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The Efficient Strategy of Passive Cooling Design in Desert Housing: A Case Study in Ghadames, Libya

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Abstract

Ghadames is classified as one of the World's Heritage City. It combines two parts: conventional urban (vernacular) and modern urban. Unluckily, in the new development, a sustainable issue which was enhanced in the conventional part is not adopted at all in the new urban design, so that it is reflected on the residential building design where this is not integrated with the prevailing climate in the region.

In this context, the study aims to understand the passive design strategies of domestic vernacular buildings in hot dry climate and to apply design techniques which can utilize the favourable elements and at the same time can minimize the unfavourable elements of the local climate on a modern building. This study attempts to evaluate and propose the application of design solutions of passive cooling techniques for improving the indoor thermal environment conditions. However, this study is considering thermal performance of building envelope in naturally ventilated buildings and how to reduce energy loads in hot arid zone of Libya and Ghadames City, in particular in terms of using passive cooling techniques which have the most profound effect on a building's indoor environment.

In support of the aim of this thesis, field studies have been undertaken (both in Winter and Summer 2014) covering a questionnaire-based survey', indoor environment monitoring by HOBO data loggers and outdoor monitoring of local climate by a weather station. Accordingly, the analyses have been carried out to investigate the influence of the outer envelope design of a typical family house prototype with benefits of nocturnal ventilation where the adaptive thermal comfort has the potential of improving indoor comfort zones.

In that perspective, DesignBuilder simulation programme was considered with actual monitored weather data to investigate passive cooling strategies on different scenarios that can affect the composition of roof

and walls design in order to enhance adaptive thermal comfort during winter and summer (chosen months; January and June 2014) in the new urban area of Ghadames.

Ultimately, the recommendations proposed guidelines suggested controlling the indoor comfort temperature, reducing energy loads, deriving benefits from designed thermal insulation and thermal mass.

This thesis is dedicated to my beloved parents and my family for their endless prayers, love, support and encouragement.

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Chapter I

Introduction

1.1 Demand of Passive Cooling Design in Ghadames

Natural ventilation is a significant process to maintain indoor houses of Ghadames City when the outdoor temperature cannot maintain thermal comfort. The sun is a primary source beating down the building envelope which absorbs heat from sunlight through the roof, walls and windows, thus rising indoor temperatures to uncomfortable levels. However, providing air conditioning system can bring some comfort. Nevertheless, installing air conditioning unit and operating it will deliver additional costs of expensive bills. Furthermore, conventional air conditioners use refrigerants made of chlorine compounds that are suspected contributors to the depletion of the ozone layer and global warming (NREL, 1994).

The recent prevailing trend towards a passive architectural design has become a universal obligation where passive cooling maintains a comfortable indoor temperature as an alternative to using a mechanical system for reducing energy loads. However, in Libya architectural solutions that are considered are how to produce passive design for buildings that are not major contributors to environmental and societal needs.

In hot dry climate of Ghadames, a vernacular building design can be used as a starting point to realise how the environmental stresses and climatic hazards influence the architectural elements of the home and how the buildings can be more responsive. However, in Libya building regulations did not consider the climatic design issue as conditions should follow as well as there is a lack of knowledge between the authority, architects, contractors and residents to improve indoor thermal performance. Consequently, modern architecture of people in Ghadames has suffered from architectural solutions proposed by designers for whom the idea of protecting the environment is not a priority. Accordingly, the key objective of this study is to consider the influence of climate on the architectural elements and to identify passive strategies that can produce comfortable indoor spaces to enhance people’s living standards and future well-being.

In brief, the field studies identified these facts which have led to use building thermal simulation that focused on how the internal performance of buildings can be enhanced for comfortable living and for providing good satisfaction by passive cooling techniques.

1.2 Problem Statement

At first since the 1970's, the economic development in Libya has occurred alongside the modernization, growth of population and housing demand that resulted in large mass construction of residential buildings in the whole country, in particular Ghadames where modern houses are characterized by the influence of the modern international style of design. At the same time, a part of old Ghadames City was destroyed as a result of Italian invasion in 1911 and French Occupation in 1949, all together resulted in the Libyan government moving the whole population to the new part of town (Chojnacki, 2003) & (Libyan State report, 1985).

