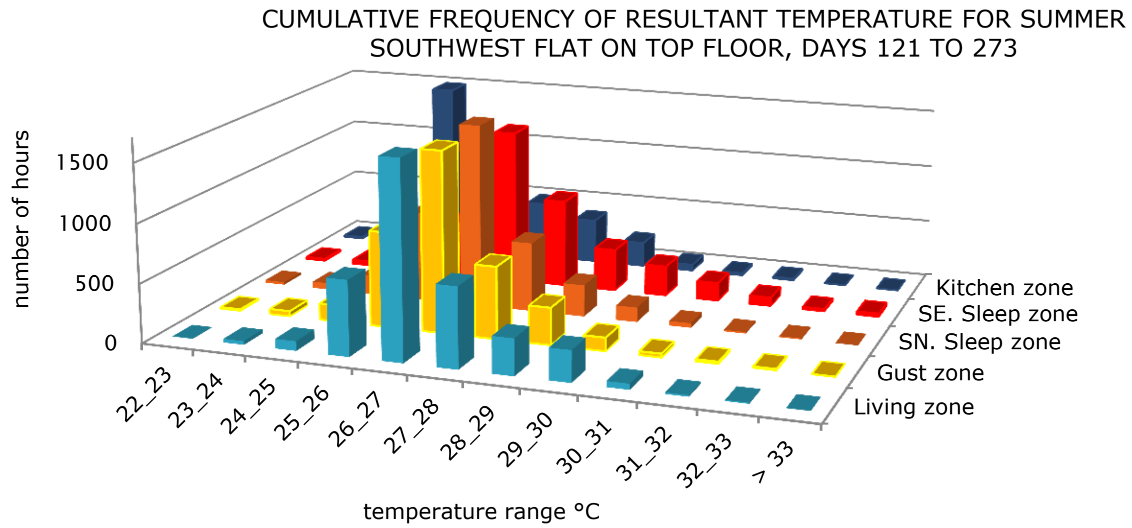
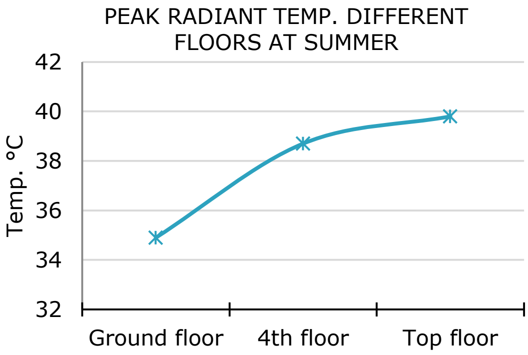


Figure 8.42: number of hours in relation with cumulative frequency of mean radiant temperatures during summer on southwest top flat

To conclude, here is a comparing between the three floors and it can be seen that the earth cover significantly improves the internal temperatures on ground floors, although these temperatures do not meet CIBSE's recommendation of temperatures design for habitable rooms but still the lowest ones between the other floors where the temperature rise to unacceptable level. Only 131 hours during the summer time are recorded to be within the range of comfort level while 2074 hours are above the comfort level in this southwest top flat.



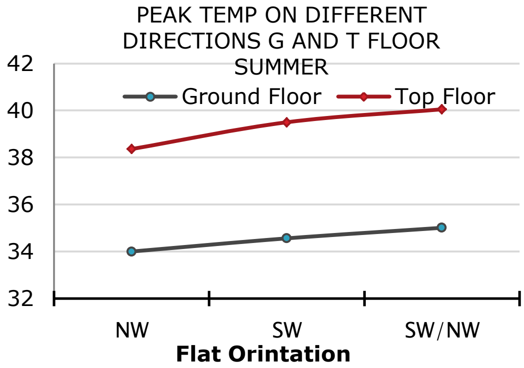


Figure 8.43: a) Peak temperature in different heights floors during summer time
b) Peak temperature in different directions on ground and top floor during summer time

Figures 8.43 (a & b) demonstrate that the differences between temperature on different floors and different directions. It is realizable that the ground floor has the lowest temperature between the other floors as a result of that; floor structure is in contact with the ground and lose heat by conduction into the ground itself in addition to the ground type of Darnah city which is sold rock that being a dense and highly integrated material, can conduct heat rapidly.

9.7.2. EXTERNAL SURFACE ANALYSIS

Another simulation has carried out in order to investigate the previous results to see which part of the building or its environment are transferring the most heat to internal zones. Also, testing the current material of the building envelope is essential in order to discover materials' strength and weakness so more examination are carried on both opaque and transparent external surfaces especially west and south ones. A test run on transparent surfaces is solar gain investigation and on other hand, Internal and external temperature surfaces, solar gain and internal and external conduction tests were organized on opaque surfaces.

8.7.2.1. Solar gain through glazed surfaces on different floors

Almost all of the windows are without external shading and all of these windows are using fabric blind (or curtains) as internal shading such a method is not a very efficient heat secure mechanism which can be used to good effect in winter, but is rarely desirable in summer that because it blocks the soft breeze too. An investigation on heat that is coming from solar gain at different floors show a very close result between 4th floor and top floor and the result varied on ground floor. Southwest surface on ground floor receives sun heat almost all the day hours but the amount is less than the northwest surface that as a consequence of the window's size in this direction which is much smaller than the NW one. Than this southwest surface turns to balcony's door at up floors instead of the small window. Another finding is the heat obtained from NW window shows a similar value at the three floors and almost at the same time of the day however, heat gained from the SW surfaces doubled at up floors. The two Figures below (8.44 & 8.45) show that;

peak solar gain on ground floor occurs at 17:00, 18:00 O'clock through northwest window whereas on the other two floors the peak gain arisen at 15 O'clock through southwest balcony door. This heat gain is undesirable at this time of the year and needs to depart the space by cool it down.

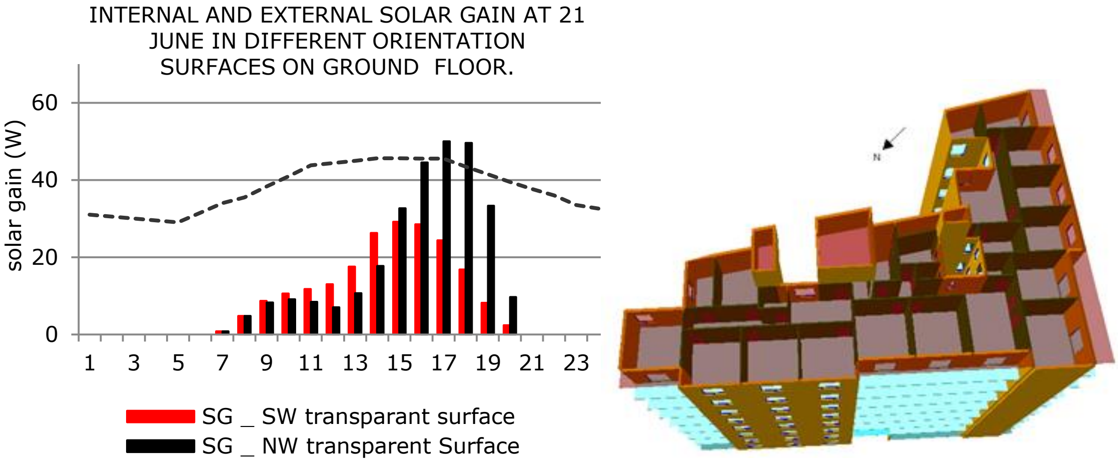
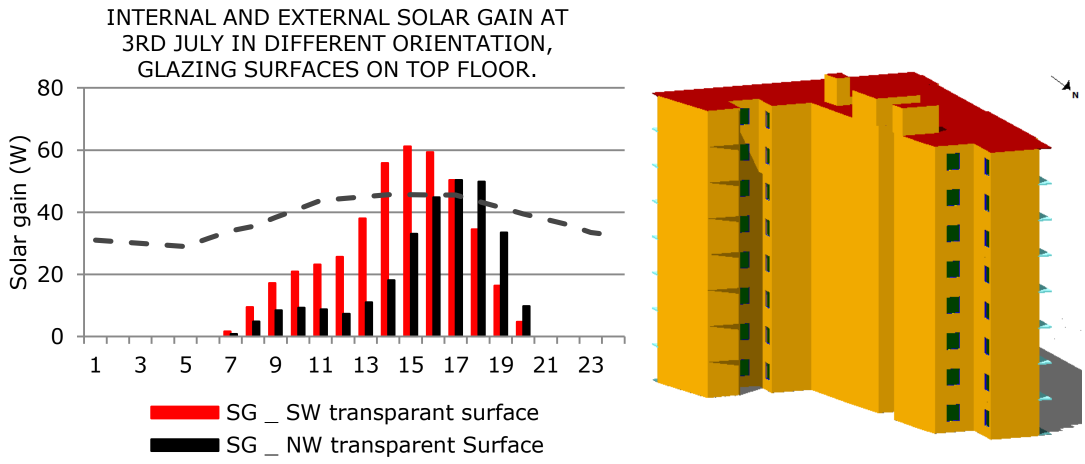


Figure 8.44: Solar gain through glazing at ground floor on hottest day average



8.45: Solar gain through glazing at top floor on hottest day average

8.7.2.2. Effect of using internal curtains on internal solar gain

The study survey revealed that 96% of people do use fabric curtains as a method of shading devices because of that, four zones were selected as an experiment to test the effectiveness of curtains as a solar controller. Two of them located on ground floor while the others on top floor. Data set at 15:00 pm which is the peak temperature hour. Evidence from simulation ground zones indicating that curtain does reduce internal solar gain on ground floor and top floor by 2.0% and 1.7% respectively, if its kept close all of the heat period. However, observation shows that the occupants do not know how to use these solar mean properly and almost all the day they leave it open for sunlight reason. In contrast, it is apparent from above table that very little improvement is shown in zone temperature when curtains are in use on ground level (reduction in temperature just 1.0%). Interestingly, on top floor the temperature increased with curtains in use, this result can be explained by blocking cross ventilation which is highly occur on top floor and help to reduce the temperature up to 1°C.

Table 8.5: Solar gain through a curtain's window compared with bare window on ground and top flats_ TAS results

Ground floor	External wall solar gain (w)	Zone temp. °C	Zone RH %
Window with curtains	1212.56	30.50	51.23
Window without curtains	1212.56	30.65	56.63
Reduction %	0.0	1.0	5.4
Top Floor	**External wall solar gain (w)**	**Zone temp. °C**	**Zone RH %**
Window with curtains	1418.92	35.7	43.28
Window without curtains	1418.92	34.3	48.20
Reduction %	0.0	-1.1	1.1

9.7.2.3. Analysis of external Opaque surfaces (walls & roof) at different floors

1. Opaque external surface temperature

In the case of opaque elements, the sun acts to heat up exposed surfaces, thereby increasing the amount of heat flowing through the building fabric. Considering Figure 8.46 it is clearly that west facing is the worse directions to have a surface directed to it. West facing surfaces are affected by direct solar radiation from afternoon to evening. From late afternoon to evening the altitude of the sun is lower allowing solar radiation to enter on a more horizontal path. The intensity of solar radiation in the summer months at these times is still high and it coincides with peak outside air temperatures. For instance, the temperature of external southwest surface can reach up to 50°C on late afternoon hour. In a building element, instantaneous heat flow will depend upon the characteristics of the materials that make up that element, as well as overall surface area and the temperature difference between inside and outside therefore since the conditions at the exterior surfaces appear to be similar on all floors it gives a conclusion of that in consideration of these surfaces are without insulation a huge quantity of heat will flow indoor resulting in overheating the next zone.

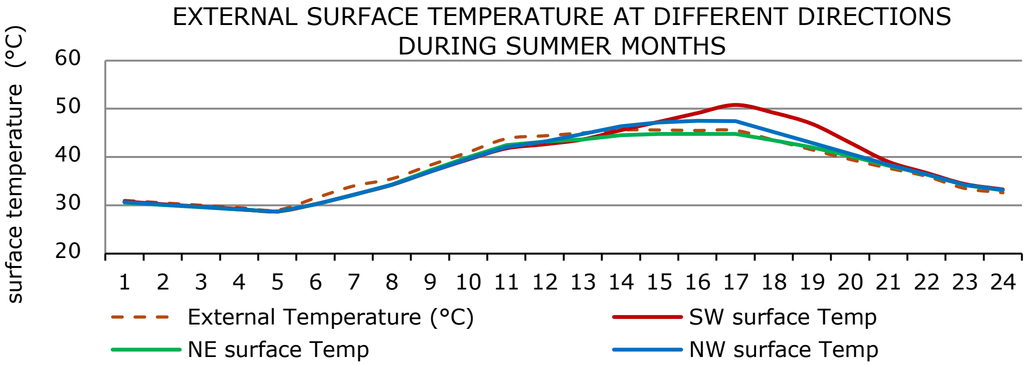


Figure 8.46: Peak temperature recorded on external surface on all floors during summer months

2. Opaque surface external conduction

Conduction is the amount of heat transfer through the fabric of the construction (in this case the heat is an internal heat). If the value is positive, the heat is being transferred to the near side of the surface. If it is negative, it is being transferred away. Conduction gains occur when heat from the outside flows through the external building envelope. This occurs almost exclusively by conduction so for this reason simulation by TAS runs to measure this phenomenon and neglected the others such as convection and radiation.

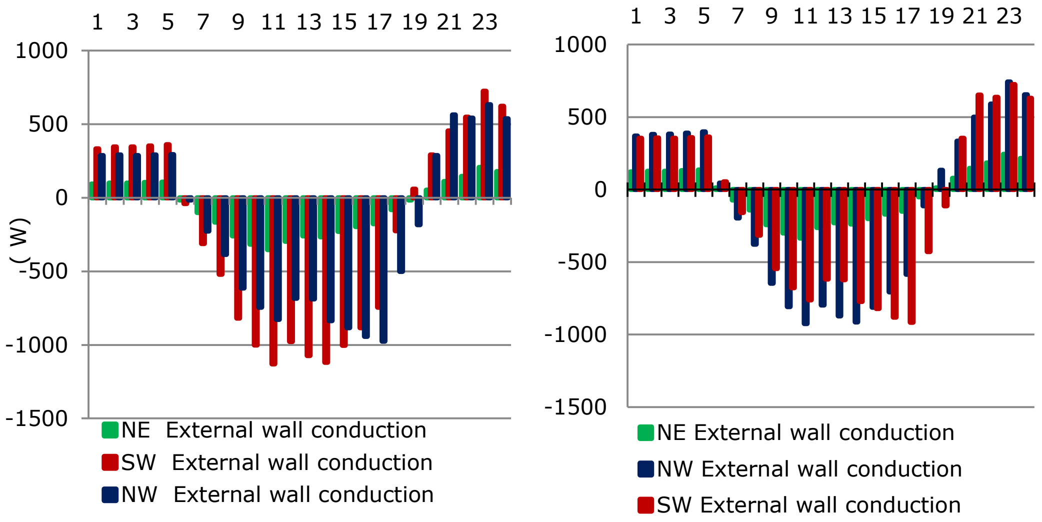


Figure 8.47: Heat conduction through external walls during summer times. A. ground floor and B. top floor

The amount of heat transfer through the fabric of the construction shown in Figure 8.47 that the positive value means the heat is being transferred to outdoor when the temperature indoors is higher than outside while the negative means that heat is being transferred indoors during day time from 7:00 O'clock to around 17:00 O'clock. The most important implementation reflected on the performance of SW wall is the increase in heat gain over night as the wall is observing more heat during the day time. It seems that the mechanism of heat transfer takes time to shift the direction of heat travelling from outer surface to inner and in the opposite direction. Considering this Figure prove that high temperature of external surface flow indoor by conduct to indoor zones.

3. Solar gain through windows and glazing balcony's doors

Indirect solar gains through opaque elements are slightly more complex. This is because the incident solar radiation acts first to increase the external surface temperature of the element. Figure 8.48 shows solar gain in W, this energy heats up the external surface and quickly transferred through the structure to indoors resulting in increasing the indoor temperature. Once more, southwest surface is the worse surface between the other envelopes' surfaces. For example, at 18:00 O'clock the southwest surface gain 2808.6 W and most of this value subsequently will transfer indoors. An investigation on heat that is coming from solar gain at different floors shows a varied result but not great significant difference. Southwest surface on ground floor receives sun heat almost all the day hours but the amount is less than the northwest surface that as a consequence of the window's size in this direction which is much smaller than the NW one. On top floor the southwest surface turns to balcony's door instead of the small window and therefore transfers mush more heat. Another finding is the heat obtained from NW window shows a similar value at the two floors and almost at the same time of the day however, heat gained from the SW surfaces doubled at up floors.

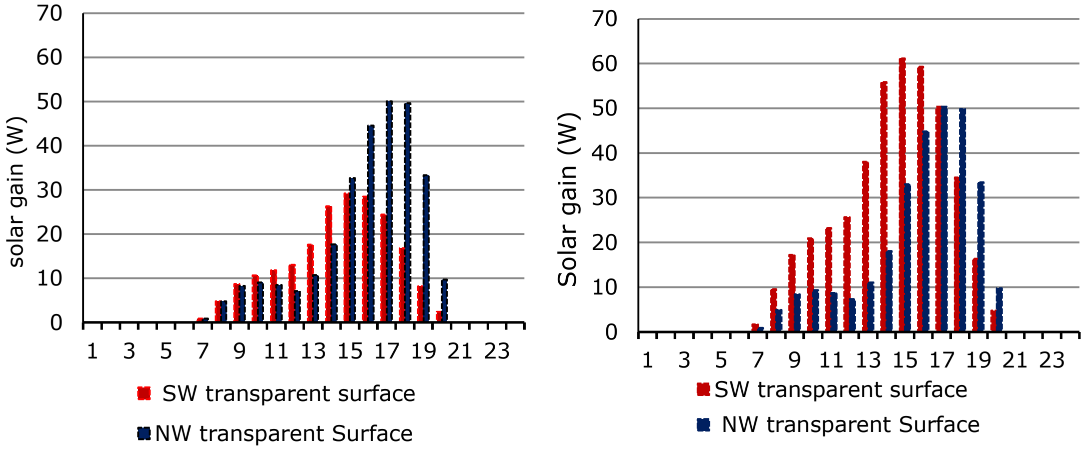


Figure 8.48: analysis results of external surface solar heat gain at different walls directions on a. ground floor and b. top floor summer time

One point that has to be highlighted is the direction of heat flow in glazing when comparing it with the solid wall. It can be noted that as glazing has a very poor thermal mass, it cannot hold or observe heat within its layers. It delivers the heat straight away once there are any temperature differences between outdoor and indoor. This can be proofed by seeing that as there is sunlight outdoor which indicting that outdoor is wormer than indoor, there is a continuous heat gain. In contrast, once it gets darker and the indoor is going to be cooler than outdoor, the heat flow reveres its direction. It has to be highlighted that the total heat conduction of glazing is by far lower than the one of solid wall. This done not indicate that glazing is not transferring any form of heat; it is more affective in delivering radiation heat for instance.

8.8. Results Summary

The results presented in the above chapter aimed to investigate the observation data and analysis that were obtained from fieldwork. The work took three steps; simulate all case study buildings than chose six different ones a la their location, orientation and design, last step was more detailed simulation on the isolated case B7 which was selected to be base. Some of the obtained results from simulation work are presented here in points as following;

1. Size of building do affect heat gain value, simulations show that narrow building (such as B2 & B3)is performing better than wide one, particularly if it has one or more façades directed to west or south where these two directions

found to be the worse directions in relation with room temperature. This led to another result; buildings' orientation play a significant role on heat gain during summer time, rooms are located on south or west show a high room temperature than those located on east or north directions. Top floor's rooms that located on a big courtyard are shown a better performance than those located on small courtyard while rooms of ground floor show reverse results in both courtyard cases.

2. Location near the sea is giving many advantages to occupants of these buildings; one of them is better performance in heat gain and less room temperature. And, to some extent, vegetation has some effect on indoor temperature and that according to its location, size and density; the result of the only case with tree bank located on east side (B10) shows value of 2541 W of heat gain on ground flats while the value was 11893.5 W without these trees, the simulation carried out on 21st of Jun.
3. In respect to indoor temperature, top flats is the worse where the temperature reach up to 39°C on peak day hours beside the temperature drop to uncomfortable level during night, the situation is different on ground flat when simulation indicated better performance on ground floor even though the recorded temperature still above the comfort level but not as high as those recorded on top floor.
4. Results of TAS simulation show that temperature at peak hour (16:00 and 17:00 O'clock) was in west or southwest flats. On top flats the highest temperature witnessed (38.0°C) and on ground flats was 31.1°C.
5. Lower temperatures at peak hour at west or southwest directions were as follows; 32.0°C recorded on top flats and on ground the lower temperature found to be 28.2°C and these recorded in peak hours of the day (16:00 and 17:00 O'clock). In regards to north flats to some extent lower temperatures were shown on ground floor where the highest temperature at peak hour was 29.3°C and on top flats the highest temperature at 17:00 hour was 32.7°C and 31.9°C in as lowest temperature on peak hour in north zones.
6. An investigation on solar heat flow through materials at different floors show a very close result between middle floors and top one while the ground case result varied. Southwest northwest surfaces on ground floor receive sun heat almost all the day. Simulation in relation with heat sources show that building envelope is the winner source of heat gain and transferring the heat from outside to indoor more than other sources such as occupants, equipment and light.

APPLYING NEW MODIFY AND IMPROVEMENT MATERIALS TO CASE STUDY BUILDINGS

Chapter 9 : Applying new modify and improvement materials to existing and future buildings

9.1. Introduction

This chapter concerns with the enhancement of the indoor thermal comfort of the residential buildings (in the case study area) by improving the building' envelopes, this approach for the improvement is attained for two reasons; the first is that the fabrics loss/gain has great impact on the thermal comfort and the thermal performance of case buildings as it is revealed through the survey as well as through the thermal simulation of the buildings. The survey indicated that the heat loss and gain through walls and roofs are the most influence factors causing discomfort in almost all flats particularly during summer. Also, the thermal simulation showed that the majority of heat gain in summer is the fabrics gain and represents up to 81% of the total heat gain. The second reason is that the quality of the buildings envelope can be controlled and monitored by the government and may this study be taken into account in the new housing project which still under planning in Libya. In this study, thermal simulation was conducted for different proposed buildings' components including; walls, roofs and windows. The proposed fabrics are applied on one case (B7). The potential improvement of the indoor thermal comfort is investigated by altering each element separately. Afterwards, combinations of the proposed components are simulated to reflect the thermal comfort levels attained through summer season to reflect the energy reduction achieved.

9.2. The use of insulation materials

In TAS software the most important aspect to be considered along with U-value of the building section is thermal storage. The used materials of case study buildings have the property of conducting heat or cold into or out from rooms. These materials have some insulation value presented in air space included within the hollow concrete block, which is not, however, effective to the extent desired for comfortable indoor environment. Results from TAS simulation presented in previous chapter show that large amount of outdoor heat flow indoors through walls, windows and roof. In addition, observation show that occupants in these buildings are using more A.C system or other ways for cooling during hot summer days which subsequently lead to high energy consumptions even though occupants have no other choices to feel comfortable. This research proves that insulations can reduce heat flow up to 66% when modified walls and roof are combined. Various types of insulation materials were applied to the walls and roofs in order to identify the possibility of increase thermal comfort indoors. Insulation materials that used in simulation at different thickness are; Mineral wool, fibre-glass, polystyrene, sheep’s wool, polystyrene, and polyurethane. Analyses that shown in this chapter are the output results from simulate B7 building as chosen to be the standard building because of its position of been isolated and there are no surroundings can affect heat flow through its external surfaces.

9.2.1. A case selecting as a sample among others

Due to time constraints, the proposed enhancements of fabrics could not be tested on all the studied buildings whose thermal performances were analysed in the previous chapter. Therefore, one standard building was drawn in accordance with three aspects; (1) thermal comfort, and (2) less sea effect, (3) no buildings surrounding effect. The least comfort building was identified and selected.

9.2.2. Simulation of the walls

9.2.2.1 Thermal modelling of various walls

As mentioned earlier in the literature view of this thesis (section 2.2), some authors indicate that the effectiveness of capacitive insulation (thenna1 mass) is acceptable where the diurnal variation of ambient temperatures exceeds 10 degree. According to the weather condition of the studied buildings' location, the range between monthly mean maximum and minimum temperature for the 12 months is higher than 10 degree. Therefore, thermal mass is proposed to be applied for the walls in order to examine its competence in achieving better thermal comfort particularly in the case study buildings. In addition, various resistive insulations were proposed because of their ability to control the heat flow through the walls in both directions. However, using resistive insulation could be appropriate in summer as the heat loss through walls is significantly higher than heat gain, as revealed by the thermal analysis of the example of case B7 in the previous chapter. This means that the thermal performance of walls with higher conductance could be more appropriate for summer. Therefore, in order to identify the best thermal comfort level that can be achieved through the all seasons, various types and thickness of walls were proposed and simulated. The resultant temperature in both a summer and a winter day was estimated with the implementation of the various proposed walls and compared with the MRT temperature in the case of the existing wall. Furthermore, the percentages of comfort hours through each season and through the whole year were predicted with the implementation of the proposed walls. Description for the tested walls and the simulation results are provided in the following subsections. Table 9.1 shows selected materials which built for TAS simulation, the materials chosen on the base of U-value as it has been shown that in average residential buildings, the total heating load is usually more sensitive to changes in wall U-value than to changes in the amount of thermal mass. However, total cooling load can often be impacted more by the addition of thermal mass than by wall insulation. 11 types of construction’s materials developed or modified were used in this stage; attached each time in different order to find out if this component has an effect on indoor temperature. The simulation runs on average summer day (21st Jun) also, it is important to note that W1, R1 and G1 are the current materials used in case study buildings and these surfaces are without insulations. The other coded materials are built up in order to get a better material that allows less heat transfer through external and internal layers of one complete surface such as wall and roof. Table (9.1) provides the proposed walls explaining their layers, thicknesses, and thermal conductance.

Table 9.1: description of different composition of simulated walls _ information are arranged according to U-value

Wall code	Description	Thickness (mm)	U-Value W/m² °C	Time constant Hrs
W1(existing use)	▪ Outside: external rendering ▪ Hollow concrete block ▪ Internal mortar plaster ▪ Inside: internal paint	15 200 20	3.11	3.97
W2	▪ Outside: Masonry (marble) ▪ Air gap ▪ Hollow concrete block ▪ Internal mortar plaster ▪ Inside: internal paint	25 15 200 15	1.30	6.03
W3	▪ Outside: cement rendering ▪ Mineral wool ▪ Hollow concrete block ▪ Internal sand cement plaster ▪ Inside: internal paint	20 50 200 15	0.64	9.93
W4	▪ Outside: cement rendering ▪ Fibre-glass quilt ▪ Hollow concrete block ▪ Internal sand cement plaster ▪ Inside: internal paint	20 50 200 15	0.54	10.76
W5	▪ Outside: cement rendering ▪ Expanded Polystyrene board[EPS] ▪ Hollow concrete block ▪ Internal sand cement plaster ▪ Inside: internal paint	20 75 200 15	0.46	10.41
W6	▪ Outside: cement rendering ▪ Extruded Polystyrene ▪ Hollow concrete block ▪ Internal sand cement plaster ▪ Inside: internal paint	20 50 200 15	0.40	11.68
				Continues
W7	▪ Outside: cement rendering ▪ Fibre-glass quilt ▪ Air gap ▪ Hollow concrete block ▪ Internal sand cement plaster ▪ Inside: internal paint	20 75 15 200 15	0.37	11.80
W8	▪ Outside: cement rendering ▪ Sheep's wool ▪ Hollow concrete block ▪ Internal mortar plaster ▪ Inside: internal paint	20 50 200 15	0.35	37.10
W9	▪ Outside: mortar plaster ▪ Extruded Polystyrene ▪ Hollow concrete block ▪ Internal sand cement plaster ▪ Inside: internal paint	15 50 200 15	0.32	10.83

W10	▪ Outside: cement rendering ▪ Polystyrene ▪ Hollow concrete block ▪ Internal mortar plaster ▪ Inside: internal paint	20 75 200 15	0.29	12.47
W11	▪ Outside: cement rendering ▪ Polyurethane ▪ Hollow concrete block ▪ Internal mortar plaster ▪ Inside: internal paint	20 75 200 15	0.22	12.53
W12	▪ Outside: cement rendering ▪ Polyurethane ▪ Hollow concrete block ▪ Internal mortar plaster ▪ Inside: internal paint	20 100 200 15	0.18	13.00

9.2.2.2 Temperature with proposed walls

The resultant temperature (RT) in both a summer and a winter days was estimated with the implementation of the various proposed walls (Figures 9.1 and 9.2). The simulation tests were applied on case B7 (ground floor and top floor)

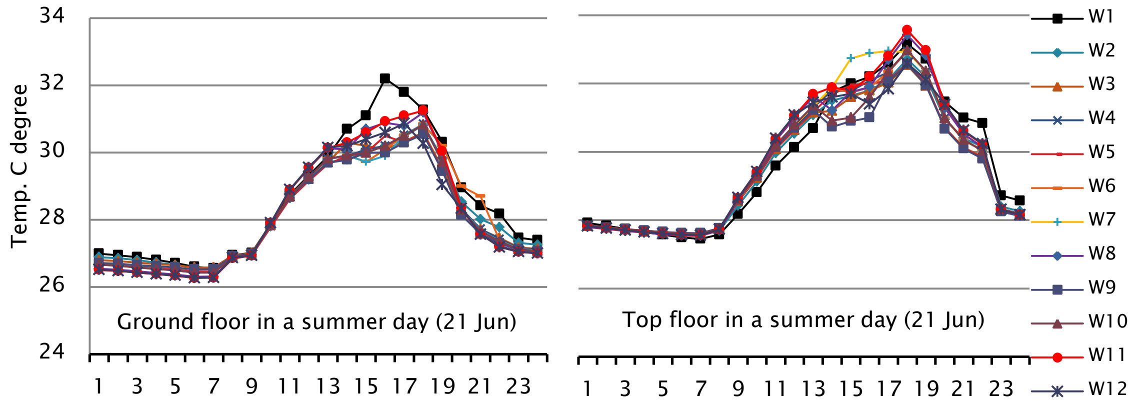


Figure 9.1: Summer Resultant Temperature in case B7 on ground and top floors with various proposed walls

As indicated in Figures 9.1 and 9.2, the lowest RT in a summer-day is estimated when applying W9 (a 200mm Hollow concrete block with 50mm extruded polystyrene) which has the highest time constant among all the proposed walls, followed by a very close result of using W10 (75mm Polystyrene). By using W9 or W10, the potential reductions in the resultant temperature on ground floor ranging between (0.3 to 2.2 °C) and (0.2 to 1.0 °C) on top floor achieved in a summer day. In contrast, W8 and W9 are the least efficient proposed walls for winter, as they allow for more heat loss resulting in drop in temperature. By using W12 (a 200mm Hollow concrete block with 100mm polystyrene), which has the lowest U-Value of the proposed walls, a more steady thermal environment is sustained as the internal temperature swings decrease with an average of 0.8 °c and 1.6 °c in winter and summer respectively.

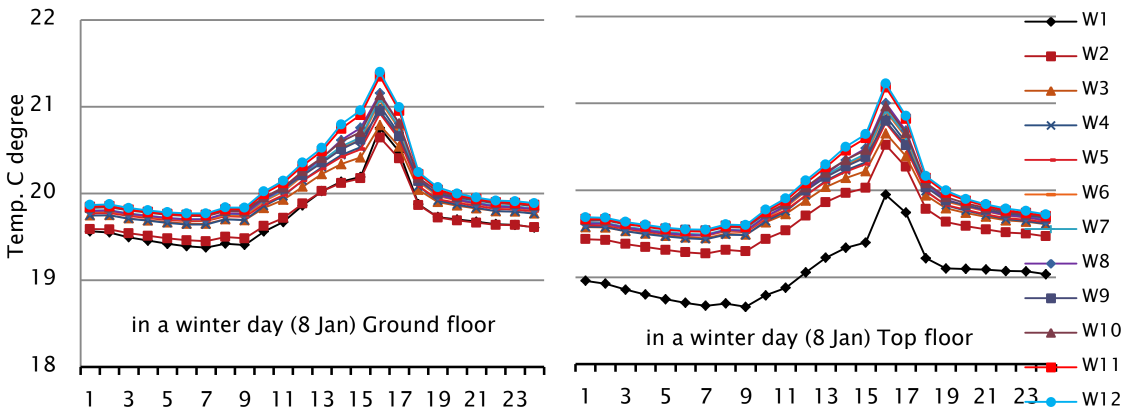


Figure 9.2: Winter Resultant Temperature in case B7 on ground and top floors with various proposed walls

Furthermore, this wall (W12) shown the lowest temperature during night time at ground floor on the summer day, while it recorded the highest temperature on both floors all day on winter tested day. In summer, the magnitude of potential reduce in temperature is higher than that in winter and reaches maximum of 2.0 °C on ground floor 1.0 °C on top floor and that on summer day. The temperature is reduced by the double between ground and top floor during summer, however, dissimilarity occurs during winter time where maximum reduce happened on top floor more than ground ones, 1.3 °C and 0.8 °C respectively. The potential improvement obtained by using W7 (a 200mm Hollow concrete block with 75 mm Fibreglass quilt and an air gap) is similar to that of W6 with a considerably increase in temperature at midday on top floor, summer day. Overall, using W7 and W6 has the potential to improve the internal thermal environment only in winter and that is also similar to W5, W4 and W3. The results revealed also by incorporating insulation materials such as mineral wool, glass wool, foamed polyurethane, extruded polystyrene, and expanded polystyrene with various thicknesses, 50mm and 100mm, a possible increase in temperature of about (1.2 to 2.7 °C) and (1.0 to 3.3 °C) could be obtained in summer on ground and top floor respectively. In winter, the magnitude of potential increase in temperature is lower than that in summer and ranges between (0.2 to 0.8 °C) and (0.6 to 1.3°C) on ground and top floor respectively. Overall, greater increase in temperature is attained with greater thickness and lower thermal conductance of the insulation material. Therefore the highest increase in temperature is achieved by using 100mm extruded polystyrene and the lowest is achieved by using 50mm mineral wool. Consequently, applying insulation materials for walls has the potential to improve thermal environment in winter but could make it worse in summer. Furthermore, The resultant temperature of the case of W1 (the existing wall), in both summer and winter that wall still the highest one during summer and lowest one during winter which proof that wall enhancement is needed to improve the existing situation. In a comparison between the potential improvements on both floors, it is observed that the highest possible increase or reduction in the temperature by applying the proposed walls is achieved on ground floor and then the top floor especially during summer.

9.2.2.3 Thermal Comfort with Proposed Walls

The percentages of comfort hours, where PMV ranges from (+ 1) to (-1), in summer and winter seasons were estimated with the implementation of the various proposed walls on both ground and top floors (see Figure 9.3). The potential increase or reduction of the percentage of comfort hours comparing with the existing wall is also provided in Table 9.2.

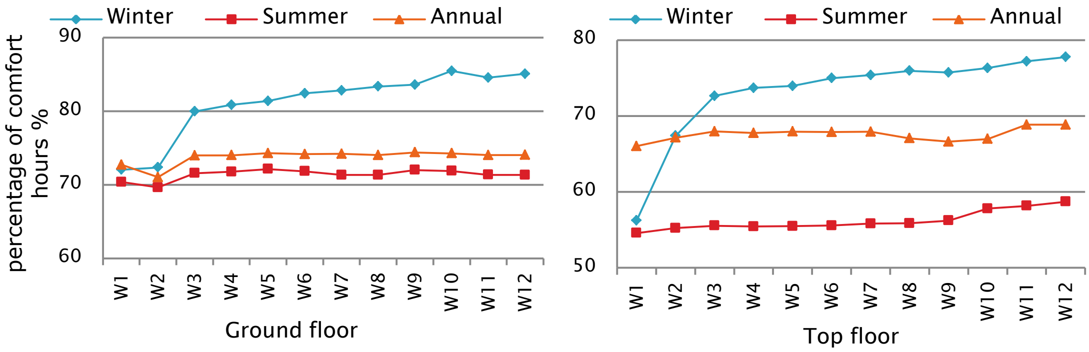


Figure 9.3: The potential increase or reduction of the percentage of comfort hours on both ground and top floors

Table 9.2: The potential increase or reduction of the percentage of comfort hours

	Ground floor			Top floor		
walls type	summer	winter	annual	summer	winter	annual
W2	- 0.7%	0.3%	-1.7%	- 0.4%	11.2%	-1.9%
W3	4.2%	7.9%	1.3%	-1.9%	16.4%	-1.1%
W4	4.4%	8.8%	1.3%	2.3%	17.5%	-1.3%
W5	4.8%	9.3%	1.6%	2.3%	17.7%	-1.1%
W6	4.5%	10.4%	1.4%	2.6%	18.8%	-1.2%
W7	4.0%	10.7%	1.5%	2.7%	19.2%	-1.1%
W8	4.5%	11.3%	1.3%	2.7%	19.7%	-1.0%
W9	4.6%	11.5%	1.7%	2.6%	19.5%	-0.8%
W10	4.5%	13.4%	1.6%	2.9%	20.1%	-1.1%
W11	4.5%	12.5%	1.3%	3.4%	20.9%	-1.2%
W12	4.5%	13.0%	1.3%	3.6%	21.5%	-1.2%

The result revealed that by applying W2 (a 200mm hollow concrete block with 25mm Masonry marble) very slight potential reductions of the percentages of comfort hours of about 0.7% and 0.4 could occur in summer on ground and top floors respectively, while a tiny increase of about 0.3% could be achieved in winter on ground floor whereas on top floor an increase of 11.2% could it be achieved. Overall, applying W2 could lead to a slight annual reduction of the percentages of comfort hours of about 1.7% and 1.9% on ground and top floors respectively.

Additionally, the highest percentages of comfort hours in summer on ground floor could be obtained by using W5 (a 200mm hollow concrete block and 75mm expanded polystyrene board) which are about 4.8% but the case is different when applying this wall on top floor where the highest percentages of comfort hours in summer occur when applying W12 not W5. On the other hand, the lowest percentages of comfort hours in winter on both floors are obtained by using W2.

By applying W8, W11 and W12 on ground floor similar results are obtained during summer and at annual level with a potential increase of the percentages of comfort hours of about 4.5%. However, in winter on same floor still with same walls types the possible increase of the percentages of comfort hours are difference between these walls with 11.8%, 12.5% and 13.0% increase in W8, W11 and W12 respectively. The results also revealed that by using W4 and W5 on top floor a similar increase of the percentages of comfort hours could take place in summer of about 2.3%, and a close result in winter of 17.5% and 17.7% respectively to these walls types, and in the entire year a reduction of the percentages of comfort hours ranges from 1.3% to 1.1% respectively. similar results occurred second time with these walls (W6 and W9) and (W7 and W8) on top floor where an increase of the percentages of comfort hours ranging from (2.6% to 2.6%) could occur in summer for each wall group, while in winter, the case differ with a possible increase of about 18.8%, 19.2%, 19.7& and 19.5% in W6, W7, W8 and W9 respectively.

The results revealed also by incorporating insulation materials with various thicknesses, 50mm and 100mm, could cause a possible increase in the percentages of comfort hours ranging about 13% to 21% on both floors in winter. However, in summer, the possible increase in the percentages of comfort hours is lower where it ranges between from (4% to 4.8%) and (2.3%to 3.6%) could take place on ground and top floors respectively. Taken as a whole, applying insulation materials in the proposed walls could lead to a slight annual increase of the percentages of comfort hours ranging about from (1.3% to 1.7%) on ground floor and a reduction that ranging about from (0.8% to 1.9%) on top floor.

Overall, greater increase in comfort hours is attained with greater thickness and lower thermal conductance of the insulation material. Therefore the highest increase in the percentage of comfort hours is achieved by using l00mm extruded polystyrene and the lowest is achieved by using 50mm mineral wool. In a comparison between the potential improvements in the thermal comfort on both floors, it is observed that the highest possible increase in the percentage of comfort hours by applying the proposed walls is achieved on ground floor in summer while the highest possible increase in the percentage of comfort hours in winter is achieved on top floor. This could be due to that ground floor benefit from earth to cool down during summer months, also the ground floor has its own characteristics such as surrounding buildings that keep the walls almost all day in shade and initially have effect on their thermal performance. This also revealed that highest possible increase in the percentage of comfort hours by applying the proposed walls in winter is exist on top floor because of walls are exposed to winter sun more and almost all buildings case are with lower surroundings than the building case itself.

9.2.3. Simulation of the roof

Roof used in the case buildings is flat type, which is mainly affecting top floor and since heat gain through this type of roofs is constant and independent of building proportion and orientation of building therefore the need for insert insulation materials within this surface is essential in hot climate countries. Flat roof is exposed to sun heat all daylong resulting in more deal solar gain received comparing by external walls in same building. In roof simulation different types of insulations were inserted than simulation runs many times to calculate the possibility reduction that can be achieved by adding these materials, example of these materials are polystyrene, bitumen, asphalt and air gap in different thickness. Results in this research show a good potential for saving energy by reducing heat flow indoors. Modifying the traditional roof is essential key, for example simulation using roof type R12 shows that indoor temperature can be reduced up to 4 degrees when this type of roofs applied along with W12 and G6 on top floors, and heat flow reduced by 63.1% with same above group. This reduction is as a result of using polyurethane materials (100mm) while when polyurethane material used (50mm) a reduction of 60.5% has been shown that the effect of the thickness of insulation materials. Table (9.3) provides the proposed roofs explaining their layers, thicknesses, and thermal conductance.

Table 9.3: description of different composition of simulated roofs _ information are arranged according to U-value

Roof code	Description	Thickness (mm)	U-Value W/m² °C	Time constant
R1	▪ Outside: cement rendering ▪ Concrete reinforced ▪ Inside: sand cement plaster	20 300 15	5.03	4.0
R2	▪ Outside: cement rendering ▪ Concrete reinforced ▪ Asphalt ▪ Inside: sand cement plaster	20 300 15 19	2.04	9.99
R3	▪ Outside: Roof tile ▪ Cement rendering ▪ Concrete reinforced ▪ Air gap ▪ Concrete reinforced ▪ Inside: plaster board	40 20 150 200 150 15	0.95	33.40
R4	▪ Outside: concrete roof tiles ▪ Bitumen	40 20		

	▪ Concrete reinforced ▪ Inside: sand cement plaster	300 15	1.9	16.50
R5	▪ Outside: concrete roof tiles ▪ Min wool quilt ▪ Bitumen ▪ Concrete reinforced ▪ Inside: sand cement plaster	20 50 20 200 15	0.58	23.73
R6	▪ Outside: Roof tiles ▪ Fibre-glass ▪ Bitumen ▪ Concrete reinforced ▪ Inside: plaster board	40 50 20 200 15	0.46	24.76
R7	▪ Outside: Roof tiles ▪ Polystyrene ▪ Bitumen ▪ Concrete reinforced ▪ Inside: plaster board	40 50 20 200 15	0.36	25.70
R8	▪ Outside: Roof tiles ▪ Min wool quilt ▪ Bitumen ▪ Concrete reinforced ▪ Inside: plaster board	40 75 50 200 15	0.34	27.93
R9	▪ Outside: Roof tiles ▪ Fibre-glass ▪ Bitumen ▪ Concrete reinforced ▪ Inside: plaster board	40 75 75 200 15	0.32	29.88
R10	▪ Outside: Roof tiles ▪ Bitumen ▪ Sheep's wool ▪ Concrete reinforced ▪ Inside: plaster board	40 20 100 200 15	0.29	24.88
R11	▪ Outside: Roof tiles ▪ Polystyrene ▪ Bitumen ▪ Concrete reinforced ▪ Inside: plaster board	40 75 50 200 15	0.26	28.86
R12	▪ Outside: Roof tiles ▪ Polystyrene ▪ Bitumen ▪ Concrete reinforced ▪ Inside: plaster board	40 100 50 200 15	0.25	28.94

9.2.3.1 Temperature with proposed roofs

The resultant temperature (RT) in both a summer and a winter days was estimated with the implementation of the various proposed roofs and then been tested on top floors of case B7 (see Figure 9.4 below).

The results revealed that by applying (R2) which composed of reinforce concrete slap with 15mm Asphalt, a potential increase in the resultant temperature of a maximum of about 3.1° C is achieved in winter, particularly during the daytime. In addition by using (R2) a potential reduction in the temperature of a maximum of about 1.4° C is achieved in summer, particularly at early day hours and midday hours. By applying (R12) which composed of light concrete slap with 100mm Polystyrene plus 50mm Bitumen, similar results to those of (R2) are obtained with very slightly higher potential reduction and increase of the resultant temperature in summer, however, during winter a significant different between those two roof types occurs mainly at daytime when the difference in temperatures is about +1.0° C at R12 type.

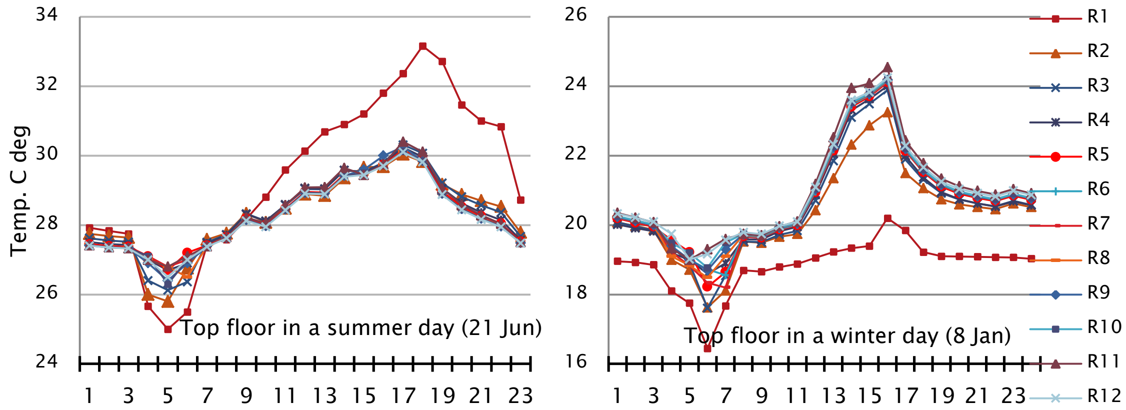


Figure 9.4: Resultant temperature on top floor with various proposed roofs, a. in a summer day b. in a winter day

The results revealed also by incorporating insulation materials such as mineral wool, glass wool, Bitumen, extruded polystyrene, and expanded polystyrene with various thicknesses, 20mm, 50mm and 100mm, a possible increase in the temperature ranging from 0.9 to 3.1 °C could be obtained in winter. In addition, a potential reduction in temperature of a maximum of 1.2 °C could be obtained in summer. Overall, greater increase and reduction in temperature in winter and summer respectively are attained with greater thickness and lower thermal conductance of the insulation material. Therefore the highest increase and reduction in the temperature is achieved by using 100mm polystyrene and the lowest is achieved by using 20mm Bitumen. Besides, it is noticed that the magnitude of reduction in RT in summer is lower than the magnitude of increase in RT in winter. This can be clarified by the thermal analysis of the existing fabrics presented in the previous chapter; where the analysis indicates that the total heat gain through roof in a summer day is lower than the total heat loss through roof in a winter day.

9.2.3.2 Thermal Comfort with Proposed Roofs

The percentages of comfort hours, where the PMV ranges from +1 to -1 (percentage of dissatisfaction is ± 25%), in summer and winter season of the year were estimated with the implementation of the various proposed roofs (see Figure 9.5). The potential increase or reduction of the percentage of comfort hours comparing with the existing roof is also provided in Table 10.4.

The result revealed that by applying (R2) which composed of reinforce concrete slap with 15mm Asphalt, a possible increase of the percentages of comfort hours of about 2.2% takes place in winter, while a slight reduction of percentages of comfort hours will happened of about 0.6% in summer.