However, when looking closely into the character of most of the recent buildings there are clear contradictions with the vernacular architecture that demonstrates a major example in harmony with the climate. Conversely, the new transformation process has no attention to scientific reference of passive cooling techniques and thermal performance in past vernacular houses in the design of a logical and inevitable response to local environment conditions.

Additionally, building regulations in Libya do not specify any requirement of thermal performance or thermal comfort in houses, excluding requirements of openings for lighting and natural ventilation in each room, the lack of proper building regulation and practice causing energy loads required in harsh seasons.

Based on the author's review, scientific studies that attempt to improve thermal performance of the houses remain few and fragmented because thermal quality issues are not considered in the building design to achieve thermal comfort.

Overall, looking through this research, a clear understanding of the holistic thermal environment of the single family house in the simulation process is identified and provides the relationship that describes the contribution of different building scenarios to enhance both thermal performance and indoor comfort.

1.3 Choice of Ghadames as a Case Study

Ghadames adopted a holistic model of sustainable urban development and architectural style in vernacular city where the following importance signs present and describes the choice of the case study.

Firstly, in 1986 UNESCO considered old Ghadames City as an International Heritage City. It is distinguished as a traditional human settlement and reflects the integration with the climate and local setting, social value and historical authenticity. Moreover, it is an outstanding example of a complex city arrangement, which presents opportunities on how to deal with extreme temperatures and to maintain comfort conditions while striking a balance with the environment in a desert climate.

Secondly, Ghadames provides an opportunity to study the contrasting examples of adaptability of architecture to climate. It combines two types of architecture: the vernacular (old city) and modern (new city). Therefore this will give real lessons and significant ideas on how the applications of sustainable design maintain indoor comfort.

Moreover, the previous studies in Ghadames (Taki et al. 1999), (Ealiwa et al. 2001) and (Chojnacki, 2003) focused on the comparison between vernacular architecture and modern architecture. They demonstrated the value of climatic architecture as achieved in the past without any attention given on to how improve indoor thermal performance in new buildings design that are considered in this study; as well as “disregarding” the key environmental conditions thereby imposing the need for many residents looking for comfort to return to the old sector of the town during the summer months.

Lastly, the choice of Ghadames in this research is for the purpose of studying the improvement of indoor thermal behaviour based on thermal simulation and sensitivity analysis with peak indoor temperatures as the criteria. The findings in this study are meaningful for building ventilation strategy integrated to building envelope design and optimization.

1.4 Aim and Objectives of the Thesis

The aim of this thesis is to evaluate and propose application of passive cooling techniques to existing houses in urban area of Ghadames. Furthermore, to develop an optimum model that can aid thermal design decisions in hot dry climates and to open pathways toward solving an old but overlooked problem in the direction of improving buildings thermal behaviour passively in Ghadames.

In this order, improving the indoor thermal comfort in naturally ventilated conditions such as reducing energy loads will be achieved through the following objectives, which will also give a holistic evaluation of a Base Case house:

- To study and explain the problems are important aspects of passive design strategies and thermal performance in the residential buildings.
- To evaluate internal climate and to find solutions that can provide qualitative, physical and psychological benefits to housing users (adaptive comfortable houses in a hot dry climate).
- To examine real weather data format for the simulation process in terms of investigating the effect of outdoor climate on building design and indoor comfort.
- To develop computer simulation models for the analysis of thermal performance of naturally ventilated buildings and to investigate the interactions between passive design and performance parameters.

- To expand knowledge and studies in this area by using building simulation for improving indoor thermal performance.

In conclusion, as the possible approaches and conditions are endless, it is hoped that the present thesis can serve as a positive portion for resolving the puzzle of indoor thermal performance in the residential buildings, hence these findings for Libya can form a basis for developing guidelines and new techniques in designing and operating unconditioned buildings in hot dry climates that can also enhance indoor comfort conditions.