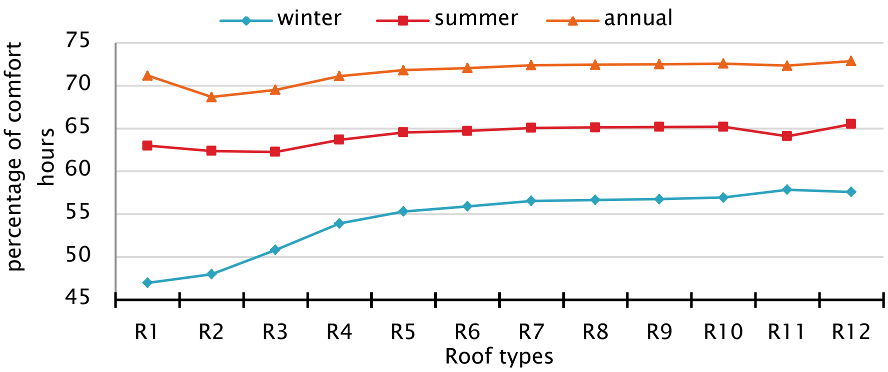


Figure 9.5: Percentage of comfort hours for various proposed roofs

Further, decrease of the percentages of comfort hours of about 1.7% occurs annually when using R2 roof type. By applying (R5) which composed of a Concrete reinforced slap with Min wool quilt and Bitumen, difference results to those of (R2) are obtained with higher potential increase of the winter percentages of comfort hours of about 10.1%, while an increase of the percentages of comfort hours will take place of 1.5% and 0.6% in summer and in the whole year respectively.

Table 9.4: percentage of increase or decrease of comfort hours for the proposed roofs

Roof type	Winter	Summer	Annual
R2	2.2%	-0.6%	-2.5%
R3	5.6%	-0.7%	-1.7%
R4	8.7%	0.6%	-0.04%
R5	10.1%	1.5%	0.6%
R6	10.7%	1.7%	0.9%
R7	11.3%	2.0%	1.2%
R8	11.4%	2.1%	1.3%
R9	11.5%	2.2%	1.3%
R10	11.7%	2.2%	1.4%
R11	12.6%	1.0%	1.2%
R12	12.3%	2.5%	1.7%

The results revealed also by incorporating insulation material with various thicknesses, 50mm and 100mm, (R7 to R12) a possible increase in the percentage of comfort hours of about 11.3 to 12.6% could be obtained in winter time. Besides, by using insulation materials a possible increase in the percentages of comfort hours ranging about from (1.0% to 2.5%) could take place in summer times. Taken as a whole, applying insulation materials in the proposed roofs could lead to a slight annual increase of the percentages of comfort hours ranging about from (1.2% to 1.7%). Overall, greater increase in comfort hours is attained with greater thickness and lower thermal conductance of the insulation material. Therefore the highest increase in the percentage of comfort hours is achieved by using 100mm extruded polystyrene and the lowest is achieved by using 50mm mineral wool. In a comparison between the potential improvements in the thermal comfort in the three columns in the above table, it is observed that the magnitude of the potential improvement by applying the proposed roofs is significantly great during winter than that in summer and annually times. This can be somewhat explained by that the climate is already warm during winter and the existing of thermal comfort as recorded by occupants is higher in winter.

9.2.4. SIMULATION OF GLAZING

Windows are the leading source of heat gain, accounting for nearly 50% of the heat that enters a home. Heat gain through glazing is depending on surface size, orientation and the present of shading devices also depending on glazing type where different types are available around the world from single to multiple layers with or without e-low, however, in third world countries such as Libya single type is the most used one which revealed the highest solar heat transferred type (+90% of solar radiation). In this research different types of glazing are simulated to test the potential for reduction heat flow and increase comfort indoors that can be achieved using each type of these glazing. As shown in Table 10.5, there are 6 forms of glazing used in TAS simulation which applied on the B7 case presenting in different types and thickness, from G1 the existing one to G6 the double clear with a blind.

Table 9.5: description of different composition of simulated glazing _ information are arranged according to U-value

Glaze code	Description	Width (mm)	U-Value W/m² °C
G1	Single clear	3	5.78
G2	Single with blind	In: light blind-15a- 6c	5.68
G3	Double clear (air)	6c-6a-6c	3.14
G4	Double clear (air)	6c-12a-6c	3.07
G5	Double clear with argon	4c-13ag-4c	2.66
G6	Double with inter blind	In: light blind-15a- 6c-20a-6c	1.60

9.2.4.1 Temperature with proposed glazing

The resultant temperature (RT) in both a summer and a winter days was estimated with the implementation of the various proposed windows on ground and top floors (Figures 9.6 and 9.7).

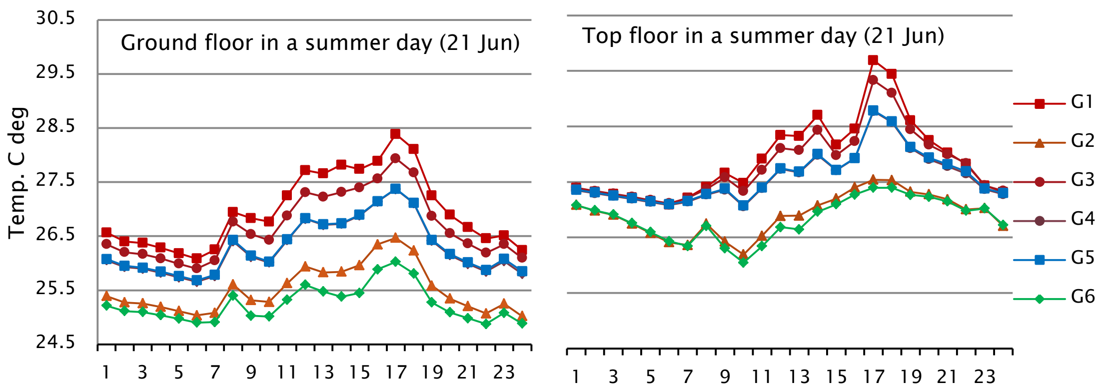


Figure 9.6: Summer Resultant Temperature in case B7 on ground and top floors with various proposed windows

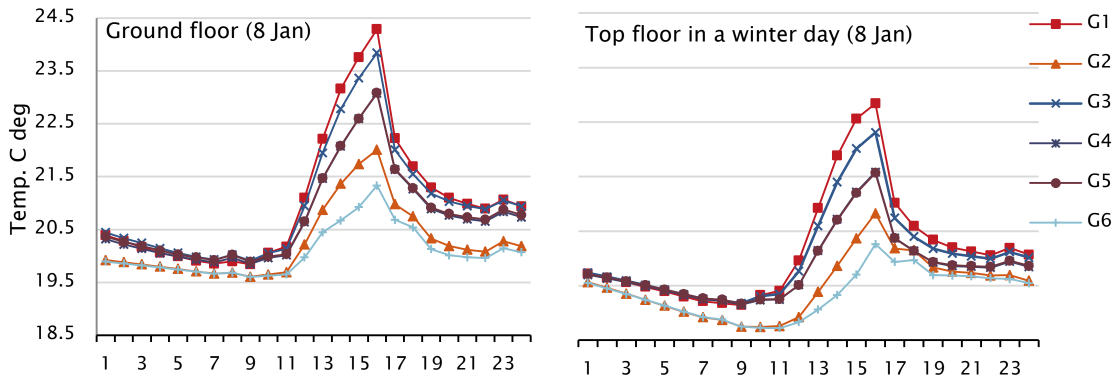


Figure 9.7: Winter Resultant Temperature in case B7 on ground and top floors with various proposed windows

The results revealed that by implementing double clear with air layer (G4) a potential reduction in the resultant temperature ranging from 0.7-1.0°C and 0.1-0.3°C on ground and top floors respectively is achieved in summer particularly during the daytime. Similar results to G4 case are shown by applying G3 type with a potential reduction in the resultant temperature of a maximum of about 0.6°C and 0.3°C respectively in summer and winter daytime. By using double glazing with argon layer (G5), a potential decrease in the resultant temperature of a maximum of about 1.0°C on both floors is achieved in summer, particularly during the daytime. However, this glazing type show a decrease in the temperature of a maximum of about 1.2°C on top floor during winter time, while a reduction of 0.8°C is occurs on ground floor. The results also revealed a significant reduction in temperature by implementing single glazing with blind (G2) both in summer and winter seasons. On ground floor during summer a reduction of 0.4–1.0°C is occurs while on top floor the reduction is 0.3-1.1°C. whereas, in winter at day time the reduction is 2.2°C on ground floor and 2°C on top floor. Such a reduction is welcome during hot summer days; however, the reduction in winter is undesirable as the temperature drop dramatically high. Similar result can be applying when using G6 type which is double glazing with internal blind, a good potential reduction is shown in summer but still the reduction in winter is high.

9.2.4.2 Thermal Comfort with Proposed Windows

The percentages of comfort hours, where the PMV ranges from (+ 1) to (-1), in each season of the year were estimated with the implementation of the various proposed windows on both ground and top floors (see Figures 9.8). The potential increase of the percentage of comfort hours comparing with the existing windows also provided in Table 9.6.

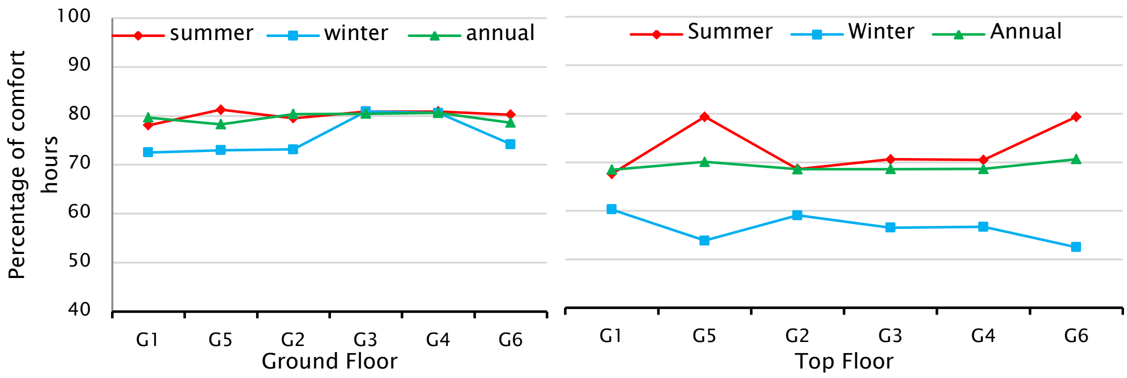


Figure 9.8: Percentage of comfort hour for proposed windows

The results show that by implementing single glazing with blinds (G2), potential increases in the percentages of comfort hours of about 3.1% and 11.8% are achieved in summer, however, the potential improvement in winter is considering with very low result at top floor of – 7.7% reduce in comfort hours. So, applying G2 seems that can be at some level benefit the ground floor but not the top floor in winter time, but taken as a whole, applying (G2) could lead to annual increases of the percentage of comfort hours of about 1.6% on top floor while it will reduce the percentage of comfort hour by 1.4% on ground floor.

Table 9.6: Potential increase or reduction of percentage of comfort hours for the proposed windows

	Ground floor			Top floor		
windows type	summer	winter	annual	summer	winter	annual
G2	3.1%	0.5%	-1.4%	11.8%	-7.7%	1.6%
G3	1.4%	0.6%	0.7%	1.0%	-1.2%	0.1%
G4	2.7%	8.4%	0.8%	3.0%	-3.8%	0.3%
G5	2.8%	8.1%	1.0%	2.9%	-3.6%	0.2%
G6	2.1%	1.6%	-1.0%	11.8%	-6.4%	2.2%

It is also observed that, among all the proposed windows, the highest magnitude of the potential improvement in terms of thermal comfort, in summer and in the entire year, is attained by using (G4). By implementing double glazing with 12mm air layer (G4), potential increases in the percentages of comfort hours of about 2.7% and 3.0% are achieved in summer on both floors, while a reduction of about 3.8%, could take place in winter on top floor. Hence, slight annual increases in the percentages of comfort hours of about 0.8% and 0.3% could be achieved on both ground and top floors respectively.

The results also show that by implementing double glazed windows with 6mm air layer (G3), a potential increase in comfort hours is achieved in summer (1.4% ground floor and 1.0% top floor), while a reduction of the comfort hours could happen in winter at top floor (1.2%), leading to slight annual improvement of about 0.7% and 0.1 on ground and top floors respectively. It is observed that, all the proposed windows are highly effective on ground floor while on top floor the case is different where the potential increase in comfort hours is high in summer but not in winter. This could be explained by that the windows on top floor are more exposed to solar radiation than that on ground floor and during winter the existing glazing system allow more sun heat penetration into the space and warm it up.

9.3. Combination of modified walls, roofs and glazing

After data collection through fieldwork, TAS and other software simulation, this section is where all those analysis and results will be translated into action in order to establish new component materials that have the potential to reduce heat gain and indoor temperature to achieve the goal of this research which is set the comfort level up. The last step of this work was to combine improved materials together, each time a group with different type of walls, roofs and glazing. Than simulation took place on each group twice to investigate heat gain which represent cool load and indoor temperature which represent thermal comfort indoors.

9.3.1. Heat gain reduction

Eelier, in chapter 9 results from TAS showed that heat gain through buildings generated by interior and external sources; however results also showed that internal sources have a little impact on comfort and building performance while external building envelope (walls, windows, roof) are responsible for almost 90% of heat expand to indoors. Results reported in the next few Figures show a decline amount of heat gain after applying the improved materials.

9.3.1.1. Walls and roofs simulation

Figure 9.9 shows the arrangement of improved walls and roofs after been grouped with each other. Results confirm that heat gain can be reduce when applying insulation materials to buildings, for example, the existing material (W1 & R1) which include no insulation supplies approved to have the maximum heat gain (87985 W.hr) while other modified materials show a huge decrease in heat gain through a year (e.g. W12& R12 = 21451 W.hr). Considering the results that presented in Figure 9.1 it is clear that roof type R12 is the most effective materials that because it shows the minimum heat gain with each type of walls. R1 type, which is the current one in use, is the highest one related to heat gain with all walls types.

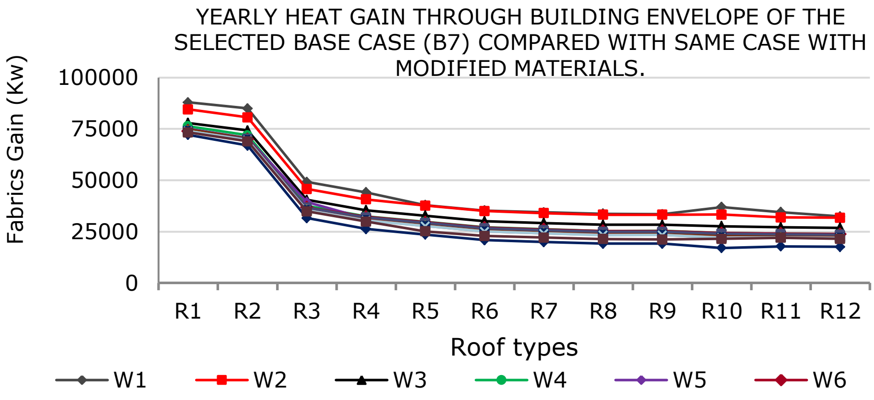


Figure 9.9: Yearly heat gain through building envelope of the selected base case (B7) compared with same case after applying new modified materials_ examine carried on top floor

Results also showed in such climate, it is clearly that huge saving could be accomplish by improving roof's materials more than if it happens in walls. In other words, the estimated yearly heat gain by combining R1 &W1 was 87985.9 W.hr, and heat gain in case of R1& W12 was 73359.6 W.hr (vary 1.19%), however, heat gain at R12 & W1 combination is 32385.4 W.hr which is differ 2.73% from the combination of same wall with roof type R1. Promising reductions which estimated by TAS simulation are presented as a percentage in Figure 10.12. Obviously, combination of R12 and W12 gives the maximum reduction of 77.8%, yet R12 is also showing a potential saving with all walls types. It is important to note that R12 roof type is the one that has an insulation of 100mm of polyurethane material.

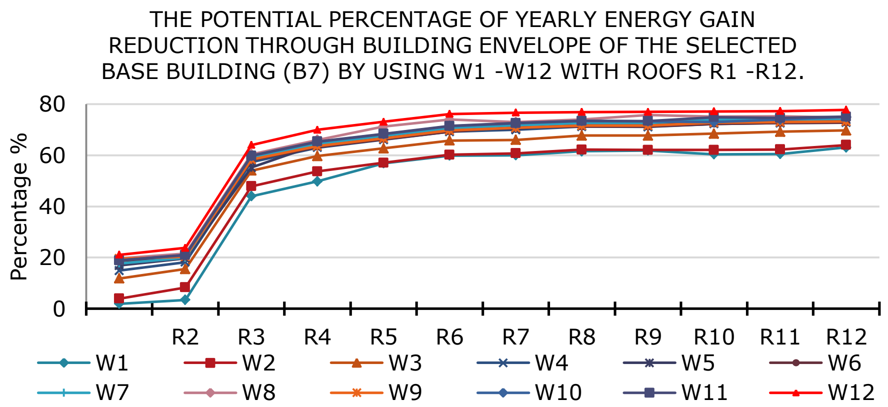


Figure 9.10: Potential percentage of yearly energy gain reduction through building envelope of the selected base case (B7) by using W1 -W12 with roofs R1 -R12.

9.3.1.2. Walls and glazing simulation

Figure 9.11 reveals the performance of various glaze typing when combine with walls W1 to W12. Single glaze type (G1) that use in case study buildings showed a maximum heat gain with respect to W1 to W12. The highest performance type was G6 type (double clear with blind) with all walls types. For example, G6 & W1 perform a yearly heat gain of 20539.3 W.hr whereas G6 & W12 respond was 19387 W.hr which make a different of 1152.3 W.hr between both cases.

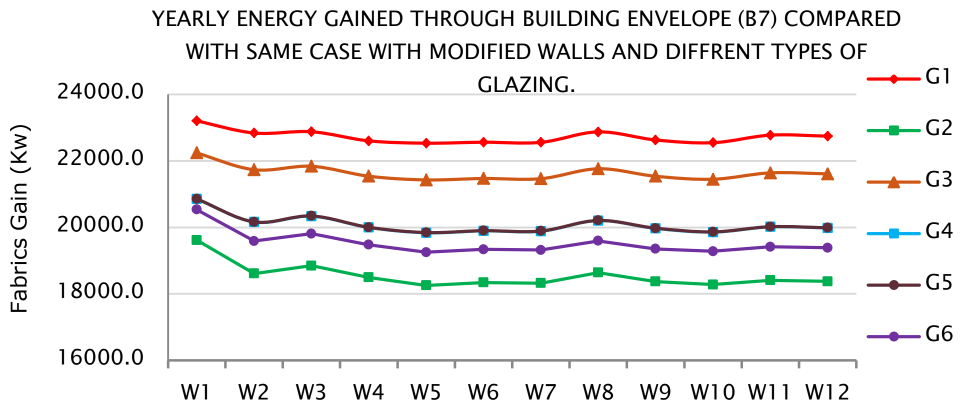


Figure 9.11: Yearly heat gain by using different walls type with glazing types_ examine carried on top floor

In the same way, percentage Figure shows a considerable heat gain reduction in all glazing types when used alongside all forms of improved walls. Yet, G2 type still the highest percentage performance form with minimum heat gained, even with W1 the existing wall it shows 16.3% reduction of heat gain but with improved walls such as W7 and W10 the reduction percentage is 24.6% and 25% respectively. on on another hand, glazing types G4, G5 and G6 fund to be also proper to use during winter season with acceptable potential of energy gain reduction. These glazing types are double layers with various thickness and design shown that a potential percentage of yearly energy reduction could be about 16%, 16.3 and 19.7% by using G4, G5 and G6 with W12 respectively as shown in Table 9.7. Overall, a reduction of 1.6% to 25% has been indicated through TAS simulation when improved glazing types are used with highest reduction of heat gain by using (G2) type; therefore, local authorities should consider serious efforts in order to start applying sealed single glazing with blinds (G2) windows in future buildings. This type of windows (G2) will be selected to be used in the combinations of fabrics for different reasons. First, the highest increase in the percentage of comfort hours in summer and in the entire year is achieved by implementing single glazing with blinds (G2). Second, single glazing is less costly than double glazing. Third, by implementing double glazing, slightly more comfort is attained in winter than that attained by using single glazing but a reduction could take place in summer leading to lower annual improvement. Fourth, blinds can be manually controlled by the occupants, while using glazing with reflective layer would reduce the solar gain in both summer and winter resulting in lower thermal comfort in winter.

Table 9.7: Potential percentage of yearly energy gain reduction through building envelope of the selected base case (B7) by using W1 -W12 with glazing types

	G1	G2	G3	G4	G5	G6
W1	0%	16.3%	4.3%	11.2%	11.5%	13%
W2	1.6%	22.7%	6.8%	15%	15.2%	18.5%
W3	1.4%	21.1%	6.3%	14.1%	14.3%	17.1%
W4	2.7%	23.4%	7.7%	16%	16.2%	19.1%
W5	3%	24.8%	8.3%	17%	17.2%	20.5%
W6	2.8%	24.5%	8%	16.6%	16.8%	20%
W7	2.9%	24.6%	8.1%	16.7%	16.9%	20.1%
W8	1.4%	22.4%	6.6%	14.9%	14.8%	18.4%
W9	2.5%	24.3%	7.7%	16.1%	16.3%	19.9%
W10	2.9%	25%	8.2%	16.8%	17%	20.3%
W11	1.9%	24%	7.2%	15.9%	16.1%	19.5%
W12	2.1%	24.2%	7.4%	16.1%	16.3%	19.7%

9.3.1.3. Roofs and glazing simulation

Results of roofs and glazing combinations indicate little different in relation with heat gain between glaze types apart from existing type (G1) which reveals the maximum heat gain with all roof types, for instance, when it joins with R4 the value of heat gain was 24069.05 W.hr and with R9 the value was 22378.7 W.hr which still higher than the heat gained by other glazing types with same roofs or the rest of other types. Result of case G1 combined with R1 in Figure 9.12 supports the observations that explained previously in chapter 8 when analyses show that existing materials absorb high level of heat that increasing indoor temperature and so affecting occupants comfort level.

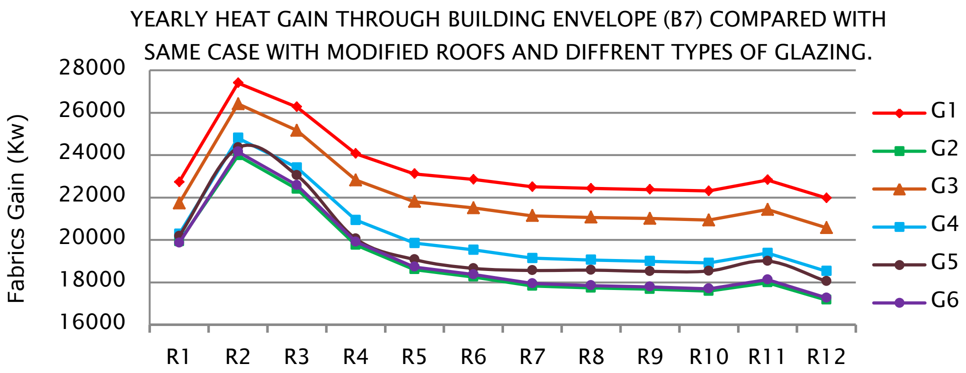


Figure 9.12: Yearly heat gain by using different roofs with glazing types_ examine carried on top floor

In additional, Table 9.8 indicates a significant change in percentage between case study glazing type (G1) and the rest of other glazing forms. G1 type is revel to be the lowest type of heat gain reduction in respect with all roof types where other types shown more potential reduce practically when used together with R7 up to R110 and R12 (for more Figures present comparison of annual loads after combing different glaze styles with different types of walls and roofs see appendix 5).

Table 9.8: Potential percentage of yearly energy gain reduction through building envelope of the selected base case (B7) by using various glazing with modified roofs

	G1	G2	G3	G4	G5	G6
R1	0.00%	14.12%	4.62%	12.07%	12.62%	14.48%
R2	-17.05%	-5.21%	-13.95%	-8.37%	-6.65%	-5.92%
R3	-13.49%	1.48%	-9.66%	-2.90%	-1.38%	0.68%
R4	-5.57%	15.05%	-0.39%	8.59%	13.30%	14.19%
R5	-1.67%	22.21%	4.26%	14.51%	19.16%	21.40%
R6	-0.52%	24.54%	5.67%	16.36%	21.82%	23.72%
R7	1.01%	27.50%	7.53%	18.77%	22.47%	26.68%
R8	1.35%	28.15%	7.93%	19.30%	22.37%	27.34%
R9	1.57%	28.59%	8.20%	19.65%	22.74%	27.77%
R10	1.88%	29.25%	8.59%	20.17%	22.62%	28.44%
R11	-0.43%	26.41%	6.04%	17.31%	19.62%	25.39%
R12	3.44%	32.42%	10.50%	22.70%	25.96%	31.64%

9.3.2 THE PROPOSED COMBINATIONS OF BUILDING ENVELOPE

With the original floor, one of the proposed windows, 5 of the proposed roofs, and also 5 of the proposed walls were selected to form 25 combinations of fabrics. The selection was based on the potential improvement in thermal comfort beside the cost of the materials. The single glazing with blinds (G2) is selected to be used in the 25 combinations of fabrics for different reasons. First, the highest increase in the percentage of comfort hours in summer and in the entire year is achieved by implementing single glazing with blinds (G2). Second, single glazing is less costly than double glazing. Third, by implementing double glazing, slightly more comfort is attained in winter than that attained by using single glazing but a reduction could take place in summer leading to lower annual improvement. Fourth, blinds can be manually controlled by the occupants, while using glazing with reflective layer would reduce the solar gain in both summer and winter resulting in lower thermal comfort in winter. Form the proposed roofs, five of them are selected (R7, R8, R9, R10, and R12) and from the proposed walls six of them are selected (W5, W7, W10, W11, and W12) to form the combinations as explained in Table (9.9).