1.5 Research Methodology

In the context of the research to achieve a better understanding, the research methodology for this study is divided into four main stages as shown in Figure 1.1.

The first stage provides the research area and research strategy and highlights the significant issues that are required to be taken into consideration through the case study. A literature review is presented to provide a background for the research targets and to help developing the research questions, as well as to express what knowledge is currently established in research area of Ghadames City.

In the second stage, a field study of an existing house in Ghadames is used to illustrate and provide valuable analysis and opportunity to learn about the problems of the housing in hot dry climates. This includes questionnaires, indoor climate monitoring of existing house by HOBO data loggers and outdoor monitoring of local climate by a weather station.

In the third stage, after performing modelling and simulation analysis, the findings of the case study and scenarios are then considered so as to provide a proper data model which will lead to new design parameters to reflect on other design options.

In the fourth stage, final remarks on building parameters (i.e. thermal performance and building envelope design) and an overview of the entire analysis, results (in terms of integration within the thesis structure) and aims are discussed and recommendations are presented.

1.6 Organization of the Thesis

In order to achieve the aim and objectives of this research study, the thesis is structured into nine chapters that covered four parts. Part I consists of a literature review and a background of desert architecture in general and Ghadames in particular; and part II & part III contain the methodology which encompasses a fieldwork and a computer energy simulation analysis; the last part comprises the findings, the discussions, the conclusions and the recommendations. The chapters are organised and outlined as follows:

Chapter 1. Introduction: this chapter presents the background, problem statement, aim and objectives and explains the research methodology adopted in the thesis.

Chapter 2. Theoretical Framework: this chapter gives an overview of the literature review that was developed to consider the most significant aspects related to passive cooling applications and natural ventilation. It looks into the issues relating to thermal comfort and bioclimatic design of the buildings in hot dry climates.

Chapter 3. Thermal Performance of Residential Building (Case Study): this chapter reviews the thermal performance of buildings and thermal human comfort in the hot dry climate of Ghadames that have been studied to provide useful insights for the problems in the field.

Chapter 4. Desert Architecture: this chapter provides comprehensive information about the nature of the climate, the context of vernacular architecture and the urban texture beside the architectural characters in the hot climate. Moreover, it contributes to lessons learnt from desert architecture through case studies.

Chapter 5. It explains two methods that are adopted in this research, the first method being based on-site measurements. This included monitoring data of weather observation that was collected for indoor house and outdoor local climate. It clarifies climatic conditions of Ghadames and uses this data in energy simulation analysis to improve indoor design quality. In addition, the chapter discusses climate measurement methods and concludes with climate conditions of Ghadames and outdoor weather condition in the simulation base model. The second method uses a questionnaire-based survey to investigate people's satisfaction with their environment in contemporary homes in terms of thermal comfort condition. The target survey area, the structure and the coding of the questionnaire were discussed along with the methods of analysis.

Chapter 6. Building Simulation, Calibration and Validation: in this chapter, a holistic knowledge about the building simulation is provided. The importance of building design and simulation environment as well as the evaluation of the capability of building simulation are considered. Furthermore, the chapter explains the modelling process and the simulation in DesignBuilder as well as the use of a weather data file, alongside the modelling of the case study building. Finally, this chapter contains previous validations of DesignBuilder and its reliability, and also the validation of DesignBuilder simulation to the current case study.

Chapter 7. Simulation Analysis: in this chapter, a natural ventilation plan is presented and considered for the simulation and thermal performance analyses, such as the thermal mass and the roof design. All the results might lead to the choice for the best design option from different design options in the general discussion and conclusion.

Chapter 8. Conclusions and Recommendations: this chapter is concerned with summarising the main conclusions of this thesis and also presenting the general recommendations and indications for further research directions.

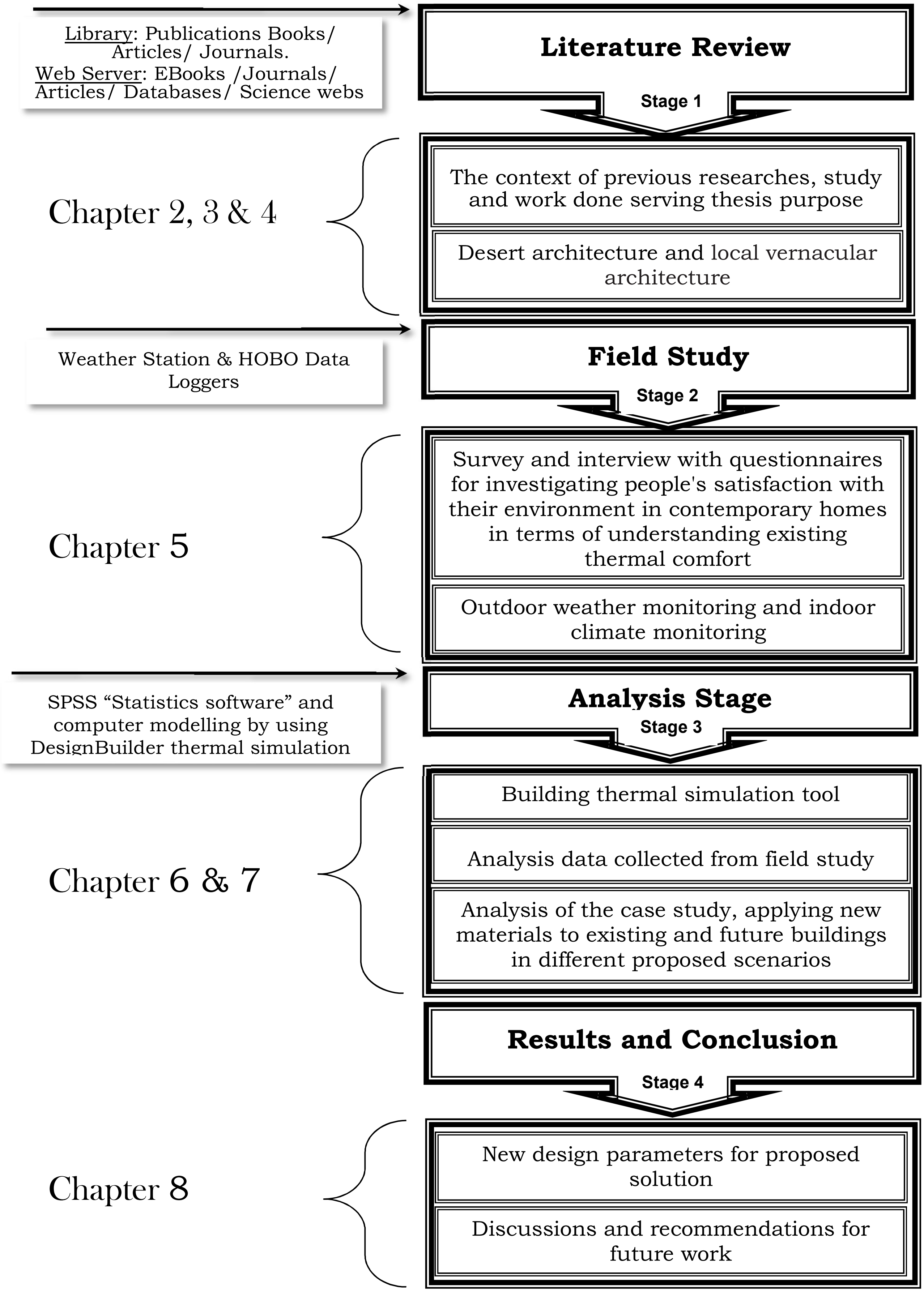


Figure 1.1: The plan shows the research methodology of this study

Chapter II

Theoretical Framework

2.1 Introduction

The literature review assists in establishing an initial strategy framework for the analysis of the case study and an understanding the knowledge of the research field undertaken. The first part of a literature review considered the relevant studies of passive cooling in naturally ventilated buildings. This provides some studies of vernacular buildings and the fundamental principles of passive cooling. Moreover, it covers recent studies that enhanced natural ventilation cooling techniques, which are: the adaptive thermal comfort, the thermal performances and the effects of cooling techniques that were achieved by applying these methods. Furthermore, the literature review considers the status of passive cooling developments in hot-dry climate.