Table 9.9: Description for the proposed combinations of fabrics

	Combination **code** = integrated elements				
A	C1a= W5 R7 G2	C2a= W7 R7 G2	C3a= W10 R7 G2	C4a= W11 R7 G2	C5a= W12 R7 G2
B	C1b= W5 R8 G2	C2b =W7 R8 G2	C3b =W10 R8 G2	C4b =W11 R8 G2	C5b =W12 R8 G2
C	C1c= W5 R9 G2	C2c = W7 R9 G2	C3c = W10 R9 G2	C4c = W11 R9 G2	C5c = W12 R9 G2
D	C1d= W5 R10G2	C2d= W7 R10G2	C3d= W10 R10G2	C4d= W11 R10G2	C5d= W12R10G2
E	C1e= W5 R12 G2	C2e= W7 R12 G2	C3e= W10 R12 G2	C4e= W11 R12 G2	C5e= W12 R12G2

These chosen walls are selected as they generate the highest potential improvement for thermal comfort in summer among the other proposed walls. Similar is the selected roofs which are selected to form a combination with relatively good annual potential improvement in terms of thermal comfort and energy savings. Besides, the proposed roofs (R7, R8, R9, R10 and R12) and the walls (W5, W7, W10, W11, and W12) which incorporate extruded polystyrene and expanded polystyrene with various thickness, 50mm and 100mm also mineral wool and glass wool are selected to form combinations with high potential improvements for the entire year as overall and for summer in particular.

9.3.3. Temperature with proposed combinations of fabrics

Another essential simulation was needed to find out more about comfort level indoors that is the resultant temperature (RT) in both a summer and a winter days was estimated with the implementation of the 25 proposed combinations on the isolated case B7 to investigate the changes that happened after applying the new modified materials. All in all, applying new combinations of improved materials indicate that there are huge reductions in indoor temperature which subsequently improve the level of thermal comfort for buildings' occupant which was the goal of this research. Also, what needs to be emphasised here is that different insulations materials can be used in same building that because earlier simulations in chapter 9 show lower temperatures on ground floor and more hours of comfort temperatures were recorded, therefore, for example, combination of W12, R12 &G6 may not suit the case of ground floor. Combination of W7& R7 or W9& R9 with G4, G5 & G6 appear to be more suitable in ground floor. Also, simulation shows the use of roofs such as R7 up to R12 is useless at ground and middle floors that because these floors have internal roofs which exposed to sun are zero hours.

The results revealed that by implementing the fabrics combination (C1 a-e) as shown in part (a) of Figure 9.13, potential reductions in the resultant temperature ranging from (2.5°C – 4.0°C) are achieved in summer among all five combinations that include wall type W5 (hollow concrete block 200mm and expanded Polystyrene board 75mm) with the highest reduction is obtained by applying (C1e _ 4.0°C) and the lowest is obtained by applying (C1a _ 2.5°C). Whereas, part (b) of Figure 9.13 shows the result of the second combination which formed using W7 (hollow concrete block 200mm and fibre glass quilt 75mm) where the results show that potential reductions in the resultant temperature are ranging from (2.6°C – 4.2°C) with a significant reduction when applying C2e (W7, R12 &G2) particularly in the late night hours with (3.1°C – 4.3°C) reductions. By implementing the combination (C3 a-e) potential increases in the resultant temperature ranging from (2.1°C – 4.0°C), and (2.6°C – 4.2°C) are achieved in summer by applying (C3a,b,c and d) and C3e respectively as the first four combinations show very close results. Besides, potential reductions in the resultant temperature ranging from (3.1°C – 4.2°C) are achieved in summer when applying C4 a, b and e.

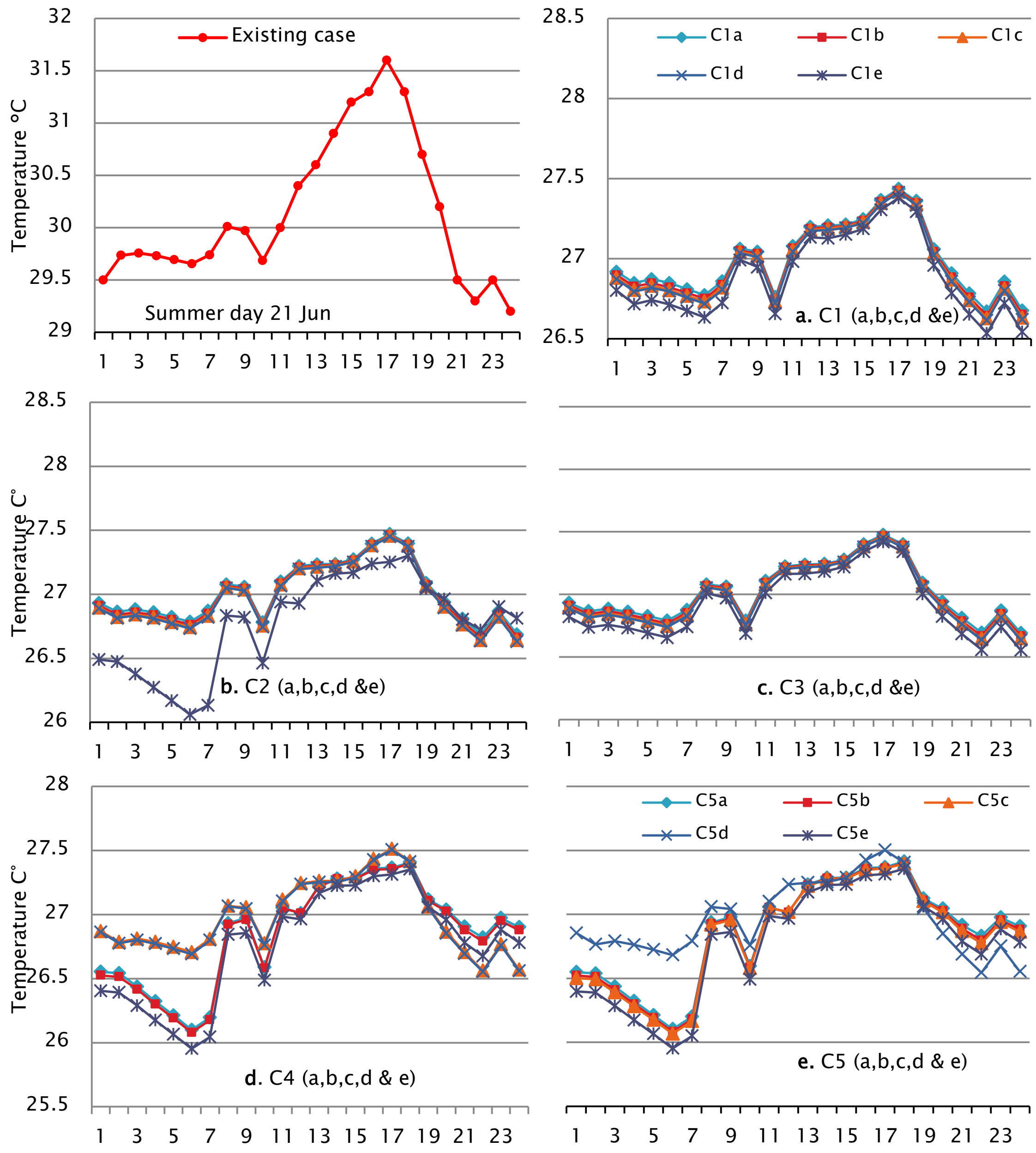


Figure 9.13: Resultant Temperature in case B7 with various combinations of fabrics on a summer day (21st Jun) _ first graph present the existing case of B7 while a to e graphs present C1 to C5 with the 25 combinations, five in each combination

However, by implementing (C4c and C4d), less reduction is taken place in summer particularly in the late night hours and early day hours, and a maximum reduction of (2.6 – 3.9°C) is achieved particularly in the evening. The results also indicated that by implementing the fabrics combinations (C5) that used wall type W12 (hollow concrete block 200mm and polyurethane 100mm) potential increases in the resultant temperature with C5a, C5b and C5c ranging from (3.0°C – 4.2°C) are achieved in summer. Besides, potential reductions in the resultant temperature ranging from (2.6°C - 4.0°C) and (3.3°C - 4.3°C) are achieved in summer by applying C5d and C5e in respectively.

The second investigation that took place was on a winter day (8th January) as presented in the graphs below along with the Figure of the existing case study building (Figure 9.14). The results indicated that by implementing the fabrics combinations (C1a – C1e) potential increases in the resultant temperature ranging from (5.1°C - 6.3°C) is achieved in winter.

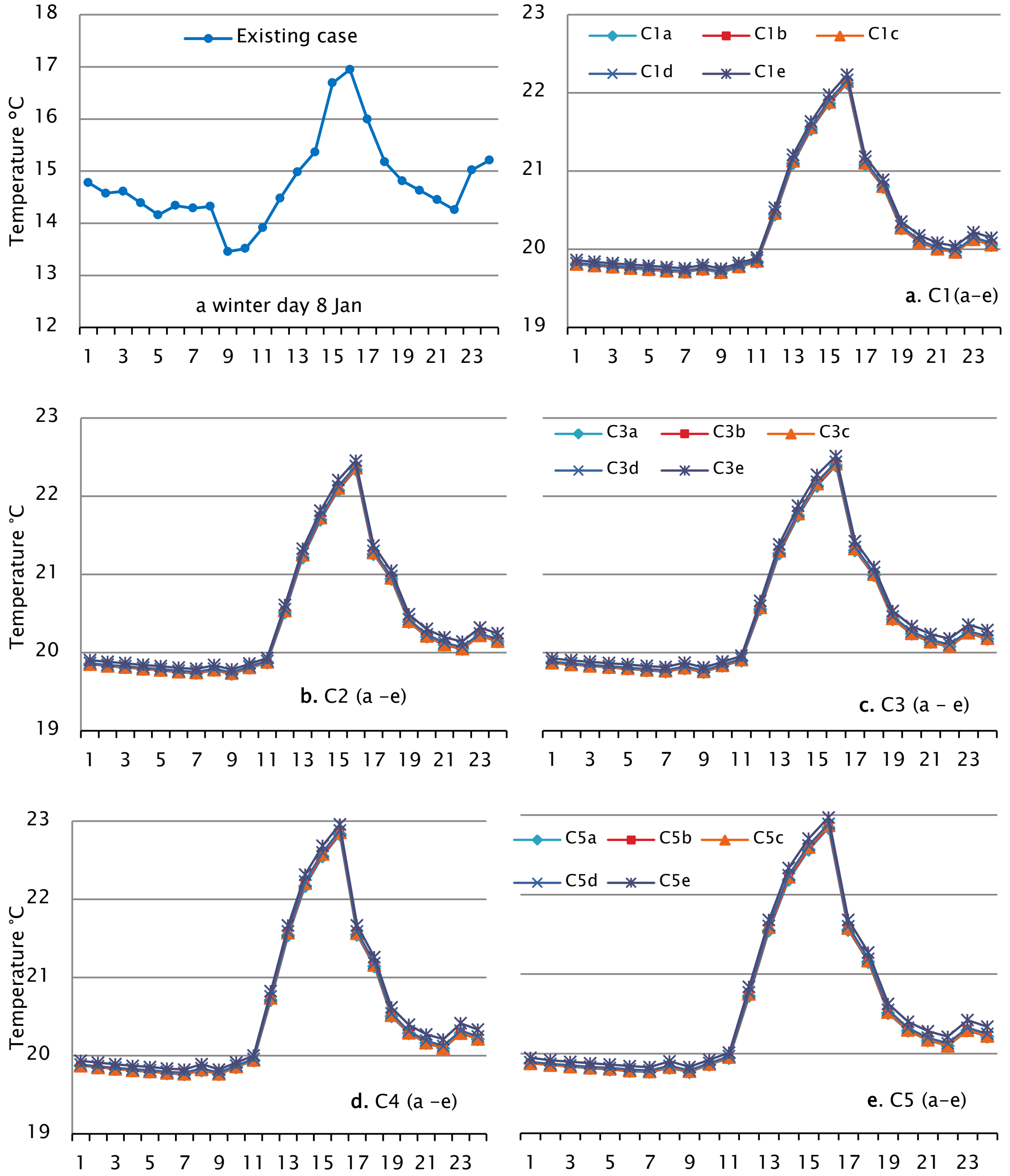


Figure 9.14: Resultant Temperature in case B7 with various combinations of fabrics on a winter day (8th January) _ first graph present the existing case of B7 while a to e graphs present C1 to C5 with the 25 combinations, five in each combination

Besides, C2 (a – e) show almost similar potential increases in the resultant temperature which again ranging from (5.3°C – 6.3°C) and a maximum of 0.3°C, are achieved between each group of C2 combinations and the maximum is always achieved when apply C2e. By implementing the combinations (C3 a-e) potential increases in the resultant temperature ranging from (5.4°C -6.3°C) and (5.6°C – 6.4°C) are achieved in winter with maximum increase with C3e. It worth mention that the three combinations c1, c2 and c3 are shown almost same potential increases in the resultant temperature in winter, these three groups are enclose wall type W5, W7 and W10 which all have 75mm insulation thickness of these materials expanded polystyrene, fibre-glass quilt and polystyrene which might cause significant increase in the temperature. The results also indicated that by implementing the fabrics combinations (C4 to C5) potential increases in the resultant temperature ranging is shown more than those first three groups with an extra increase of 0.5°C. Combinations of C4 (a-e) show a potential increases in the resultant temperature ranging from (5.8°C – 6.4°C) is achieved in winter, with the highest increase is obtained by applying (C4e) and the lowest is obtained by applying (C4a). Besides, a very close result is achieved by applying the groups of C5 (a-e) with a potential increase in the resultant temperature ranging from (5.9°C -6.4°C).

In the light of the above results, it can be concluded that, in terms of internal temperature, the fabric combination (e) in all groups is the best in summer, and the highest achievement is achieved with C5e group, while the fabric combinations of C1, C2 and C3 are the best in winter that because C4 and C5 are shown a slightly high temperature for winter as well as the increased temperatures are close to the discomfort range for winter.

9.3.4. Thermal Comfort with proposed combinations of fabrics

The percentages of comfort hours, where the PMV ranges from (+1) to (-1), in summer, winter and in a whole year were estimated with the implementation of the various combinations of fabrics (see Figures 9.15). The results show that by implementing the fabrics combination (C1a to C1e), the potential increases in the percentage of comfort hours ranging from about (21% to 23%) is achieved in summer months, with the highest is obtained by applying (C1e) and the lowest is obtained by applying (C1a). Besides, in winter, less potential increase is taken place that ranging from (19% to 21%).Taken as a whole, applying the fabrics combinations (C1a to C1e*)* could lead to annual increases in the percentage of comfort hours ranging from about (19% to 20%).

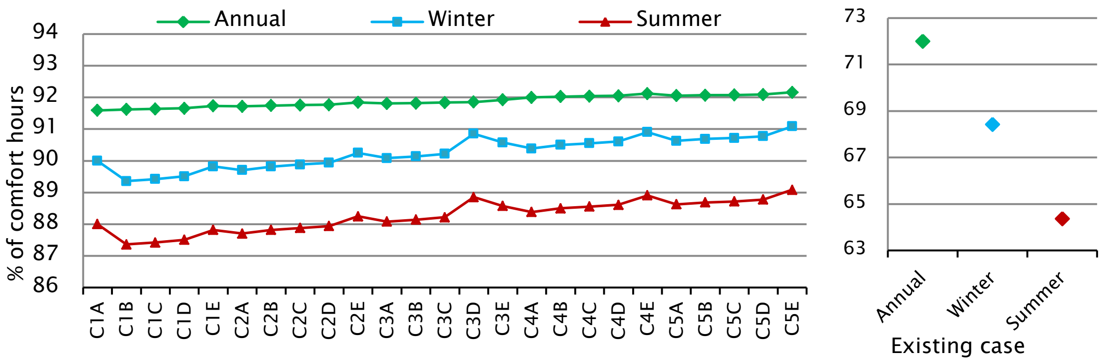


Figure 9.15: Percent of comfort hours for various combinations of fabric (left) and the percent of comfort hours of the existing case study B7 (right)

The results also revealed that by implementing the fabrics combinations (C2a to C2e), relatively great potential increases in the percentages of comfort hours ranging from about (21.2% to 21.8%) is achieved in winter, with the highest is obtained by applying (C2e) and the lowest is obtained by applying (C2a). Besides, in summer, a potential increase in the percentage of comfort hours from (23.3% to 24.5%).Taken as a whole, applying fabrics combinations (C2 a-e) could lead to relatively great annual increases in the percentage of comfort hours of approximately 19.7%. By implementing the fabrics combinations (C3a to C3e), potential increases in the percentages of comfort hours of about 23.7% to 24.5% are achieved in summer, and about 21.7% to 22.4% are achieved in winter. Taken as a whole, applying fabrics combinations (C3a to C3e) could lead to annual increases in the percentage of comfort hours with the maximum is achieved by applying C3e (about 19.9%), and the lowest is achieved with C3a (about 19.3%).

The results also showed that by implementing the fabrics combinations (C4a to C4e), relatively great potential increases in the percentages of comfort hours ranging from about 21.2% to 22.5% are achieved in winter with all combinations with the highest is obtained by applying (C4e) and the lowest is obtained by applying (C4a). Besides, in summer, a potential increase in the percentage of comfort hours of approximately 24.5% is achieved within all C4 groups, while an annual increase in comfort hours is just about 20%. By implementing the fabrics combinations (C5 a-e), potential increases in the percentages of comfort hours ranging from (24% to 24.9%) are achieved in summer, and about 22.2% to 22.7%, are achieved in winter. Taken as a whole, applying fabrics combinations (C5 a-e) could lead to annual increases in the percentage of comfort hours of about 22%. It is observed that the highest potential annual increase is always obtained by applying (e) at all five group combinations and the lowest is obtained by applying (a) during any season. This means that; in terms of annual thermal comfort, the combinations (e) which comprise 75mm Polystyrene and 50mm Bitumen as an insulation materials are shown the highest increase in the percentage of comfort hours in summer and in the entire year. This result is also led to same conclusion that given in the previous chapter of that the effect of roofs is the highest among improvement shown by walls and windows.

9.3.5. Energy Savings with Proposed Combinations of Fabrics

The energy savings of the proposed fabrics combinations is measured approximately where the flats are assumed with air conditioning in order to estimate the annual heating and cooling loads. The lower and upper temperatures are set 20°C and 27 °C respectively. Figure 10.19 provides the total annual loads with the implementation of the various fabrics combinations. The results show that by implementing the fabrics combination (C1 to C5), a great potential savings in the annual loads could be achieved with the highest saving is obtained by applying (C5e). Figure 9.16 presents these potential saving beside compare these Figures with the existing situation of the case study ones as highlighted in red colour.

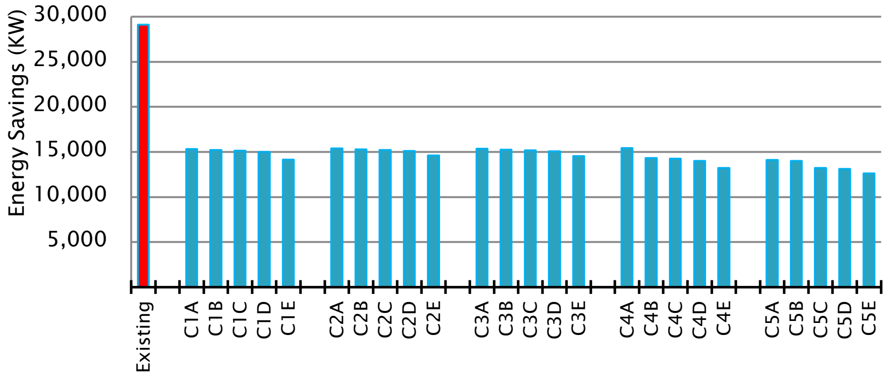


Figure 9.16: Energy Savings annual cool load for various combination of fabric

Although, there is a relatively close possible saving by applying either of C1,C2 and C3 combinations still the (C1e) group shown the highest saving among the other groups in these three combinations with almost double saving of about 14.800 Kw/year. The results also revealed that by implementing the fabrics combinations of C4 (a-e) a great potential savings in annual load is ranging from about 13.300 kw/year to 15.890 Kw/year with C4e been the highest saving fabric group. Whereas by applying the fabric combinations of C5 (a-e) the potential saving shows its maximum particularly with group C5e where the possible saving rise to 76.3% with about 12.600 Kw/year. Overall, the highest savings in the annual loads could be achieved by implementing the fabrics combinations (C5c, C5d and C5e), followed by (C4e and C1e), and the lowest is achieved by implementing the fabrics combinations (C1a, C2a, C3a and C4a).

9.4. Results Summary

Modelling the base case B7 in TAS after applying various type of insulation materials to the walls and the roof along with change the glazing type, proves that insulations can reduce heat flow up to 70% when modified walls and roof are combined. Simulations also show a good potential for saving energy by modifying the traditional roof, for example simulation using roof type R12 shows that indoor temperature can be reduced up to 4.5°C when this type of roofs applied along with W12 and G2 on top floors, and heat flow reduced by 63.1% with same above group. This reduction is as a result of using polyurethane materials (100mm) while when polyurethane material used (50mm) a reduction of 60.5% has been shown that the effect of the thickness of insulation materials. In addition to, improved roofs showed the greatest saving in energy more than walls or glazing. Overall, roofs show 63.1% reduction and walls 21.4% while 9.1% has been indicated through TAS simulation when improved glazing types are used. And in term of temperature reduction a range of 3 to 5 degrees with different types of insulations. Effect of thermal mass improving is presented in the below Figure; yellow is the comfort percentage in old buildings' envelope and the red is the percentage after improvement.

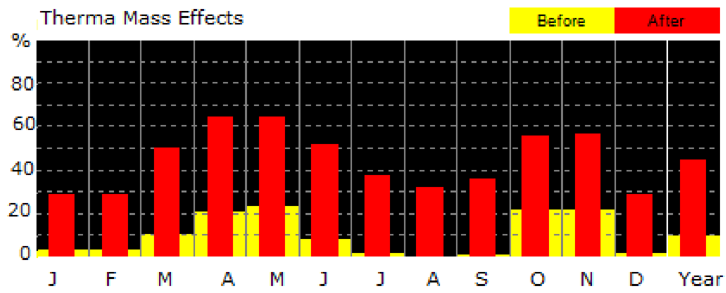


Figure 9.17: the performance of thermal mass before and after buildings envelope improvements

CONCLUSIONS
AND RECOMMENDATIONS

Chapter 10 : Conclusion and Recommendation for Future Work

10.1 Introduction

The major aim of this thesis is to evaluate the indoor environment of multi-store residential buildings mainly the thermal comfort, beside other aspects such as energy consumption and annual loads, and to propose alternate envelopes seeking for potential enhancement in thermal comfort level. The case study buildings are influenced by a wide range of complicated factors, including dense urban environment, economic limitations, absence of regulations, environmental issues, and political consideration, which make any proposed modifications for these buildings more difficult. Studying these buildings, was to help assessing the value of the improvement that has already planned by the Libyan government and to bring greater comprehension of the indoor conditions that still needs more enhancements. After analysing the studied buildings, various fabrics are proposed for the future residential buildings looking for potential improvement in the indoor thermal environment.