The second part of the literature review focuses on the aspects related to the architecture design in hot dry climate like the architectural responses to a hot climate and the desert architecture. The study presents different aspects of local architecture expression that are integrated with the hot dry climate and design characteristics on comfort living as well as the potential for considering these aspects in recent building designs.

2.2 Passive Cooling in Vernacular Buildings

Passive cooling in vernacular buildings is part of the traditional technologies within local environmental contexts to enhance indoor climate comfort. Although some of them are currently no longer properly functioning because of changed cultural and ecological situations, especially those of the hot-arid climates of Iran, they are also undervalued and unused in new constructions (Foruzanmehr and Nicol, 2008) and also in Ghadames, Libya where the experience of vernacular buildings are not considered in order to help upgrade the development process in new housing areas (Almansuri et al. 2008). However, the passive cooling technique can achieve its optimum performance and potential benefit

with careful and meticulous design (Adenan, 2013). In this regard, the key challenge is to learn fundamental lessons and principles of vernacular architecture and to find ways of integrating those principles into development programmes to plan new settlements or to upgrade existing ones (Foruzanmehr and Nicol, 2008).
Recently, research adopted scientific methods to analyse the effectiveness of traditional techniques. In this regard, qualitative studies were devoted to assess the aspects of passive cooling strategies, while the quantitative approach involved in-depth studies to evaluate the real performance of thermal environment under climate factors through field measurement.

Taylor et al. (2009) applied qualitative studies to vernacular architecture in hot-dry climate of Oman. The study outcome illustrated that vernacular architecture of the region both culturally and climatically provide appropriate solutions for creating comfortable environments utilising only natural and renewable forms of energy.

Regarding the benefit of using the application of qualitative and quantitative studies, Foruzanmehr and Nicol, (2008) study naturally ventilated building in the city of Yazd, Iran where the climate is hot and dry. The studies pointed out the acceptability and applicability of traditional Iranian architectural technologies in a modern context as well as their effectiveness in reducing energy consumption and CO_2 emission. However in quantitative study, Meir and Roaf (2006) investigated different building technologies and materials, morphologies under different arid conditions typical of the Middle Eastern and Mediterranean climatic regions to provide resilient buildings for the 21st Century. The investigations carried out a number of methods and techniques, including monitoring, modelling, numerical analysis, simulation and infra-red thermography. Interestingly, vernacular prototypes were built with high thermal mass, with very limited fenestration area, usually unglazed. These properties make them very inert in relation to ambient daily fluctuations. Therefore, the results presented that an extreme inertia is counter-productive due to the inability of such structures to take advantage of solar gains in winter and of night cooling by cross ventilation in summer, primarily, but only, due to their limited fenestration size. However, the construction technology adapted to the environmental constraints proved to be uncomfortably hot in summer and uncomfortably cold in winter, for most of the hours of the day. On the other hand, the thermal performance of such buildings proved to be better in highland and mountain regions rather than the lowlands and more humid coastal plains.

In conclusion, it is comprehensible that the benefit from quantitative methods can be applied through the analysis to derive passive cooling principles without copying on existing solutions. Further details about the studies of Ghadamesian traditional houses are given in Chapter 4.

2.3 Passive Cooling Technique

This review focuses on passive cooling by ventilation. The reasons for this are: firstly, night-time ventilation is well-accepted as a passive cooling technique, by tradition, in hot-dry climate. Secondly, the strategies of opening windows, when using cross ventilation or single sided ventilation, can release heat gain inside buildings (DeKay and Brown, 2014). It means that nocturnal ventilation techniques could be applied to the building modification. In a broader context, they are comprehensive books focused on Mediterranean climate and hot dry arid of desert climate. These references on passive cooling by the authors Givoni (1994) & (1998), Santamouris and Asimakopoulos (2001), give an overview of the passive cooling of buildings, broadly categorized under three sections. Firstly, reduce heat gains by using protection techniques from solar heat such as enhancing the micro-climate around the buildings by using vegetation and water surfaces to increase the relative humidity and lowering the air and surface temperatures. Moreover, aperture sizes, glazing type and using solar control, overhangs for shading and envelope insulation, all contribute to thermal resistance for the heat flow through the building envelope. Secondly, modify heat gains by enhancing the thermal storage through using thermal mass and phase change construction materials. Thirdly, remove internal heat by using a natural cooling technique to exclude heat gain load from interior spaces.

On the whole, the natural ventilation for summer supply of fresh air helps to reduce overheating, while in winter, ventilation is normally reduced to levels sufficient to remove excess moisture and pollutants (Walker, 2010). However, the thermal behaviour of a building is strongly (thermal insulation, low proportion of glazing, outdoor solar shading, the use of thermal mass) coupled to ventilation and air infiltration. At the same time, airflow depends on the different thermal levels of the building zones (Allard, 1998). Night ventilation techniques, known as nocturnal ventilative cooling, can improve internal microclimate from heat and solar protection, and heat modulation and dissipation methods and systems. This can greatly contribute to buildings' cooling load reduction and can increase thermal comfort during the summer (Santamouris, 2005).

2.4 Nocturnal Ventilation

Night ventilation or nocturnal ventilative cooling is one of the low-cost passive cooling techniques that may contribute to reducing the cooling load of buildings and to improving thermal comfort of occupants. Santamouris et al. (2010) expressed that night ventilation is one of the more efficient passive cooling techniques. It is based on the circulation of the cool ambient air to decrease both the temperature of the building's structure and of the indoor air. Therefore, the efficiency of the technique is mainly based on the relative difference between the outdoor and indoor temperatures during the night period. However, this technique is more effective where a building includes a reasonably high thermal mass to absorb the heat during the day, when temperatures are warmer and solar radiation and internal loads act to increase interior temperatures, the building mass absorbing and storing heat. At night, when outdoor air temperatures are cooler, outdoor air is circulated through the building (Grondzik, 2006). Credit

Cavelius et al. (2009) stated that there is a significant amount of exposed thermal mass of heavy weight construction, the free cooling at night can be stored in the building fabric and used to offset heat gains the next day as it has the advantage of depressing daytime space temperatures by up to 3°C. However, the configuration of night ventilation varies as a function of time and depends on the wind characteristics and the thermal state of the building. At the same time, it also depends on the occupant's behaviour, such as opening or closing windows and doors that eases the acceptable temperature through psychological adaptation (Allard, 1998). However, Blok et al. (2007) assured that air motion requires a driving force and an adequate number of openings to produce airflow. This can be induced through pressure differences arising from inside and outside temperature differences or from wind.

Clearly, the benefit of making night ventilation can be an effective means of removing accumulated heat and protecting internal conditions during the day in four ways (Kolokotroni et al. 1999):
Firstly, employing night ventilation can be achieved with a variety of cross ventilation schemes that rely on wind induced flow or stack effect to reduce peak internal temperatures. Secondly, reducing air temperatures through thermally massive components of the building structure can be flushed with cool night-time air. Thirdly, by reducing slab temperatures to allow them to act as a heat sink during the following day. Fourthly, creating a time lag between the occurrence of external and internal maximum temperatures allows a reduction in extreme swings of alternating hot and cold temperatures.

However, in such a weather of Ghadames where high temperature of outdoor environment in summer is prevalent, night cooling refers to the operation of natural ventilation at night in order to purge excess heat and cool down the building structure. This cycle allows the mass to discharge and renew its potential to absorb more heat, and this has been the most effective solution achieved in vernacular architecture.