A combination of methods was practised to achieve the research aims and objectives including two main methods, the questionnaires and the computer model, along with other methods such as observations and site visit. The questionnaire in this study is used as a main tool to examine the indoor environment conditions; with focus on thermal comfort. The computer model is utilized to analyse the thermal performance of the existing buildings, and to identify the potential enhancement in thermal comfort and energy savings of the proposed alternate materials for buildings' envelope. About 337 flats are surveyed with an average response rate of 77.1 % and data gathered are analysed using statistical analysis software (mostly Excel). Afterwards, using a selected Thermal Analysis Software (TAS), twelve buildings are simulated and analysed and six of them are chosen for further examination and then just one which is the only isolated case was picked to be the modelling of the proposed modifications. A number of conclusions and recommendations are drawn based on the research results. The main conclusions are briefly presented in the following sections, followed by recommendations for further research.

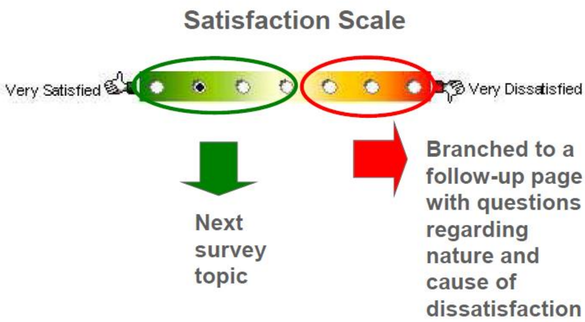
10.2 Conclusions

This research has investigated human thermal comfort for midrise residential buildings by a field survey in the summer seasons of 2010 and 2011, in a typical Mediterranean climate of Darnah, Libya and then models the result using computer software. Since no other research workers have conducted such studies in north

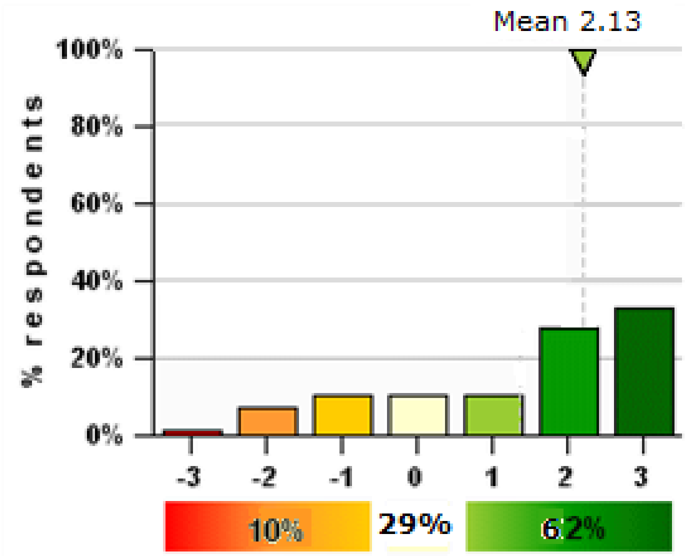
Libya, this present work will complement the existing knowledge of thermal comfort field around the world giving it uniqueness in terms of knowledge contribution in this field. These results obtained in the field survey in Darnah have been accepted as reasonable and therefore may be used as input data in further thermal comfort work. The following conclusions have been drawn from this study and are presented in three sections:

1. CONCLUSIONS BASED ON FIELD SURVEY

- Observation showed that achieving a comfort condition is far complicated and do not depending only on orientation or internal heat sources the problem seems to be also related to the performance of building's envelope, materials, insulations and shading devices. Simulation approved that also by shown a great deal of heat gain through building's fabric.
- The most significant barriers to improving energy efficiency in buildings is a lack of knowledge about the determinant factors for energy use. Building energy consumption is mainly influenced by six factors: (1) climate, (2) building envelope, (3) building services and energy systems, (4) building operation and maintenance, (5) occupants' activities and behaviour and (6) Indoor Environment Quality provided (IEQ). Current research focuses in the main on building envelope factor. However, climate and the other factors reflect human behaviours – how people operate equipment, how many children they have etc, and these factors can also strongly influence building energy use.
- From 12 buildings suggest that the majority occupants in these buildings were general uncomfortable and they need to use cooling means especial from early afternoon up to late night during summer days. However, some responds came uncertain due to lack of understanding to the meaning of thermal comfort as well as people think they are comfortable because they answer under the present of A.C (those occupants asked to take the survey again and answer it while the A.C switch it off for at least one day with the present of a collector).



And the fieldwork survey showed that 62% of occupants of the 12 buildings case study are uncomfortable. Using PMV Tool along with the survey data analyses showed that the mean of PMV in case study buildings is 2.13 on Fanger scale.



- Little means of solar devises are used in few buildings but the majority use internal curtains which made with different types of fabric designed and chosen by occupants themselves. However, curtains are the least effective option as they allow the radiation to enter the space (either directly or as long-wave radiation from the heated glass) before shading the occupant and if user control is necessary, use blinds encased in a double glazed unit where excess heat gains are vented to the outside.
- Observation showed also that cross ventilation is effected by occupants behaviours, that because the key, of course, is to have open windows (or voids) on opposite directions of the structure to allowing winds to circulate freely which is unavailable in almost all flats as the survey observed, occupants tend to close windows for privacy reason, other tell that they drop their heavy curtain all the day which mean that long-wave radiation gets trapped between the window and the curtain and ends up heating the air within this space. This heated air will tend to rise, exiting out the top and

drawing in cooler air from below. This forms quite an effective thermosyphon that continually draws cool air from the bottom of the space, heats it up and pushes it out the top underneath the ceiling. Over a whole day this can significantly increase internal room temperatures. Also, as the return-air ducts of most air conditioning systems are in the ceiling, this hot air can add significantly to air conditioning loads.

2. CONCLUSION BASED ON THERMAL ANALYSIS

- Size of building do affect heat gain value, simulations show that narrow building (such as B2 & B3)is performing better than wide one, particularly if it has one or more façades directed to west or south where these two directions found to be the worse directions in relation with room temperature. This led to another result; buildings' orientation play a significant role on heat gain during summer time, rooms are located on south or west show a high room temperature than those located on east or north directions. Top floor's rooms that located on a big courtyard are shown a better performance than those located on small courtyard while rooms of ground floor show reverse results in both courtyard cases.
- Location near the sea is giving many advantages to occupants of these buildings; one of them is better performance in heat gain and less room temperature. And, to some extent, vegetation has some effect on indoor temperature and that according to its location, size and density; the result of the only case with tree bank located on east side (B10) shows value of 2541 W of heat gain on ground flats while the value was 11893.5 W without these trees, the simulation carried out on 21st of Jun. In this type of climate, Vegetation's (in our case trees) reduce building energy use by lowering temperatures and shading buildings during the summer, and blocking winds in winter. However, they also can increase energy use by shading buildings in winter, and may increase or decrease energy use by blocking summer breezes. Thus, proper tree placement near buildings is critical to achieve maximum building energy conservation benefits.
- In respect to indoor temperature, top flats is the worse where the temperature reach up to 39°C on peak day hours beside the temperature drop to uncomfortable level during night, the situation is different on ground flat when simulation indicated better performance on ground floor even though the recorded temperature still above the comfort level but not as high as those recorded on top floor.
- An investigation on solar heat flow through materials at different floors show a very close result between middle floors and top one while the ground case

result varied. Southwest northwest surfaces on ground floor receive sun heat almost all the day. Simulation in relation with heat sources show that building envelope is the winner source of heat gain and transferring the heat from outside to indoor more than other sources such as occupants, equipment and light.

- Research showed that compact buildings work better for hot climate than isolated ones. Case B11 which blocked from three sides shows the lowest room temperature on 21^{st} of June between the other cases.
- A conclusion that draw based on occupants feeling and behaviour is that; the problems of the existing situation in building apartments as explored by the research analysis can be seen from three different angles: The primary concern has been the indoor thermal quality, mainly degraded by the thermal performance of the buildings and the possibility for occupants to live in a comfortable environment. As things stand at present, this problem appears to have been solved by the extensive use of mechanical cooling, and the occupants are fairly satisfied with this situation for the time being. Their satisfaction, though it may be temporary, has been attained through the low energy cost policy which compensates the disadvantage of the high energy consumption needed by the occupants to balance the poor thermal performance for their buildings. Although the potential for saving energy through the application of energy saving strategies is overwhelming, the economic motives are not there to compel those occupants towards changes or at least to raise their concern about the situation. If and only if, the government makes a decision to lift the subsidy will the whole picture be redrawn. Such a scenario will certainly impose a considerable economic stress on the occupants and will introduce a new tension between thermal comfort and economic comfort. In the short term either one of these notions will prevail over the other, but both of them are essential for the long term comfort of the occupants. Proposed strategies such as the application of insulation materials and the installation of shading devices are neither practical nor applicable from the particular angle of the occupants. Being tenants or temporary occupants will not encourage the modification of an apartment, even if it is badly needed, although the existence of effective enforcement tools would make a major difference to this aspect of the situation.
- A further key to dealing with this obstacle lies with the owners of buildings; they can invest in their buildings as a part of an integrated national scheme to upgrade the existing buildings for the sake of the national economy. This is, of

course, a difficult goal to achieve but not an impossible one. It can be done by adopting a comprehensive plan where the government plays the major part in providing the facilities and even the money, in order to make the implementation of such strategies more workable from the owners' side. The other angle on this problem is that of the building professional. The main concern of these professionals is with new projects and developments. However, they do have a potential contribution to make in relation to the energy concerns of existing buildings, which is something that they have shown some reluctance to undertake because, in general terms, it is not a financially profitable area. Architects, energy analysts, and all the relevant professionals in the building industry are concerned with the technical aspects of the problem, but one of the obstacles to the implementation of energy saving measures is the lack of information provided by building professionals. Almost all other parties in this circle need to be fully aware of the nature of the problem, its technicality, its dimensions, and its effective solution. So in this sense the professionals need to provide society with more factual data so that any decision to be taken would be founded on very solid ground. More involvement and interaction with the users of this building type is needed, through investigation by empirical and fieldwork studies, in order to understand more about the existing situation.

- Result of base building showed that indoor temperatures are far lower than those on middle and top floors, this must be considered when insulation to be inserted in building envelope. In other word, different types of insulation materials may use in one building since what suit ground floor is completely diverse from top ones.

3. CONCLUSION BASED ON THERMAL MODELLING OF PROPOSED FABRICS

- In view of the thermal analysis of the case study buildings and the available material in the local market, twelve walls, twelve types of roofs, and six types of window were proposed for the simulation by TAS. Afterwards, twenty five combinations (C1a to C5e) of five types of walls, five types of roofs, and one type of windows (single glazed windows with blinds) were selected and simulated to ascertain the overall thermal performance of the case buildings and to identify the total improvement which could be achieved. These combinations are explained in details in the previous chapter.
- Applying various types of insulation materials to the walls and the roof along with change the glazing type, proves that insulations can reduce heat flow up

to 78% when modified walls and roof are combined. Summer of results of the new modifying materials is given in details at appendix 4, Table 3.

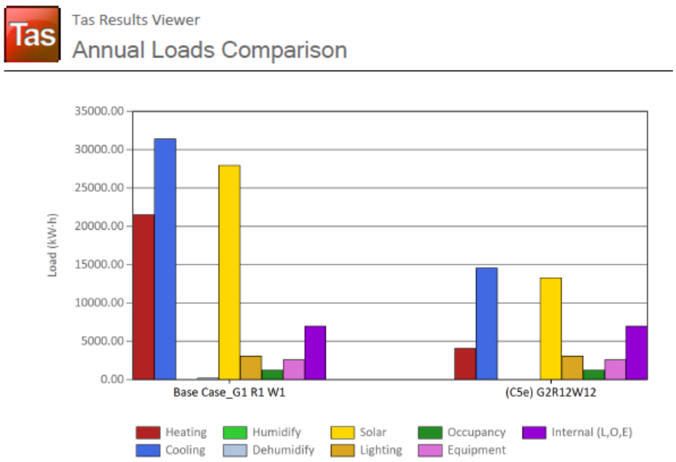
- This research show a good potential for saving energy by modifying the traditional roof, for example simulation using roof type R12 shows that indoor temperature can be reduced up to 4 degrees when this type of roofs applied along with W12 and G6 on top floors, and heat flow reduced by 63.1% with same above group. This reduction is as a result of using polyurethane materials (75mm) while when polyurethane material used (50mm) a reduction of 60.5% has been shown that the effect of the thickness of insulation materials.
- Improved roofs showed the greatest saving in energy more than walls or glazing. Overall, roofs show 63.1% reduction and walls 21.4% while 9.1% has been indicated through TAS simulation when improved glazing types are used. And in term of temperature reduction a range of 4 to 6 degrees with different types of insulations.
- In the light of the thermal comfort, the results show that by implementing the fabrics combination (C1a to C1e), the potential increases in the percentage of comfort hours ranging from about (21% to 23%) is achieved in summer months, with the highest is obtained by applying (C1e) and the lowest is obtained by applying (C1a). Besides, in winter, less potential increase is taken place that ranging from (19% to 21%).Taken as a whole, applying the fabrics combinations (C1a to C1e) could lead to annual increases in the percentage of comfort hours ranging from about (19% to 20%). The results also revealed that by implementing the fabrics combinations (C2a to C2e), relatively great potential increases in the percentages of comfort hours ranging from about (21.2% to 21.8%) is achieved in winter, with the highest is obtained by applying (C2e) and the lowest is obtained by applying (C2a). Besides, in summer, a potential increase in the percentage of comfort hours from (23.3% to 24.5%).Taken as a whole, applying fabrics combinations (C2 a-e) could lead to relatively great annual increases in the percentage of comfort hours of approximately 19.7%. By implementing the fabrics combinations (C3a to C3e), potential increases in the percentages of comfort hours of about 23.7% to 24.5% are achieved in summer, and about 21.7% to 22.4% are achieved in winter. Taken as a whole, applying fabrics combinations (C3a to C3e) could lead to annual increases in the percentage of comfort hours with the maximum is achieved by applying C3e (about 19.9%), and the lowest is achieved with C3a (about 19.3%).

- The results also showed that by implementing the fabrics combinations (C4a to C4e), relatively great potential increases in the percentages of comfort hours ranging from about 21.2% to 22.5% are achieved in winter with all combinations with the highest is obtained by applying (C4e) and the lowest is obtained by applying (C4a). Besides, in summer, a potential increase in the percentage of comfort hours of approximately 24.5% is achieved within all C4 groups, while an annual increase in comfort hours is just about 20%. By implementing the fabrics combinations (C5 a-e), potential increases in the percentages of comfort hours ranging from (24% to 24.9%) are achieved in summer, and about 22.2% to 22.7%, are achieved in winter. Taken as a whole, applying fabrics combinations (C5 a-e) could lead to annual increases in the percentage of comfort hours of about 22%. It is observed that the highest potential annual increase is always obtained by applying (e) at all five group combinations and the lowest is obtained by applying (a) during any season. This means that; in terms of annual thermal comfort, the combinations (e) which comprise 75mm Polystyrene and 50mm Bitumen as an insulation materials are shown the highest increase in the percentage of comfort hours in summer and in the entire year. This result is also led to same conclusion that given in the previous chapter of that the effect of roofs is the highest among improvement shown by walls and windows. The energy savings of the proposed fabrics combinations is measured approximately where the flats are assumed with air conditioning in order to estimate the annual heating and cooling loads. The lower and upper temperatures are set 20°C and 27 °C respectively.
- Potential reductions in the resultant temperature ranging from (2.5°C – 4.0°C) are achieved in summer among all five combinations that include wall type W5 with the highest reduction is obtained by applying (C1e _ 4.0°C) and the lowest is obtained by applying (C1a _ 2.5°C). Whereas the result of the second combination which formed using W7 where the results show that potential reductions in the resultant temperature are ranging from (2.6°C – 4.2°C) with a significant reduction when applying C2e (W7, R12 &G2) particularly in the late night hours with (3.1°C – 4.3°C) reductions. By implementing the combination (C3 a-e) potential increases in the resultant temperature ranging from (2.1°C – 4.0°C), and (2.6°C – 4.2°C) are achieved in summer by applying (C3a,b,c and d) and C3e respectively as the first four combinations show very close results. Besides, potential reductions in the resultant temperature ranging from (3.1°C – 4.2°C) are achieved in summer when applying C4 a, b and e. However, by implementing (C4c and C4d), less

reduction is taken place in summer particularly in the late night hours and early day hours, and a maximum reduction of (2.6 – 3.9°C) is achieved particularly in the evening. The results also indicated that by implementing the fabrics combinations (C5) that used wall type W12 potential increases in the resultant temperature with C5a, C5b and C5c ranging from (3.0°C – 4.2°C) are achieved in summer. Besides, potential reductions in the resultant temperature ranging from (2.6°C - 4.0°C) and (3.3°C - 4.3°C) are achieved in summer by applying C5d and C5e in respectively.

- The second investigation that took place was on a winter day (8th January). The results indicated that by implementing the fabrics combinations (C1a – C1e) potential increases in the resultant temperature ranging from (5.1°C - 6.3°C) is achieved in winter. Besides, C2 (a – e) show almost similar potential increases in the resultant temperature which again ranging from (5.3°C – 6.3°C) and a maximum of 0.3°C, are achieved between each group of C2 combinations and the maximum is always achieved when apply C2e. By implementing the combinations (C3 a-e) potential increases in the resultant temperature ranging from (5.4°C -6.3°C) and (5.6°C – 6.4°C) are achieved in winter with maximum increase with C3e. It worth mention that the three combinations c1, c2 and c3 are shown almost same potential increases in the resultant temperature in winter, these three groups are enclose wall type W5, W7 and W10 which all have 75mm insulation thickness of these materials expanded polystyrene, fibre-glass quilt and polystyrene which might cause significant increase in the temperature. The results also indicated that by implementing the fabrics combinations (C4 to C5) potential increases in the resultant temperature ranging is shown more than those first three groups with an extra increase of 0.5°C. Combinations of C4 (a-e) show a potential increases in the resultant temperature ranging from (5.8°C – 6.4°C) is achieved in winter, with the highest increase is obtained by applying (C4e) and the lowest is obtained by applying (C4a). Besides, a very close result is achieved by applying the groups of C5 (a-e) with a potential increase in the resultant temperature ranging from (5.9°C -6.4°C).
- In all cases considering the feasibility of different approaches to reduce the heat gains through the roof, one should give serious consideration to lowering the roof solar absorptance. As the cost effectiveness of roof insulation is attractive, one design strategy for total cost savings would be un-insulated massive walls and well insulated roofs of lighter weight. The external walls act as the thermal heat storage capacity and would bear the load of the roof eliminating the need for columns, etc.

- Shading the roof can be an effective means of reducing ceiling temperatures (Ch: 4 _ Figure 4.10). This not only will reduce the cooling requirements of buildings, but will provide more comfortable environments.
- Simulation show that combination of wall type W12 and roof type R12 along with G2 is the highest performance one in term of heat gain and indoor temperature reduction, this result is drawn in the Figures below with compare the result to existing materials (W1, R1 and G1).



Building	Heating	Cooling	Humidify	Dehumidify	Solar	Lighting	Occupancy	Equipment	Internal (L,O,E)
Base Case_G1 R1 W1	21546.0	31420.6	0.0	207.1	27955.5	3093.8	1286.1	2612.8	6992.7
(C5e) G2R12W12	4111.3	14602.7	0.0	36.4	13298.6	3093.8	1286.1	2612.8	6992.7

Lastly, some struggles have faced this research which related to the research and the researcher, summarized as follows:

- Absence of location weather data, where the student has to created completely which took around 3 months from research period,
- Absence of data on number of buildings in the case study, such as plans, elevations and history therefore the student has to draw these files and seek help with history,
- Lack of research facilities, relevant professionals and requisite literature,

It was under these constraints that the research was planned and carried on to not only address the existing problem but to create a new strategy for local buildings through understanding the local climate and occupants' needs, in additional to open up a large opportunities for people to participate actively towards the achievement of save local energy. Also, after selecting the participants and samples of buildings, it important to brief the subjects about the experimental project and questionnaire in more detail. The questionnaire has been translated into Arabic for the first time and by doing this the researcher might face some difficulties to translate these scientific concepts; therefore the student needs to be more calm and patient with the subjects. As well as the needs to explain the whole questionnaire in more details and how to fill or report their votes, after dividing participants into small groups, to avoid any misunderstanding of any question and to be sure that they are going to return the questionnaires back fully completed. Another difficult step was that, clearance from the project grant or university where the project is researching, then followed by a legal permission, when arriving to the case study location, from main Government Authorisation offices in Tripoli, and another prior-arrangement with the local authority office in Darnah to liaise their permission and introduce the fieldwork to the local people in order to make them more co-operative.

10.3 Recommendations for further research

Since climate is changing around the world;

- Extra measurement data in thermal comfort of different times of year in Darnah, and from different regions in Libya are recommended. Fieldwork showed that thermal comfort is not fully understood this led to huge waste in energy in this area. More researches will help to consider Fanger's model when PMV reaches a value of +2. In addition, neutral temperatures can be then calculated using adaptive models for such cool conditions. The information definitely will help to make more general conclusions and would contribute to make a new `Global Standard' for assessment of thermal comfort in different climates including hot regions.
- The measurement of human thermal comfort in these environments can be complemented with the assessment of air quality perceived by the occupants, together with their performances in their homes. Thermal adaptation is a reaction of the human being to a specific climate, which largely depends upon environmental and behavioural adaptation. These factors have a considerable influence and should be the focus of future research and development, and include acclimatization and socio-cultural issues, such as religion, life style, incentive, working patterns, clothing level, diet, and activity level, etc.
- Investments by the government should take place in order to study the effect of different types of glazing and insulations to formulate recommendations on materials that suit the climate condition. The effect of humidity on thermal comfort should be also investigated since fieldwork survey recorded a sign of uncomfortable that related to humidity at the case study.
- Harmonization between urban planners, architects, thermal comfort modellers, together with occupants' past experience should be well established for providing comfortable environments with minimum energy consumption. In addition, building regulations and planning bye-laws should

be reviewed critically to respond to the users' social and personal needs, as well as their thermal requirements.

Last:

It is seen that this study has been fulfilled within the frame of the main aims and objectives stated earlier in chapter one. The importance of this research direction will not only be reflected on building users, but also help the government to reduce the energy particularly that used for A.C system. Furthermore, this study has tackled a difficult task that deals with thermal comfort in relation with energy use in existing situation of a large sector of the residential building type and the findings and the recommendation must be considered as a suggestive and guide lines rather than conclusive. It is believed that this study has introduced innovative ideas and contributions to knowledge. However, another continuation for this research is to consider it as a part of similar investigations in apartment building stocks in different cities in Libya. This series will be useful to develop a national code of practice for energy conservation in the existing apartment buildings and in general, it provides some useful tools and techniques for evaluating and enhancing the environmental performance of residential buildings located with Mediterranean environment.

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APPENDICES

APPENDIX 1: THE QUESTIONNAIRE

Dear all;
I am doing a PhD degree in Architecture and Built Environment at the University of Nottingham, UK.
This questionnaire aims to find out the human thermal comfort standards in high rise residential buildings in order to design and re-built a building that would performance with its environment probably and saving us and the next generation huge energy consumption.
I am hereby asked you to fill all the questions which are very important stage in my research and ensure you that all the data in this questionnaire will be used in research field only and will treated it privately and confidently.

Please tick the answer that you believe is the most appropriate. Many thanks

Occupancy information

Are you over 40?	Yes ☐	No ☐
How long have you been living in this flat?	Less than 5 years ☐	5_ 10 years ☐
	11_15 years ☐	More than 15 years ☐
How many persons are living in the flat? (write the number inside the box)	Adults ☐	children ☐

Flat information

Floor No:		Flat No:		
What is the size area of your flat?	50_ 100 m²☐		101_150 m²☐	
	151_200 m² ☐		More than 200 m² ☐	
How many rooms are there in the flat? (write the number inside the box)	Bedrooms ☐	Guest rooms ☐	Living room ☐	
What is the colour of your flat walls;	External walls…………………	Dark colour	Bright colour	Other............
	Interior walls…………………..	Dark colour	Bright colour	Other............
When was the last time you paint your walls?	Less than 1 year ☐		1_3 years ☐	
	3_5 years ☐		More than 5 years ☐	
When was the last time you re-new your walls?	Less than 1 year ☐		1_3 years ☐	
	3_5 years ☐		More than 5 years ☐	

Energy consumption

What type of energy are you using in your flat? Please tick as many as you use	Electricity ☐	Coal ☐
	Gas ☐	Other ☐ specify ….………….

Do you think that the energy consumptions in your flat is;	Low ☐	Reasonable ☐	High ☐

Do you have in your flat some of these appliances? Please tick as many as you have and state the number beside it	Fridge ☐	Hoover ☐	Television ☐	Bread maker ☐
	Freezer ☐	Mixer ☐	Washing machine ☐	Fan ☐
	Gas cooker ☐	Air conditioner ☐	Microwave ☐	Video ☐
	Electric cooker ☐	Dryer machine ☐	Electricity fire ☐	Dishwasher ☐
	Kettle ☐	Dishwasher ☐	Computer ☐	Other (specify) ....

In your Kitchen for ventilation, do you use?	Fresh air through window ☐	Mechanical fan ☐	Adjustable air vent in wall or ceiling ☐

In the following rooms can you tell the watts do you use for light bulbs? Please refer to the above drawing for rooms' location		Florescent	Normal bulbs	Low _E bulbs
	Guest room			
	Living room			
	Bedrooms			
	Kitchen			

In summer, which form do you use for cooling each room in your flat? Please refer to the above drawing for rooms' location.		Natural ventilation	Portable fan	Ceiling fan	A.C
	Guest room				
	Living room				
	Bedroom 1				
	Bedroom 2				
	Bedroom 3				
	Kitchen				

In winter, which form do you use for cooling each room in your flat? Please refer to the above drawing for rooms' location.		Coal fire	Elect. Fire	Kerosene fire	Gas fire	A.C
	Guest room					
	Living room					
	Bedroom 1					
	Bedroom 2					
	Bedroom 3					
	Kitchen					

Thermal comfort

From health point, what do you feel towards the used means for cooling and heating?	Good effect ☐	No effect ☐
	Bad effect ☐	I do not know ☐

What do you use **to control** the sunlight inside your flat during summer time?		
	Curtains ☐	Climbed plants ☐
	Vertical blinds ☐	Insect screen ☐
	Horizontal blinds ☐	Cantilever overhang ☐
	Nothing at all ☐	Other ☐ specify ....

How do you rate your flat in terms of your thermal comfort? **Summer time**		Hot	warm	S. warm	Comfort	S. cool	Cool	Cold
	G. room							
	L. room							
	Bedroom							
	Kitchen							

How do you rate your flat in terms of your thermal comfort? **Winter time**		Cold	Cool	S. cool	Comfort	S. warm	war m	Hot
	G. room							
	L. room							
	Bedroom							
	Kitchen							

Do you use windows for cross ventilation		Always	Sometimes	Never
	Morning			
	Afternoon			
	Evening			
	Night			

Do you use the existing balconies in your flat?		Always	Sometimes	Never
	Summer			
	Winter			

How old is your A.C?			
	Less than 1 Y	Do not have	5_10 years
	2_4 years		More than 10 Y

In a typical day, how many hours do you use your A.C? (please tick the duration on the opposite slot)	☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐ 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 14

Would you prefer your flat's windows?		East	South	North	West
	Bigger				
	As they are				
	Smaller				
	Not there				

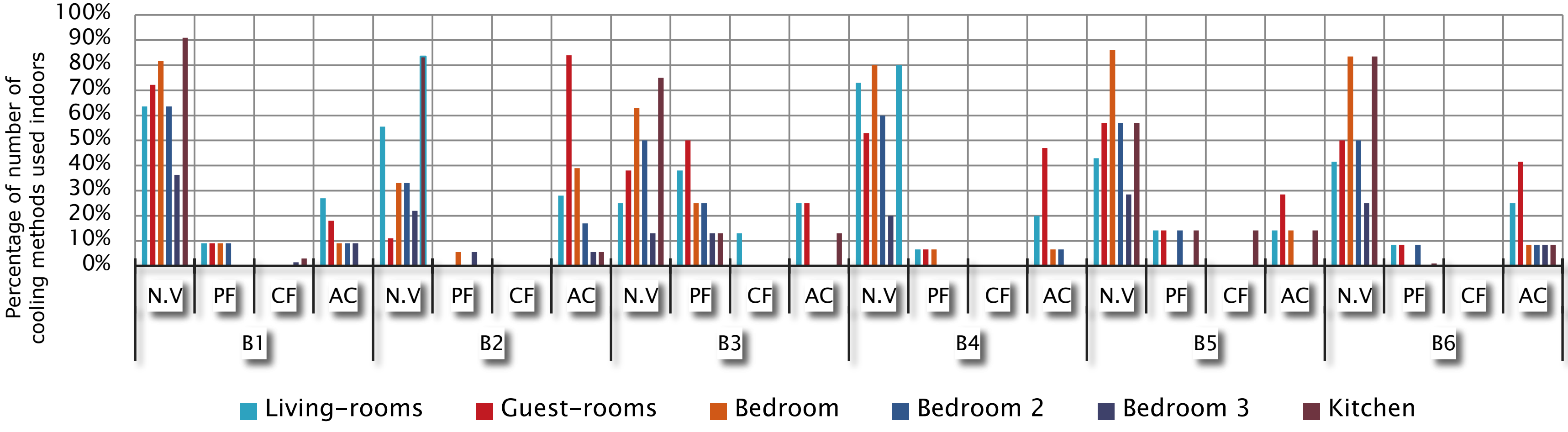
Which is the coldest room in the winter?			
	G. room	L. room	Kitchen
	Bedroom 1	Bedroom 2	Bedroom 3

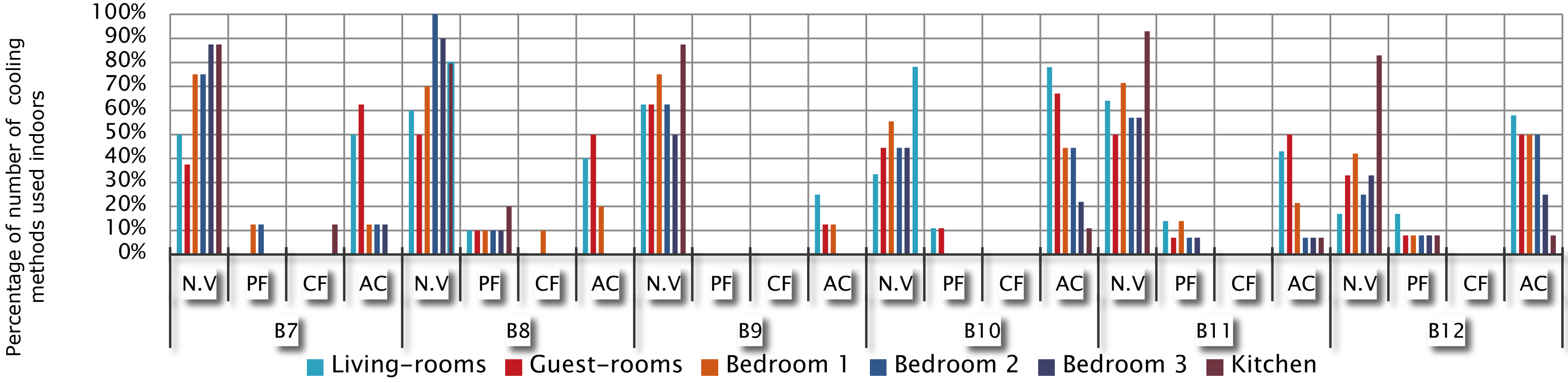
Which is the warmest room in the summer?			
	G. room	L. room	Kitchen
	Bedroom 1	Bedroom 2	Bedroom 3

At what temperature do you set your thermostat in **winter** time?	....
At what temperature do you set your thermostat in **summer** time?	....

In order of importance, when you paying new comfort system; how do you rate the following factors?	comfort Efficiency	Reliability Price	Other (describe)
Others			
Overall, How sure you are from your answer above? (please rate)	Very sure ☐ ☐ ☐ 50/50 ☐ ☐ ☐ not sure		
Overall, How satisfied are you with the temperature in your flay?	Very Satisfied ☐ ☐ ☐ natural ☐ ☐ ☐ Very Dissatisfied		

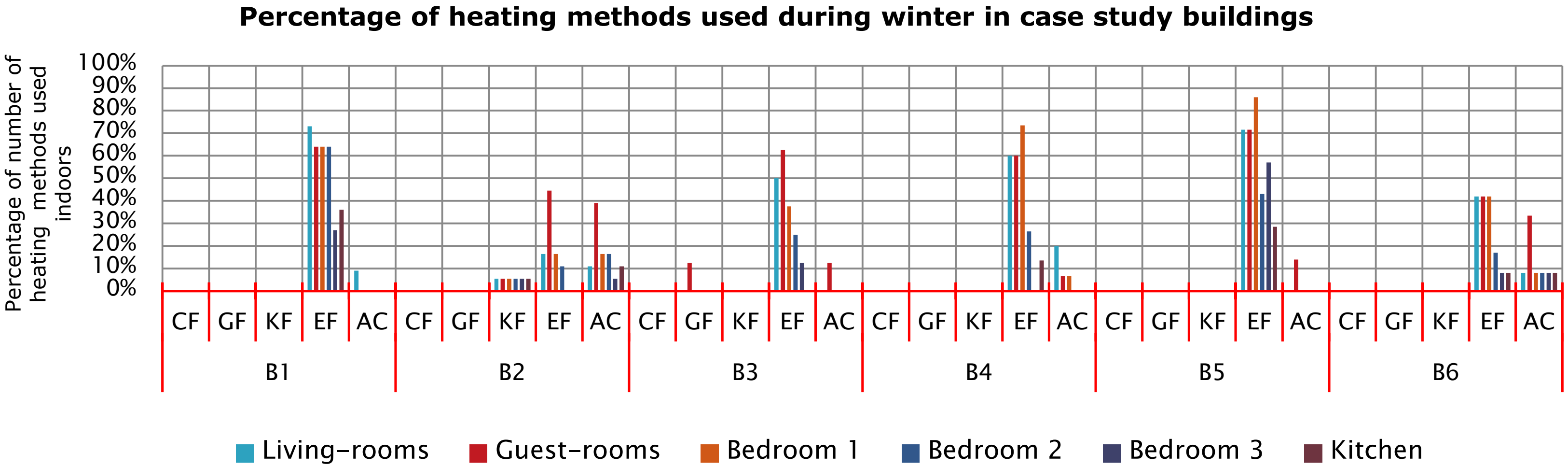
Percentage of cooling methods used during summer in case study buildings

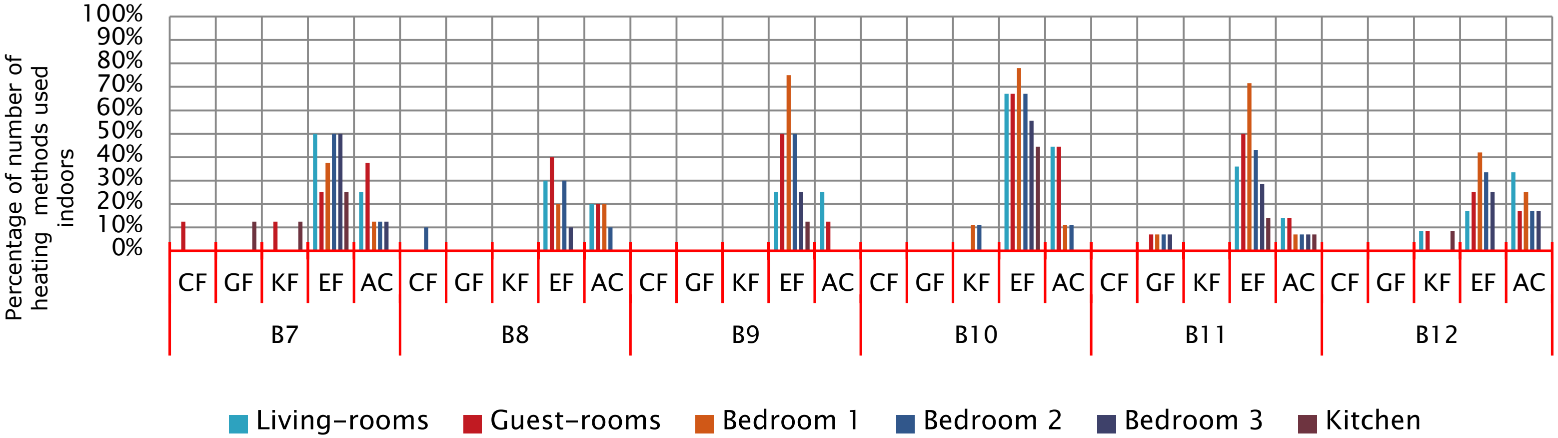




Percentage of cooling methods used during summer in case study buildings

NV: Natural Vent PF: Portable Fan CF: Ceiling Fan A.C: air condition





Percentage of heating methods used during winter in case study buildings

CF: coal fire GF: gas fire KF: kerosene fire EF: elect. Fire A.C: air condition

APPENDIX 2: NEW MATERIALS USED TO IMPROVE INDOOR COMFORT

This section details the thermal properties of each layer of the construction types used in chapter 10 as new materials. The top layer is always inside the building and the description, from left to right, includes the layer number, the layer code, the width used (in millimetres), the conductivity of the material (in W/m² K), the density of material (in kg/m³), the specific heat capacity of the material (J/kgK) and a short description. It can also be appreciated that internal and external solar absorption, internal and external emissivity, and conductance (U-value) were left similar for all construction types.

A. Walls

Opaque Construction — Name: wall type 1 — Description:

Solar Absorptance		Emissivity		Conductance (W/m²·°C)	Time Constant
Ext. Surf.	Int. Surf.	External	Internal		
0.400	0.400	0.900	0.850	1.635	4.090

Layer	M-Code	Width (mm)	Conducti...	Convecti...	Vapour D...	Density (...	Specific ...	Description
Inside	am1s\39	15.0	999.999	0.0	5.565	0.001	0.001	WHITE
2	am1block\4	200.0	0.35	0.0	14.800	1050.0	1057.0	
3	am1plast\23	20.0	0.5	0.0	19.200	1300.0	769.0	CEMENT RENDERING...

Opaque Construction — Name: Wall type 2 — Description:

Solar Absorptance		Emissivity		Conductance (W/m²·°C)	Time Constant
Ext. Surf.	Int. Surf.	External	Internal		
0.400	0.700	0.900	0.900	1.301	6.033

Layer	M-Code	Width (mm)	Conducti...	Convecti...	Vapour D...	Density (...	Specific ...	Description
Inside	Mortar in inner leaf	15.0	0.88	0.001	9999.000	1750.0	1000.0	Mortar in inner leaf or ot...
2	am1block\4	200.0	0.35	0.0	14.800	1050.0	1057.0	
3	Air	30.0	0.01	2.527	1.000	0.0	0.0	Air filled gap
4	Masonry	25.0	0.79	0.001	50.000	1600.0	850.0	

Opaque Construction — Name: Wall type 3 — Description:

Solar Absorptance		Emissivity		Conductance (W/m²·°C)	Time Constant
Ext. Surf.	Int. Surf.	External	Internal		
0.700	0.800	0.900	0.900	0.639	9.930

Layer	M-Code	Width (mm)	Conducti...	Convecti...	Vapour D...	Density (...	Specific ...	Description
Inside	sand cement pla...	15.0	0.72	0.001	0.700	1860.0	840.0	
2	Hollow conc. Blo...	200.0	0.77	0.001	999.000	1700.0	1000.0	
3	Min wool quilt, 5...	50.0	0.04	0.001	1.000	12.0	1030.0	Mineral wool quilt, 50 m...
4	Render External,...	20.0	0.57	0.001	9999.000	1300.0	1000.0	External render

Opaque Construction — Name: Wall type 4 — Description:

Solar Absorptance		Emissivity		Conductance (W/m²·°C)	Time Constant
Ext. Surf.	Int. Surf.	External	Internal		
0.400	0.400	0.900	0.850	0.537	10.761

Layer	M-Code	Width (mm)	Conducti...	Convecti...	Vapour D...	Density (...	Specific ...	Description
Inside	am1s\39	15.0	999.999	0.0	5.565	0.001	0.001	WHITE
2	am1block\4	200.0	0.35	0.0	14.800	1050.0	1057.0	
3	Fiberglass quilt	50.0	0.04	0.0	2.880	12.0	833.0	GLASS FIBRE 1 *3
4	am1plast\23	20.0	0.5	0.0	19.200	1300.0	769.0	CEMENT RENDERING...

Opaque Construction — Name: Wall type 5 — Description:

Solar Absorptance		Emissivity		Conductance (W/m²·°C)	Time Constant
Ext. Surf.	Int. Surf.	External	Internal		
0.350	0.800	0.900	0.900	0.46	10.416

Layer	M-Code	Width (mm)	Conducti...	Convecti...	Vapour D...	Density (...	Specific ...	Description
Inside	sand cement pla...	15.0	0.72	0.001	0.700	1860.0	840.0	
2	Hollow conc. Blo...	200.0	0.77	0.001	999.000	1700.0	1000.0	
3	EPS, 75 mm	75.0	0.04	0.001	9999.000	15.0	1300.0	75 mm of expanded pol...
4	Cement renderin...	20.0	1.0	0.001	0.100	1570.0	896.0	

Opaque Construction | Name: Wall type 6 | Description:

Solar Absorptance		Emissivity		Conductance (W/m²·°C)	Time Constant
Ext. Surf.	Int. Surf.	External	Internal		
0.400	0.400	0.900	0.850	0.406	11.689

Layer	M-Code	Width (mm)	Conducti...	Convecti...	Vapour D...	Density (...	Specific ...	Description
Inside	am1s\39	15.0	999.999	0.0	5.565	0.001	0.001	WHITE
2	am1block\4	200.0	0.35	0.0	14.800	1050.0	1057.0	
3	polystyrene	50.0	0.027	0.001	9999.000	40.0	1300.0	Extruded polystyrene, 5...
4	am1plast\23	20.0	0.5	0.0	19.200	1300.0	769.0	CEMENT RENDERING...

Opaque Construction | Name: Wall type 7 | Description:

Solar Absorptance		Emissivity		Conductance (W/m²·°C)	Time Constant
Ext. Surf.	Int. Surf.	External	Internal		
0.400	0.400	0.900	0.850	0.371	11.858

Layer	M-Code	Width (mm)	Conducti...	Convecti...	Vapour D...	Density (...	Specific ...	Description
Inside	am1s\39	15.0	999.999	0.0	5.565	0.001	0.001	WHITE
2	am1block\4	200.0	0.35	0.0	14.800	1050.0	1057.0	
3	air gap 50	50.0	0.0	0.5	1.000	0.0	0.0	50MM AIR (DOWNWA...
4	Fiberglass quilt	75.0	0.04	0.0	2.880	12.0	833.0	GLASS FIBRE 1 *3
5	am1plast\23	20.0	0.5	0.0	19.200	1300.0	769.0	CEMENT RENDERING...

Opaque Construction | Name: Wall type 8 | Description:

Solar Absorptance		Emissivity		Conductance (W/m²·°C)	Time Constant
Ext. Surf.	Int. Surf.	External	Internal		
0.800	0.600	0.950	0.700	0.359	36.957

Layer	M-Code	Width (mm)	Conducti...	Convecti...	Vapour D...	Density (...	Specific ...	Description
Inside	Mortar plaster	15.0	0.016	0.001	0.001	600.0	1000.0	
2	am1block\4	200.0	0.35	0.0	14.800	1050.0	1057.0	
3	Sheep's wool	50.0	0.04	0.001	9999.000	25.0	1000.0	Agrément Certificate...
4	sand cement pla...	20.0	0.72	0.001	0.700	1860.0	840.0	

Opaque Construction | Name: Wall type 9 | Description:

Solar Absorptance		Emissivity		Conductance (W/m²·°C)	Time Constant
Ext. Surf.	Int. Surf.	External	Internal		
0.600	0.800	0.700	0.900	0.324	11.193

Layer	M-Code	Width (mm)	Conducti...	Convecti...	Vapour D...	Density (...	Specific ...	Description
Inside	sand cement pla...	15.0	0.72	0.001	0.700	1860.0	840.0	
2	Hollow conc. Blo...	200.0	0.77	0.001	999.000	1700.0	1000.0	
3	polystyrene	50.0	0.027	0.001	9999.000	40.0	1300.0	Extruded polystyrene, 5...
4	Mortar in inner leaf	15.0	0.88	0.001	9999.000	1750.0	1000.0	Mortar in inner leaf or ot...
5	Mortar plaster	15.0	0.016	0.001	0.001	600.0	1000.0	

Opaque Construction | Name: Wall type 10 | Description:

Solar Absorptance		Emissivity		Conductance (W/m²·°C)	Time Constant
Ext. Surf.	Int. Surf.	External	Internal		
0.400	0.400	0.900	0.850	0.295	12.472

Layer	M-Code	Width (mm)	Conducti...	Convecti...	Vapour D...	Density (...	Specific ...	Description
Inside	am1s\39	15.0	999.999	0.0	5.565	0.001	0.001	WHITE
2	am1block\4	200.0	0.35	0.0	14.800	1050.0	1057.0	
3	polystyrene	75.0	0.027	0.001	9999.000	40.0	1300.0	Extruded polystyrene, 5...
4	am1plast\23	20.0	0.5	0.0	19.200	1300.0	769.0	CEMENT RENDERING...

Opaque Construction | Name: Wall type 11 | Description:

Solar Absorptance		Emissivity		Conductance (W/m²·°C)	Time Constant
Ext. Surf.	Int. Surf.	External	Internal		
0.400	0.600	0.900	0.700	0.226	49.690

Layer	M-Code	Width (mm)	Conducti...	Convecti...	Vapour D...	Density (...	Specific ...	Description
Inside	Mortar plaster	15.0	0.016	0.001	0.001	600.0	1000.0	
2	am1block\4	200.0	0.35	0.0	14.800	1050.0	1057.0	
3	Polyurethane	75.0	0.026	0.001	9999.000	30.0	1800.0	Polyurethane insulating ...
4	am1plast\23	20.0	0.5	0.0	19.200	1300.0	769.0	CEMENT RENDERING...

Opaque Construction — Name: Wall type 12 — Description:

Solar Absorptance		Emissivity		Conductance (W/m²·°C)	Time Constant
Ext. Surf.	Int. Surf.	External	Internal		
0.400	0.600	0.900	0.700	0.185	53.618

Layer	M-Code	Width (mm)	Conducti...	Convecti...	Vapour D...	Density (...	Specific ...	Description
Inside	Mortar plaster	15.0	0.016	0.001	0.001	600.0	1000.0	
2	am1block\4	200.0	0.35	0.0	14.800	1050.0	1057.0	
3	Polyurethane	100.0	0.026	0.001	9999.000	30.0	1800.0	Polyurethane insulating ...
4	am1plast\23	20.0	0.5	0.0	19.200	1300.0	769.0	CEMENT RENDERING...

B. Roofs

Opaque Construction — Name: Internal floor — Description:

Solar Absorptance		Emissivity		Conductance (W/m²·°C)	Time Constant
Ext. Surf.	Int. Surf.	External	Internal		
0.400	0.500	0.900	0.900	4.55	2.260

Layer	M-Code	Width (mm)	Conducti...	Convecti...	Vapour D...	Density (...	Specific ...	Description
Inside	Tiles	20.0	0.23	0.001	0.001	1500.0	1300.0	
2	am1concd\2	150.0	1.13	0.0	34.000	2000.0	920.0	CONCRETE 3⁄ m.c. 9 *3
3	Plaster - type 2	0.02	0.21	0.001	6.000	900.0	850.0	

Opaque Construction — Name: Roof type 1 — Description:

Solar Absorptance		Emissivity		Conductance (W/m²·°C)	Time Constant
Ext. Surf.	Int. Surf.	External	Internal		
0.350	0.800	0.900	0.900	5.032	4.043

Layer	M-Code	Width (mm)	Conducti...	Convecti...	Vapour D...	Density (...	Specific ...	Description
Inside	sand cement pla...	15.0	0.72	0.001	0.700	1860.0	840.0	
2	Concrete Reinfor...	300.0	1.9	0.001	999.000	2300.0	840.0	Reinforced concrete, 1...
3	Cement renderin...	20.0	1.0	0.001	0.100	1570.0	896.0	

Opaque Construction — Name: Roof type 2 — Description:

Solar Absorptance		Emissivity		Conductance (W/m²·°C)	Time Constant
Ext. Surf.	Int. Surf.	External	Internal		
0.700	0.800	0.900	0.900	3.229	7.205

Layer	M-Code	Width (mm)	Conducti...	Convecti...	Vapour D...	Density (...	Specific ...	Description
Inside	sand cement pla...	15.0	0.72	0.001	0.700	1860.0	840.0	
2	Concrete Reinfor...	300.0	1.9	0.001	999.000	2300.0	840.0	Reinforced concrete, 1...
3	Bitumen	20.0	0.17	0.001	9999.000	1050.0	1000.0	Pure Bitumen
4	concrete roof tiles	20.0	1.5	0.001	9999.000	2100.0	1000.0	Concrete tiles (typically f...

Opaque Construction — Name: Roof type 3 — Description:

Solar Absorptance		Emissivity		Conductance (W/m²·°C)	Time Constant
Ext. Surf.	Int. Surf.	External	Internal		
0.700	0.700	0.900	0.900	2.042	14.998

Layer	M-Code	Width (mm)	Conducti...	Convecti...	Vapour D...	Density (...	Specific ...	Description
Inside	Plasterboard (cei...	15.0	0.07	0.001	9999.000	700.0	1000.0	Plasterboard (ceiling)
2	Concrete Reinfor...	300.0	1.9	0.001	999.000	2300.0	840.0	Reinforced concrete, 1...
3	Bitumen	20.0	0.17	0.001	9999.000	1050.0	1000.0	Pure Bitumen

Opaque Construction | Name: Roof type 4 | Description:

Solar Absorptance		Emissivity		Conductance (W/m²·°C)	Time Constant
Ext. Surf.	Int. Surf.	External	Internal		
0.700	0.730	0.900	0.900	0.957	33.401

Layer	M-Code	Width (mm)	Conducti...	Convecti...	Vapour D...	Density (...	Specific ...	Description
Inside	Plasterboard (cei...	15.0	0.07	0.001	9999.000	700.0	1000.0	Plasterboard (ceiling)
2	Concrete Reinfor...	200.0	1.9	0.001	999.000	2300.0	840.0	Reinforced concrete, 1...
3	am1cav\16	200.0	0.0	1.3	1.000	0.0	0.0	200MM AIR (UPWARD...
4	Concrete Reinfor...	150.0	1.9	0.001	999.000	2300.0	840.0	Reinforced concrete, 1...
5	Cement renderin...	20.0	1.0	0.001	0.100	1570.0	896.0	
6	Ceiling tile	40.0	0.09	0.001	9999.000	250.0	1000.0	Typical ceiling tile, cond...

Opaque Construction | Name: Roof type 5 | Description:

Solar Absorptance		Emissivity		Conductance (W/m²·°C)	Time Constant
Ext. Surf.	Int. Surf.	External	Internal		
0.700	0.730	0.900	0.900	0.588	23.737

Layer	M-Code	Width (mm)	Conducti...	Convecti...	Vapour D...	Density (...	Specific ...	Description
Inside	Plasterboard (cei...	15.0	0.07	0.001	9999.000	700.0	1000.0	Plasterboard (ceiling)
2	Concrete Reinfor...	200.0	1.9	0.001	999.000	2300.0	840.0	Reinforced concrete, 1...
3	Bitumen	20.0	0.17	0.001	9999.000	1050.0	1000.0	Pure Bitumen
4	Min wool quilt, 5...	50.0	0.04	0.001	1.000	12.0	1030.0	Mineral wool quilt, 50 m...
5	concrete roof tiles	20.0	1.5	0.001	9999.000	2100.0	1000.0	Concrete tiles (typically f...

Opaque Construction | Name: Roof type 6 | Description:

Solar Absorptance		Emissivity		Conductance (W/m²·°C)	Time Constant
Ext. Surf.	Int. Surf.	External	Internal		
0.700	0.730	0.900	0.900	0.469	24.769

Layer	M-Code	Width (mm)	Conducti...	Convecti...	Vapour D...	Density (...	Specific ...	Description
Inside	Plasterboard (cei...	15.0	0.07	0.001	9999.000	700.0	1000.0	Plasterboard (ceiling)
2	Concrete Reinfor...	200.0	1.9	0.001	999.000	2300.0	840.0	Reinforced concrete, 1...
3	Bitumen	20.0	0.17	0.001	9999.000	1050.0	1000.0	Pure Bitumen
4	Fiberglass quilt	50.0	0.04	0.0	2.880	12.0	833.0	GLASS FIBRE 1 *3
5	Ceiling tile	40.0	0.09	0.001	9999.000	250.0	1000.0	Typical ceiling tile, cond...

Opaque Construction | Name: Roof type 7 | Description:

Solar Absorptance		Emissivity		Conductance (W/m²·°C)	Time Constant
Ext. Surf.	Int. Surf.	External	Internal		
0.700	0.730	0.900	0.900	0.359	40.051

Layer	M-Code	Width (mm)	Conducti...	Convecti...	Vapour D...	Density (...	Specific ...	Description
Inside	Plasterboard (cei...	15.0	0.07	0.001	9999.000	700.0	1000.0	Plasterboard (ceiling)
2	Concrete Reinfor...	300.0	1.9	0.001	999.000	2300.0	840.0	Reinforced concrete, 1...
3	Bitumen	20.0	0.17	0.001	9999.000	1050.0	1000.0	Pure Bitumen
4	polystyrene	50.0	0.027	0.001	9999.000	40.0	1300.0	Extruded polystyrene, 5...
5	Ceiling tile	40.0	0.09	0.001	9999.000	250.0	1000.0	Typical ceiling tile, cond...

Opaque Construction | Name: Roof type 8 | Description:

Solar Absorptance		Emissivity		Conductance (W/m²·°C)	Time Constant
Ext. Surf.	Int. Surf.	External	Internal		
0.700	0.730	0.900	0.900	0.335	42.591

Layer	M-Code	Width (mm)	Conducti...	Convecti...	Vapour D...	Density (...	Specific ...	Description
Inside	Plasterboard (cei...	15.0	0.07	0.001	9999.000	700.0	1000.0	Plasterboard (ceiling)
2	Concrete Reinfor...	300.0	1.9	0.001	999.000	2300.0	840.0	Reinforced concrete, 1...
3	Bitumen	50.0	0.17	0.001	9999.000	1050.0	1000.0	Pure Bitumen
4	Min wool quilt, 5...	75.0	0.04	0.001	1.000	12.0	1030.0	Mineral wool quilt, 50 m...
5	Ceiling tile	40.0	0.09	0.001	9999.000	250.0	1000.0	Typical ceiling tile, cond...

Opaque Construction | Name: Roof type 9 | Description:

Solar Absorptance		Emissivity		Conductance (W/m²·°C)	Time Constant
Ext. Surf.	Int. Surf.	External	Internal		
0.700	0.730	0.900	0.900	0.319	44.697

Layer	M-Code	Width (mm)	Conducti...	Convecti...	Vapour D...	Density (...	Specific ...	Description
Inside	Plasterboard (cei...	15.0	0.07	0.001	9999.000	700.0	1000.0	Plasterboard (ceiling)
2	Concrete Reinfor...	300.0	1.9	0.001	999.000	2300.0	840.0	Reinforced concrete, 1...
3	Bitumen	75.0	0.17	0.001	9999.000	1050.0	1000.0	Pure Bitumen
4	Fiberglass quilt	75.0	0.04	0.0	2.880	12.0	833.0	GLASS FIBRE 1 *3
5	Ceiling tile	40.0	0.09	0.001	9999.000	250.0	1000.0	Typical ceiling tile, cond...

Opaque Construction | Name: Roof type 10 | Description:

Solar Absorptance		Emissivity		Conductance (W/m²·°C)	Time Constant
Ext. Surf.	Int. Surf.	External	Internal		
0.700	0.730	0.900	0.900	0.291	39.506

Layer	M-Code	Width (mm)	Conducti...	Convecti...	Vapour D...	Density (...	Specific ...	Description
Inside	Plasterboard (cei...	15.0	0.07	0.001	9999.000	700.0	1000.0	Plasterboard (ceiling)
2	Concrete Reinfor...	300.0	1.9	0.001	999.000	2300.0	840.0	Reinforced concrete, 1...
3	Sheep's wool	100.0	0.04	0.001	9999.000	25.0	1000.0	Agrément Certificate...
4	Bitumen	20.0	0.17	0.001	9999.000	1050.0	1000.0	Pure Bitumen
5	Ceiling tile	40.0	0.09	0.001	9999.000	250.0	1000.0	Typical ceiling tile, cond...

Opaque Construction | Name: Roof type 11 | Description:

Solar Absorptance		Emissivity		Conductance (W/m²·°C)	Time Constant
Ext. Surf.	Int. Surf.	External	Internal		
0.900	0.500	0.950	0.900	0.269	47.523

Layer	M-Code	Width (mm)	Conducti...	Convecti...	Vapour D...	Density (...	Specific ...	Description
Inside	am1tile\1	15.0	0.058	0.0	14.000	288.0	586.0	ACOUSTIC TILE/PANE...
2	am1cav\25	200.0	0.0	0.244	1.000	0.0	0.0	200MM AIR (DOWNW...
3	Concrete Reinfor...	200.0	1.9	0.001	999.000	2300.0	840.0	Reinforced concrete, 1...
4	POLYSTRENE ...	125.0	0.04	0.0	21.000	16.0	1210.0	POLYSTRENE EXPAN...
5	am1asph\1	3.0	0.43	0.0	1000.000	1600.0	1000.0	ASPHALT 1 *2

Opaque Construction | Name: Roof type 12 | Description:

Solar Absorptance		Emissivity		Conductance (W/m²·°C)	Time Constant
Ext. Surf.	Int. Surf.	External	Internal		
0.700	0.730	0.900	0.900	0.176	29.838

Layer	M-Code	Width (mm)	Conducti...	Convecti...	Vapour D...	Density (...	Specific ...	Description
Inside	Plasterboard (cei...	15.0	0.07	0.001	9999.000	700.0	1000.0	Plasterboard (ceiling)
2	Concrete Reinfor...	200.0	1.9	0.001	999.000	2300.0	840.0	Reinforced concrete, 1...
3	Bitumen	50.0	0.17	0.001	9999.000	1050.0	1000.0	Pure Bitumen
4	Polyurethane	120.0	0.026	0.001	9999.000	30.0	1800.0	Polyurethane insulating ...
5	Ceiling tile	40.0	0.09	0.001	9999.000	250.0	1000.0	Typical ceiling tile, cond...

C. Glazing

Transparent Construction | Name: (G1) Single Clear | Description:

Solar Transmittance	External Solar Absorptance		Internal Solar Absorptance		Light Transmittance	Emissivity		Conductance (W/m²·°C)	Time Constant	External Blind	Internal Blind
	Ext. Surf	Int. Surf.	Ext. Surf	Int. Surf.		External	Internal				
0.834	0.046	0.046	0.046	0.046	0.899	0.840	0.840	333.333	0.000	No	No

Layer	M-Code	Width ...	Solar ...	Ext. S...	Int. So...	Ext. E...	Int. E...	Condu...	Conve...	Vapou...	Description
Inside	Single	3.0	0.834	0.075	0.075	0.840	0.840	1.0	0.001	9999....	Generic: Generic ...

Transparent Construction — Name: (G2) 3 mm Double — Description: 3 mm air space 4-3-4

Solar Transmittance	External Solar Absorptance		Internal Solar Absorptance		Light Transmittance	Emissivity		Conductance (W/m^2·°C)	Time Constant	External Blind	Internal Blind
	Ext. Surf	Int. Surf.	Ext. Surf	Int. Surf.		External	Internal				
0.699	0.097	0.077	0.097	0.077	0.814	0.840	0.840	7.014	0.000	No	No

Layer	M-Code	Width ...	Solar ...	Ext. S...	Int. So...	Ext. E...	Int. E...	Condu...	Conve...	Vapou...	Description
Inside	Single	3.0	0.834	0.075	0.075	0.840	0.840	1.0	0.001	9999....	Generic: Generic ...
2	3 mm Air	3.0	0.000	0.000	0.000	0.000	0.000	0.01	3.6	1.000	Horizontal flow
3	Single	3.0	0.834	0.075	0.075	0.840	0.840	1.0	0.001	9999....	Generic: Generic ...

Transparent Construction — Name: (G3) 4-12-4 — Description:

Solar Transmittance	External Solar Absorptance		Internal Solar Absorptance		Light Transmittance	Emissivity		Conductance (W/m^2·°C)	Time Constant	External Blind	Internal Blind
	Ext. Surf	Int. Surf.	Ext. Surf	Int. Surf.		External	Internal				
0.671	0.101	0.078	0.101	0.078	0.796	0.840	0.840	5.545	0.000	No	No

Layer	M-Code	Width ...	Solar ...	Ext. S...	Int. So...	Ext. E...	Int. E...	Condu...	Conve...	Vapou...	Description
Inside	4 mm clear ...	4.0	0.816	0.089	0.089	0.840	0.840	1.0	0.001	9999....	
2	Air, 12 mm	12.0	0.000	0.000	0.000	0.000	0.000	0.01	2.08	1.000	
3	4 mm clear ...	4.0	0.816	0.089	0.089	0.840	0.840	1.0	0.001	9999....	

Transparent Construction — Name: (G4) 6-3-6 — Description:

Solar Transmittance	External Solar Absorptance		Internal Solar Absorptance		Light Transmittance	Emissivity		Conductance (W/m^2·°C)	Time Constant	External Blind	Internal Blind
	Ext. Surf	Int. Surf.	Ext. Surf	Int. Surf.		External	Internal				
0.667	0.107	0.082	0.107	0.082	0.724	0.840	0.100	3.912	0.000	No	No

Layer	M-Code	Width ...	Solar ...	Ext. S...	Int. So...	Ext. E...	Int. E...	Condu...	Conve...	Vapou...	Description
Inside	6 mm glass	6.0	0.814	0.086	0.086	0.840	0.100	1.0	0.001	9999....	
2	3 mm Air	3.0	0.000	0.000	0.000	0.000	0.000	0.01	3.6	1.000	Horizontal flow
3	6 mm glass	6.0	0.814	0.086	0.086	0.840	0.100	1.0	0.001	9999....	

Transparent Construction — Name: (G5) 4-12-4 low-e — Description:

Solar Transmittance	External Solar Absorptance		Internal Solar Absorptance		Light Transmittance	Emissivity		Conductance (W/m^2·°C)	Time Constant	External Blind	Internal Blind
	Ext. Surf	Int. Surf.	Ext. Surf	Int. Surf.		External	Internal				
0.510	0.313	0.060	0.102	0.244	0.756	0.840	0.840	2.532	0.000	No	No

Layer	M-Code	Width ...	Solar ...	Ext. S...	Int. So...	Ext. E...	Int. E...	Condu...	Conve...	Vapou...	Description
Inside	4 mm clear ...	4.0	0.816	0.089	0.089	0.840	0.840	1.0	0.001	9999....	
2	Air, 12 mm	12.0	0.000	0.000	0.000	0.000	0.000	0.01	2.08	1.000	
3	4 mm glass (...	4.0	0.620	0.082	0.082	0.840	0.100	1.0	0.001	9999....	

Transparent Construction — Name: (G6) 4-16 argon-4 — Description:

Solar Transmittance	External Solar Absorptance		Internal Solar Absorptance		Light Transmittance	Emissivity		Conductance (W/m^2·°C)	Time Constant	External Blind	Internal Blind
	Ext. Surf	Int. Surf.	Ext. Surf	Int. Surf.		External	Internal				
0.510	0.314	0.060	0.102	0.244	0.756	0.840	0.840	1.642	0.000	No	No

Layer	M-Code	Width ...	Solar ...	Ext. S...	Int. So...	Ext. E...	Int. E...	Condu...	Conve...	Vapou...	Description
Inside	4 mm clear ...	4.0	0.816	0.089	0.089	0.840	0.840	1.0	0.001	9999....	
2	Argon, 16 mm	16.0	0.000	0.000	0.000	0.000	0.000	0.01	1.16	1.000	
3	4 mm glass (...	4.0	0.620	0.082	0.082	0.840	0.100	1.0	0.001	9999....	

Appendix 3: Vertical and Horizontal Shadow Angles of the Case Study City (Darnah, Libya)

For design purposes it is useful to have information about the solar angles resolved on the plane of the orthogonal projection normally used in design, namely plan and elevation. The angle between the direction of the sun, resolved in the plane of the elevation, and the horizontal plane is known as the vertical shadow angle (VSA). The angle between the direction of the sun, resolved on the horizontal plane, and wall azimuth angle (the direction of the normal to the surface projected onto the horizontal plane) is known as the horizontal shadow angle (HSA). These relationships are illustrated in the diagram to the right. The VSA in a given plane is obtained from the projection of the line to the centre of the sun onto the vertical plane containing the normal to that plane. The HSA is simply the angle between the wall azimuth and the solar azimuth.

Tabulated Daily Solar Data

Latitude: 32.8°
Longitude: 22.6°
Timezone: 30.0° [+2.0hrs]
Orientation: 0.0° = North

Date: 21st June
Julian Date: 172
Sunrise: 05:26
Sunset: 19:36

Local Correction: -31.2 mins
Equation of Time: -1.6 mins
Declination: 23.4°

Local	(Solar)	Aziumuth	Altitude	HSA	VSA	Shading
05:30	(04:58)	62.3°	0.7°	62.3°	1.5°	0%
06:00	(05:28)	66.2°	6.4°	66.2°	15.4°	6%
06:30	(05:58)	69.8°	12.2°	69.8°	32.1°	15%
07:00	(06:28)	73.4°	18.2°	73.4°	48.9°	28%
07:30	(06:58)	76.8°	24.3°	76.8°	63.2°	38%
08:00	(07:28)	80.2°	30.5°	80.2°	73.9°	61%
08:30	(07:58)	83.7°	36.7°	83.7°	81.6°	66%
09:00	(08:28)	87.4°	43.0°	87.4°	87.2°	73%
09:30	(08:58)	91.3°	49.3°	91.3°	91.2°	[Behind]
10:00	(09:28)	95.9°	55.6°	95.9°	94.1°	[Behind]
10:30	(09:58)	101.6°	61.8°	101.6°	96.1°	[Behind]
11:00	(10:28)	109.2°	67.9°	109.2°	97.6°	[Behind]
11:30	(10:58)	120.9°	73.6°	120.9°	98.6°	[Behind]
12:00	(11:28)	141.8°	78.4°	141.8°	99.2°	[Behind]
12:30	(11:58)	178.3°	80.6°	178.3°	99.4°	[Behind]
13:00	(12:28)	-144.1°	78.7°	-144.1°	99.2°	[Behind]
13:30	(12:58)	-122.2°	74.0°	-122.2°	98.7°	[Behind]
14:00	(13:28)	-109.9°	68.4°	-109.9°	97.7°	[Behind]
14:30	(13:58)	-102.1°	62.3°	-102.1°	96.3°	[Behind]
15:00	(14:28)	-96.3°	56.1°	-96.3°	94.2°	[Behind]
15:30	(14:58)	-91.7°	49.8°	-91.7°	91.4°	[Behind]
16:00	(15:28)	-87.7°	43.5°	-87.7°	87.5°	73%
16:30	(15:58)	-84.0°	37.2°	-84.0°	82.1°	66%
17:00	(16:28)	-80.5°	30.9°	-80.5°	74.6°	58%
17:30	(16:58)	-77.1°	24.8°	-77.1°	64.1°	39%
18:00	(17:28)	-73.6°	18.7°	-73.6°	50.2°	27%
18:30	(17:58)	-70.1°	12.7°	-70.1°	33.5°	15%
19:00	(18:28)	-66.5°	6.8°	-66.5°	16.7°	8%
19:30	(18:58)	-62.6°	1.1°	-62.6°	2.4°	0%

Tabulated Daily Solar Data

Latitude: 32.8°
Longitude: 22.6°
Timezone: 30.0° [+2.0hrs]
Orientation: 90.0° = **east**

Date: 21st June
Julian Date: 172
Sunrise: 05:26
Sunset: 19:36

Local Correction: -31.2 mins
Equation of Time: -1.6 mins
Declination: 23.4°

Local	(Solar)	Aziumuth	Altitude	HSA	VSA	Shading
05:30	(04:58)	62.3°	0.7°	-27.7°	0.8°	0%
06:00	(05:28)	66.2°	6.4°	-23.8°	7.0°	4%
06:30	(05:58)	69.8°	12.2°	-20.2°	13.0°	14%
07:00	(06:28)	73.4°	18.2°	-16.6°	18.9°	22%
07:30	(06:58)	76.8°	24.3°	-13.2°	24.9°	34%
08:00	(07:28)	80.2°	30.5°	-9.8°	30.8°	55%
08:30	(07:58)	83.7°	36.7°	-6.3°	36.9°	70%
09:00	(08:28)	87.4°	43.0°	-2.6°	43.0°	81%
09:30	(08:58)	91.3°	49.3°	1.3°	49.3°	100%
10:00	(09:28)	95.9°	55.6°	5.9°	55.7°	100%
10:30	(09:58)	101.6°	61.8°	11.6°	62.3°	100%
11:00	(10:28)	109.2°	67.9°	19.2°	69.0°	100%
11:30	(10:58)	120.9°	73.6°	30.9°	75.8°	100%
12:00	(11:28)	141.8°	78.4°	51.8°	82.8°	100%
12:30	(11:58)	178.3°	80.6°	88.3°	89.7°	100%
13:00	(12:28)	-144.1°	78.7°	125.9°	96.7°	[Behind]
13:30	(12:58)	-122.2°	74.0°	147.8°	103.6°	[Behind]
14:00	(13:28)	-109.9°	68.4°	160.1°	110.5°	[Behind]
14:30	(13:58)	-102.1°	62.3°	167.9°	117.2°	[Behind]
15:00	(14:28)	-96.3°	56.1°	173.7°	123.8°	[Behind]
15:30	(14:58)	-91.7°	49.8°	178.3°	130.2°	[Behind]
16:00	(15:28)	-87.7°	43.5°	-177.7°	136.5°	[Behind]
16:30	(15:58)	-84.0°	37.2°	-174.0°	142.7°	[Behind]
17:00	(16:28)	-80.5°	30.9°	-170.5°	148.7°	[Behind]
17:30	(16:58)	-77.1°	24.8°	-167.1°	154.7°	[Behind]
18:00	(17:28)	-73.6°	18.7°	-163.6°	160.6°	[Behind]
18:30	(17:58)	-70.1°	12.7°	-160.1°	166.6°	[Behind]
19:00	(18:28)	-66.5°	6.8°	-156.5°	172.6°	[Behind]
19:30	(18:58)	-62.6°	1.1°	-152.6°	178.7°	[Behind]

Tabulated Daily Solar Data

Latitude: 32.8°
Longitude: 22.6°
Timezone: 30.0° [+2.0hrs]
Orientation: 180.0° = **South**

Date: 21st June
Julian Date: 172
Sunrise: 05:26
Sunset: 19:36

Local Correction: -31.2 mins
Equation of Time: -1.6 mins
Declination: 23.4°

Local	(Solar)	Aziumuth	Altitude	HSA	VSA	Shading
05:30	(04:58)	62.3°	0.7°	-117.7°	178.5°	[Behind]
06:00	(05:28)	66.2°	6.4°	-113.8°	164.6°	[Behind]
06:30	(05:58)	69.8°	12.2°	-110.2°	147.9°	[Behind]
07:00	(06:28)	73.4°	18.2°	-106.6°	131.1°	[Behind]
07:30	(06:58)	76.8°	24.3°	-103.2°	116.8°	[Behind]
08:00	(07:28)	80.2°	30.5°	-99.8°	106.1°	[Behind]
08:30	(07:58)	83.7°	36.7°	-96.3°	98.4°	[Behind]
09:00	(08:28)	87.4°	43.0°	-92.6°	92.8°	[Behind]
09:30	(08:58)	91.3°	49.3°	-88.7°	88.8°	78%
10:00	(09:28)	95.9°	55.6°	-84.1°	85.9°	87%
10:30	(09:58)	101.6°	61.8°	-78.4°	83.9°	92%
11:00	(10:28)	109.2°	67.9°	-70.8°	82.4°	96%
11:30	(10:58)	120.9°	73.6°	-59.1°	81.4°	99%
12:00	(11:28)	141.8°	78.4°	-38.2°	80.8°	100%
12:30	(11:58)	178.3°	80.6°	-1.7°	80.6°	100%
13:00	(12:28)	-144.1°	78.7°	35.9°	80.8°	100%
13:30	(12:58)	-122.2°	74.0°	57.8°	81.3°	97%
14:00	(13:28)	-109.9°	68.4°	70.1°	82.3°	94%
14:30	(13:58)	-102.1°	62.3°	77.9°	83.7°	92%
15:00	(14:28)	-96.3°	56.1°	83.7°	85.8°	88%
15:30	(14:58)	-91.7°	49.8°	88.3°	88.6°	79%
16:00	(15:28)	-87.7°	43.5°	92.3°	92.5°	[Behind]
16:30	(15:58)	-84.0°	37.2°	96.0°	97.9°	[Behind]
17:00	(16:28)	-80.5°	30.9°	99.5°	105.4°	[Behind]
17:30	(16:58)	-77.1°	24.8°	102.9°	115.9°	[Behind]
18:00	(17:28)	-73.6°	18.7°	106.4°	129.8°	[Behind]
18:30	(17:58)	-70.1°	12.7°	109.9°	146.5°	[Behind]
19:00	(18:28)	-66.5°	6.8°	113.5°	163.3°	[Behind]
19:30	(18:58)	-62.6°	1.1°	117.4°	177.6°	[Behind]

Tabulated Daily Solar Data

Latitude: 32.8°
Longitude: 22.6°
Timezone: 30.0° [+2.0hrs]
Orientation: 270.0° = **West**

Date: 21st June
Julian Date: 172
Sunrise: 05:26
Sunset: 19:36

Local Correction: -31.2 mins
Equation of Time: -1.6 mins
Declination: 23.4°

Local	(Solar)	Azimuth	Altitude	HSA	VSA	Shading
05:30	(04:58)	62.3°	0.7°	152.3°	179.2°	[Behind]
06:00	(05:28)	66.2°	6.4°	156.2°	173.0°	[Behind]
06:30	(05:58)	69.8°	12.2°	159.8°	167.0°	[Behind]
07:00	(06:28)	73.4°	18.2°	163.4°	161.1°	[Behind]
07:30	(06:58)	76.8°	24.3°	166.8°	155.1°	[Behind]
08:00	(07:28)	80.2°	30.5°	170.2°	149.2°	[Behind]
08:30	(07:58)	83.7°	36.7°	173.7°	143.1°	[Behind]
09:00	(08:28)	87.4°	43.0°	177.4°	137.0°	[Behind]
09:30	(08:58)	91.3°	49.3°	-178.7°	130.7°	[Behind]
10:00	(09:28)	95.9°	55.6°	-174.1°	124.3°	[Behind]
10:30	(09:58)	101.6°	61.8°	-168.4°	117.7°	[Behind]
11:00	(10:28)	109.2°	67.9°	-160.8°	111.0°	[Behind]
11:30	(10:58)	120.9°	73.6°	-149.1°	104.2°	[Behind]
12:00	(11:28)	141.8°	78.4°	-128.2°	97.2°	[Behind]
12:30	(11:58)	178.3°	80.6°	-91.7°	90.3°	[Behind]
13:00	(12:28)	-144.1°	78.7°	-54.1°	83.3°	100%
13:30	(12:58)	-122.2°	74.0°	-32.2°	76.4°	100%
14:00	(13:28)	-109.9°	68.4°	-19.9°	69.5°	100%
14:30	(13:58)	-102.1°	62.3°	-12.1°	62.8°	100%
15:00	(14:28)	-96.3°	56.1°	-6.3°	56.2°	100%
15:30	(14:58)	-91.7°	49.8°	-1.7°	49.8°	100%
16:00	(15:28)	-87.7°	43.5°	2.3°	43.5°	81%
16:30	(15:58)	-84.0°	37.2°	6.0°	37.3°	70%
17:00	(16:28)	-80.5°	30.9°	9.5°	31.3°	55%
17:30	(16:58)	-77.1°	24.8°	12.9°	25.3°	33%
18:00	(17:28)	-73.6°	18.7°	16.4°	19.4°	21%
18:30	(17:58)	-70.1°	12.7°	19.9°	13.4°	13%
19:00	(18:28)	-66.5°	6.8°	23.5°	7.4°	4%
19:30	(18:58)	-62.6°	1.1°	27.4°	1.3°	0%

Tabulated Daily Solar Data

Latitude: 32.8°
Longitude: 22.6°
Timezone: 30.0° [+2.0hrs]
Orientation: 0.0° = **North**

Date: 21st December
Julian Date: 355
Sunrise: 07:32
Sunset: 17:22

Local Correction: -27.5 mins
Equation of Time: 2.1 mins
Declination: -23.5°

Local	(Solar)	Azimuth	Altitude	HSA	VSA	Shading
08:00	(07:32)	122.1°	5.0°	122.1°	170.7°	[Behind]
08:30	(08:02)	126.7°	10.2°	126.7°	163.2°	[Behind]
09:00	(08:32)	131.6°	15.1°	131.6°	157.9°	[Behind]
09:30	(09:02)	137.1°	19.6°	137.1°	154.1°	[Behind]
10:00	(09:32)	143.1°	23.6°	143.1°	151.3°	[Behind]
10:30	(10:02)	149.6°	27.1°	149.6°	149.3°	[Behind]
11:00	(10:32)	156.8°	30.0°	156.8°	147.9°	[Behind]
11:30	(11:02)	164.4°	32.1°	164.4°	146.9°	[Behind]
12:00	(11:32)	172.4°	33.3°	172.4°	146.4°	[Behind]
12:30	(12:02)	-179.3°	33.7°	-179.3°	146.3°	[Behind]
13:00	(12:32)	-171.1°	33.2°	-171.1°	146.5°	[Behind]
13:30	(13:02)	-163.1°	31.8°	-163.1°	147.1°	[Behind]
14:00	(13:32)	-155.5°	29.6°	-155.5°	148.1°	[Behind]
14:30	(14:02)	-148.5°	26.6°	-148.5°	149.6°	[Behind]
15:00	(14:32)	-142.0°	23.0°	-142.0°	151.7°	[Behind]
15:30	(15:02)	-136.1°	18.9°	-136.1°	154.6°	[Behind]
16:00	(15:32)	-130.8°	14.3°	-130.8°	158.7°	[Behind]
16:30	(16:02)	-125.9°	9.3°	-125.9°	164.3°	[Behind]
17:00	(16:32)	-121.4°	4.1°	-121.4°	172.2°	[Behind]

Tabulated Daily Solar Data

Latitude: 32.8°
Longitude: 22.6°
Timezone: 30.0° [+2.0hrs]
Orientation: 90.0° = **East**

Date: 21st December
Julian Date: 355
Sunrise: 07:32
Sunset: 17:22

Local Correction: -27.5 mins
Equation of Time: 2.1 mins
Declination: -23.5°

Local	(Solar)	Aziumuth	Altitude	HSA	VSA	Shading
08:00	(07:32)	122.1°	5.0°	32.1°	5.9°	0%
08:30	(08:02)	126.7°	10.2°	36.7°	12.6°	15%
09:00	(08:32)	131.6°	15.1°	41.6°	19.8°	28%
09:30	(09:02)	137.1°	19.6°	47.1°	27.6°	29%
10:00	(09:32)	143.1°	23.6°	53.1°	36.1°	41%
10:30	(10:02)	149.6°	27.1°	59.6°	45.4°	55%
11:00	(10:32)	156.8°	30.0°	66.8°	55.6°	52%
11:30	(11:02)	164.4°	32.1°	74.4°	66.8°	62%
12:00	(11:32)	172.4°	33.3°	82.4°	78.7°	61%
12:30	(12:02)	-179.3°	33.7°	90.7°	91.0°	[Behind]
13:00	(12:32)	-171.1°	33.2°	98.9°	103.3°	[Behind]
13:30	(13:02)	-163.1°	31.8°	106.9°	115.1°	[Behind]
14:00	(13:32)	-155.5°	29.6°	114.5°	126.1°	[Behind]
14:30	(14:02)	-148.5°	26.6°	121.5°	136.2°	[Behind]
15:00	(14:32)	-142.0°	23.0°	128.0°	145.4°	[Behind]
15:30	(15:02)	-136.1°	18.9°	133.9°	153.7°	[Behind]
16:00	(15:32)	-130.8°	14.3°	139.2°	161.4°	[Behind]
16:30	(16:02)	-125.9°	9.3°	144.1°	168.5°	[Behind]
17:00	(16:32)	-121.4°	4.1°	148.6°	175.2°	[Behind]

Tabulated Daily Solar Data

Latitude: 32.8°
Longitude: 22.6°
Timezone: 30.0° [+2.0hrs]
Orientation: 180.0° = **South**

Date: 21st December
Julian Date: 355
Sunrise: 07:32
Sunset: 17:22

Local Correction: -27.5 mins
Equation of Time: 2.1 mins
Declination: -23.5°

Local	(Solar)	Aziumuth	Altitude	HSA	VSA	Shading
08:00	(07:32)	122.1°	5.0°	-57.9°	9.3°	0%
08:30	(08:02)	126.7°	10.2°	-53.3°	16.8°	17%
09:00	(08:32)	131.6°	15.1°	-48.4°	22.1°	28%
09:30	(09:02)	137.1°	19.6°	-42.9°	25.9°	28%
10:00	(09:32)	143.1°	23.6°	-36.9°	28.7°	35%
10:30	(10:02)	149.6°	27.1°	-30.4°	30.7°	46%
11:00	(10:32)	156.8°	30.0°	-23.2°	32.1°	46%
11:30	(11:02)	164.4°	32.1°	-15.6°	33.1°	57%
12:00	(11:32)	172.4°	33.3°	-7.6°	33.6°	55%
12:30	(12:02)	-179.3°	33.7°	0.7°	33.7°	54%
13:00	(12:32)	-171.1°	33.2°	8.9°	33.5°	55%
13:30	(13:02)	-163.1°	31.8°	16.9°	32.9°	57%
14:00	(13:32)	-155.5°	29.6°	24.5°	31.9°	45%
14:30	(14:02)	-148.5°	26.6°	31.5°	30.4°	45%
15:00	(14:32)	-142.0°	23.0°	38.0°	28.3°	34%
15:30	(15:02)	-136.1°	18.9°	43.9°	25.4°	28%
16:00	(15:32)	-130.8°	14.3°	49.2°	21.3°	15%
16:30	(16:02)	-125.9°	9.3°	54.1°	15.7°	7%
17:00	(16:32)	-121.4°	4.1°	58.6°	7.8°	0%

Tabulated Daily Solar Data

Latitude: 32.8°
Longitude: 22.6°
Timezone: 30.0° [+2.0hrs]
Orientation: 270.0° = **West**

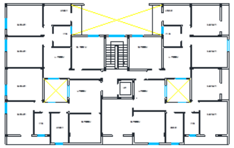
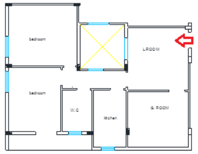
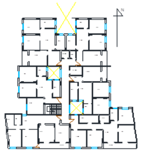
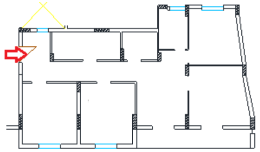
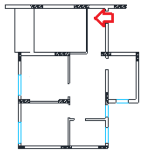
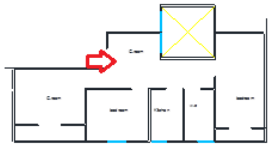
Date: 21st December
Julian Date: 355
Sunrise: 07:32
Sunset: 17:22

Local Correction: -27.5 mins
Equation of Time: 2.1 mins
Declination: -23.5°

Local	(Solar)	Aziumuth	Altitude	HSA	VSA	Shading
08:00	(07:32)	122.1°	5.0°	-147.9°	174.1°	[Behind]
08:30	(08:02)	126.7°	10.2°	-143.3°	167.4°	[Behind]
09:00	(08:32)	131.6°	15.1°	-138.4°	160.2°	[Behind]
09:30	(09:02)	137.1°	19.6°	-132.9°	152.4°	[Behind]
10:00	(09:32)	143.1°	23.6°	-126.9°	143.9°	[Behind]
10:30	(10:02)	149.6°	27.1°	-120.4°	134.6°	[Behind]
11:00	(10:32)	156.8°	30.0°	-113.2°	124.4°	[Behind]
11:30	(11:02)	164.4°	32.1°	-105.6°	113.2°	[Behind]
12:00	(11:32)	172.4°	33.3°	-97.6°	101.3°	[Behind]
12:30	(12:02)	-179.3°	33.7°	-89.3°	89.0°	58%
13:00	(12:32)	-171.1°	33.2°	-81.1°	76.7°	58%
13:30	(13:02)	-163.1°	31.8°	-73.1°	64.9°	62%
14:00	(13:32)	-155.5°	29.6°	-65.5°	53.9°	50%
14:30	(14:02)	-148.5°	26.6°	-58.5°	43.8°	55%
15:00	(14:32)	-142.0°	23.0°	-52.0°	34.6°	40%
15:30	(15:02)	-136.1°	18.9°	-46.1°	26.3°	28%
16:00	(15:32)	-130.8°	14.3°	-40.8°	18.6°	18%
16:30	(16:02)	-125.9°	9.3°	-35.9°	11.5°	5%
17:00	(16:32)	-121.4°	4.1°	-31.4°	4.8°	0%

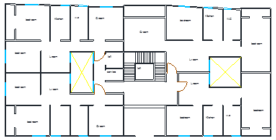
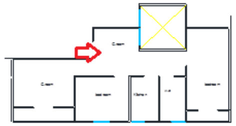
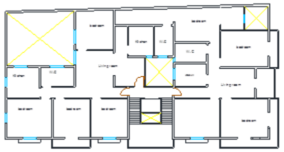
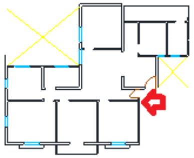
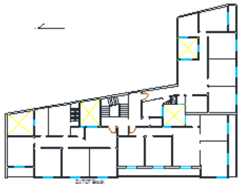
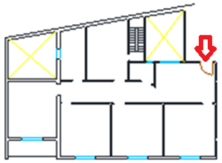
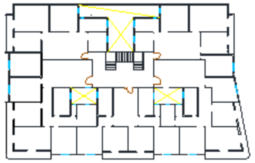
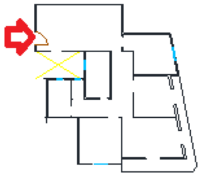
APPENDIX 4: SUMMARY OF RESEARCH FINDINGS

Table 1: Summary of case studies findings

Case code	picture	Case plan	Flat plan	Features	Max temp recorded in summer				Min temp recorded in winter				Thermal comfort**			
													summer		winter	
					°C	Zone*	day	hour	°C	Zone*	day	hour	PMV	%Percentage Dissatisfied	PMV	%Percentage Dissatisfied
B1				Basic characteristics of the case study buildings are found in table 6.3	36.9	LR	185	17	12.0	KIT	24	07	+3	99.6	-0.91	22.4
B2					36.6	BR	185	17	11.6	KIT	24	07	+3	99.4	-0.91	22.4
B3					36.4	LR	185	17	12.2	BR	24	06	+3	99.2	-0.90	22.3
B4					37.7	BR	184	17	12.1	BR	24	05	+3	100	-0.87	21

*All the zone where found to be located on the top floor of each building.

**thermal comfort at: activity rate=1.6met _ clothing, summer=0.5clo winter=1.4clo _ air velocity, summer=0.5m/s winter 0.75 m/s

Case code	picture	Case plan	Flat plan	Features	Max indoor temp recorded in summer				Min indoor temp recorded in winter				Thermal comfort			
													summer		winter	
					°C	Zone*	day	hour	°C	Zone*	day	hour	PMV	%Percentage Dissatisfied	PMV	%Percentage Dissatisfied
B5				Basic characteristics of the case study buildings are found in table 6.3	39.4	LR	186	18	12.1	BR	24	06	+3	100	-1.09	30
B6					36.9	BR	185	17	11.5	GR	24	06	+3	99.6	-0.94	23.6
B7					31.7	BR	140	17	14.2	DR	56	09	+2.15	83.7	-1.3	41
B8					37.2	BR	185	17	12.4	BR	24	05	+2.9	98.6	-0.91	22.4

LR= living room **KIT= kitchen** **BR= bedroom** **GR= guest room** **DR= dining room**

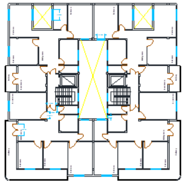
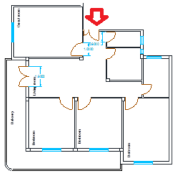
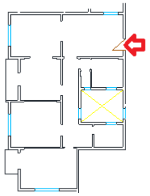
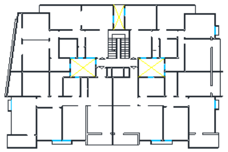
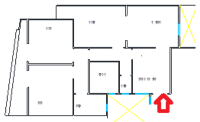
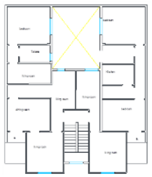
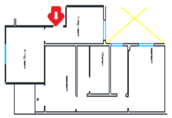
Case code	picture	Case plan	Flat plan	Features	Max temp recorded in summer				Min temp recorded in winter				Thermal comfort			
													summer		winter	
					°C	Zone*	day	hour	°C	Zone*	day	hour	PMV	%Percentage Dissatisfied	PMV	%Percentage Dissatisfied
B9				**Basic characteristics of the case study buildings are found in table 6.3**	38,1	BR	185	17	12	BR	24	06	+3	99.7	-0.73	16.1
B10					33	BR	185	16	14	BR	24	05	+2.1	77.2	-0.56	11.6
B11					35.9	KIT	185	17	11.8	BR	24	05	+3	99.0	-0.95	24
B12					35	BR	185	17	12	BR	24	05	+3	98.9	-0.91	22.5

Table 2: Samples of external surfaces examination done on all the case study buildings *G= ground floor T=top floor

BSH_ S building (case B3)

Data recorder 21-June (day 172)		SW wall	NW wall	SE wall	NE wall	Roof
Surface temp. On external wall surface at noontime (°C)	G	36.90	36.70	38.30	37.40	-
	T	37.0	36.8	38.4	37.50	42.60
Solar gain received during the day(KW)	G	3.70	5.06	5.17	4.80	-
	T	4.60	7.30	5.50	5.40	89.01
Heat gain by conduction during the day (KW)	G	0.88	1.38	1.06	1.17	-
	T	1.11	1.82	1.26	1.40	28.02

ZAT Building (Case B7)

Data recorder 21-June (172d)		SW wall	NW wall	SE wall	NE wall	Roof
Surface temp. On external wall surface at noontime (°C)	G	38.1	37.8	39.0	38.2	_
	T	38.3	38.0	39.4	38.5	43.8
Solar gain received during the day(KW)	G	11.4	15.1	3.2	11.0	_
	T	11.5	15.3	3.4	11.2	103.6
Heat gain by conduction during the day (KW)	G	4.3	4.6	1.5	4.6	_
	T	3.8	4.2	1.2	4.0	44.0

ARH Building (Case B8)

Data recorder 21-June (172d)		S wall		E wall	N wall	W wall	Roof
		Exposed	Attached				
Surface temp. On external wall surface at noontime (°C)	G	38.4	29.3	39.2	37.8	37.9	_
	T	38.5	31.4	39.4	38	37.9	42.7
Solar gain received during the day(KW)	G	10.0	0	9.0	9.2	9.8	_
	T	12.3	0	9.2	``19.3	14.5	87.3
Heat gain by conduction during the day (KW)	G	4.5	1.3	3.4	4.2	3.8	_
	T	5.2	1.5	3.2	3.9	4.3	38.4

WQF Building (Case B10)

Data recorder 21-June (172d)		SW wall	NW wall	SE wall		NE wall	Roof
				No tree shadow	Tree shadow		
Surface temp. On external wall surface at noontime (°C)	G	37.3	37.2	38.1	37.6	37.7	_
	T	38.8	38.6	38.5	_	38.3	46.9
Solar gain received during the day(KW)	G	5.5	5.2	8.7	7.7	6.8	_
	T	8.8	9.0	4.7	_	8.0	84.4
Heat gain by conduction during the day (KW)	G	2.9	3.0	4.8	4.3	3.8	_
	T	3.1	3.3	3.3	_	3.6	21.3

Table 3: Summary of modified materials findings

Wall code	Insulation type & thickness [mm]	U-Value W/m² °C	Yearly energy reduction (%)	Percentage of increase or decrease of comfort hours for the proposed walls (%)					
				Ground floor			Top floor		
				Summer	Winter	Annual	Summer	Winter	Annual
(ex) W1	None	3.11	0.00	0	0	0	0	0	0
W2	Air gap [15]	1.30	3.9	- 0.7%	0.3%	-1.7%	- 0.4%	11.2%	-1.9%
W3	Mineral wool [50]	0.64	11.8	4.2%	7.9%	1.3%	-1.9%	16.4%	-1.1%
W4	Fibre-glass quilt [50]	0.54	14.9	4.4%	8.8%	1.3%	2.3%	17.5%	-1.3%
W5	Expanded Polystyrene board [75]	0.46	16.9	4.8%	9.3%	1.6%	2.3%	17.7%	-1.1%
W6	Extruded Polystyrene [50]	0.40	18.7	4.5%	10.4%	1.4%	2.6%	18.8%	-1.2%
W7	Fibre-glass quilt [75] + Air gap [15]	0.37	17.7	4.0%	10.7%	1.5%	2.7%	19.2%	-1.1%
W8	Sheep's wool [50]	0.35	19.7	4.5%	11.3%	1.3%	2.7%	19.7%	-1.0%
W9	Extruded Polystyrene [50]	0.32	19.6	4.6%	11.5%	1.7%	2.6%	19.5%	-0.8%
W10	Polystyrene [75]	0.29	18.7	4.5%	13.4%	1.6%	2.9%	20.1%	-1.1%
W11	Polyurethane [75]	0.22	18.9	4.5%	12.5%	1.3%	3.4%	20.9%	-1.2%
W12	Polyurethane [100]	0.18	21.4	4.5%	13.0%	1.3%	3.6%	21.5%	-1.2%
Roof code	**Insulation type & thickness**	**U-Value W/m² °C**	**Yearly energy reduction %**	**Percentage of increase or decrease of comfort hours for the proposed roofs (%)**					
(ex) R1	None	5.03	0.00	-	-	-	0	0	0
R2	Asphalt [15]	2.04	3.4	-	-	-	2.2%	-0.6%	-2.5%
R3	Air gap [200]	0.95	44.0	-	-	-	5.6%	-0.7%	-1.7%
R4	Bitumen [20]	1.9	46.8	-	-	-	8.7%	0.6%	-0.04%
R5	Min wool quilt [50] + Bitumen [20]	0.58	56.9	-	-	-	10.1%	1.5%	0.6%
R6	Fibre-glass [50] + Bitumen [20]	0.46	59.9	-	-	-	10.7%	1.7%	0.9%
R7	Polystyrene [50] + Bitumen [20]	0.36	60.1	-	-	-	11.3%	2.0%	1.2%
R8	Min wool quilt [75] + Bitumen [50]	0.34	61.6	-	-	-	11.4%	2.1%	1.3%
R9	Fibre-glass [75] + Bitumen [75]	0.32	61.9	-	-	-	11.5%	2.2%	1.3%
R10	Sheep's wool [100] + Bitumen [20]	0.29	60.4	-	-	-	11.7%	2.2%	1.4%
R11	Polystyrene [75] + Bitumen [50]	0.26	60.5	-	-	-	12.6%	1.0%	1.2%
R12	Polystyrene [100] + Bitumen [50]	0.25	63.1	-	-	-	12.3%	2.5%	1.7%
Glaze code	**Insulation type & thickness**	**U-Value W/m² °C**	**Yearly energy reduction %**	**Percentage of increase or decrease of comfort hours for the proposed windows (%)**					
(ex) G1	None	5.78	0.00	0	0	0	0	0	0
G2	Inter blind	5.68	36.2	3.1%	0.5%	-1.4%	11.8%	-7.7%	1.6%
G3	Air [6]	3.14	34.5	1.4%	0.6%	0.7%	1.0%	-1.2%	0.1%
G4	Air [12]	3.07	32.3	2.7%	8.4%	0.8%	3.0%	-3.8%	0.3%
G5	Argon [13]	2.66	31.9	2.8%	8.1%	1.0%	2.9%	-3.6%	0.2%
G6	Inter blind + Air [20]	1.60	31.6	2.1%	1.6%	-1.0%	11.8%	-6.4%	2.2%