Conclusively, in hot dry climate, the superlative solution of cooling the building's interior can enhance indirectly by using natural ventilation that effectively contributes to providing comfortable thermal conditions for the occupants during night-time. However, ASHRAE 55-2010 portrayed that adaptive comfort can be applied in a range of monthly outdoor mean temperature between 10°C and 33.5°C.

2.5 Thermal Comfort

By looking at comfort, "The American Society of Heating Refrigeration and Air-conditioning Engineers" (ANSI/ASHRAE standard 55-2010) defined it as a "condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation." Thus, the achievement of certain standards of comfort is often considered a vital ingredient for the maintenance of human health (defined as a total sense of physical, mental and social well-being) (Chappells and Shove, 2004). However, Gut and Ackerknecht (1993) have different views. They believe that "the optimum thermal condition can be defined as the situation in which the least extra effort is required to maintain the human body's thermal balance".

However, focusing on hot dry climate of Ghadames, the observations made by Taki et al. (1999) and Ealiwa et al. (2001), indicate that the issue of comfort criteria in new building designs becomes less debatable since the inhabitants employed air-conditioning systems, whereas the building envelope design has not improved with an absolutely low heating and cooling demand. Therefore, the adaptive comfort model could be enhanced by using passive cooling strategies and increasing passive ventilation air flow rates during periods when the outdoor air temperature is low enough to flush heat from the building (Mikler et al. 2009), which is required for more flexible ways in assessing free running buildings by using the building simulation analysis to achieve optimum designs that can be more desirable to the occupants who would prefer living in naturally ventilated buildings.

In the context of this research, it is appropriate to provide an overview of the above factors that affect thermal comfort in order to assist with interpreting the stage of simulation processes.

2.6 Adaptive Thermal Comfort

Nicol et al. (2002) expressed that *"Adaptive thermal comfort is therefore a function of the possibilities for change as well as the actual temperatures achieved."* Therefore, it is applicable only for spaces where the thermal conditions are regulated primarily by the occupants through opening and closing of windows in case of neither mechanical cooling nor mechanical ventilation are allowed, demonstrating dynamic relation between people and their daily environment with their clothing and activities where metabolic rates range from 1.0 to 1.3 met (58.15 to 75.6 W/ m^2) (Olesen and Brager, 2004).

In this regard, the application of a study on adaptive thermal comfort in hot dry climate, Ghadames, Libya (summer seasons of August 1997 and July 1998) by Taki et al. (1999) pointed out that the neutral temperatures of the residence, when they felt neutral on their thermal sensation vote were 31.6°C for old buildings and 29.4°C for new air-conditioned buildings. However, the distinction between thermal sensation vote in both cases and the comparison of the behaviour of the residents indicated that the adaptive model is shown to be valid, without modification, in predicting the thermal comfort of sedentary occupants in Ghadames' environment. However, according to the questionnaires and the actual mean votes (AMV) of the subjects considered in the study, they believe that building designs, together with adaptation effects, have significant implications for energy consumption, as the desired inside neutral temperature range will be between 28°C and 32°C in relationships between the AMV and globe temperature in all buildings tested in Ghadames.

An intrinsic study undertaken by Ealiwa et al. (2001), differentiated between PMV (predicted mean vote) and PPD (predicted percentage of dissatisfied) to measure adaptive thermal comfort within two types of buildings: old (traditional) and new (contemporary), in Ghadames' oasis, in Libya. The survey was undertaken in the summer seasons of 1997 and 1998, which were typical of the hot dry climate. However, the PMV model in the form of ISO 7730 as a tool of analysis cannot be used in old naturally ventilated buildings without modifications, in order to predict the overall thermal comfort of the occupants. Conversely, in new buildings, a good agreement between the PMV values and the AMV of the occupants in new air-conditioned buildings is possible. It shows that 67% of subjects in four new buildings were feeling neutral, while 33% were feeling slightly warm. The occupants in the new constructed buildings relied more on air-conditioning being turned on so as to achieve the indoor air temperature between 25-31°C.

2.6.1 Adaptive Comfort Standard in ASHRAE Standard 55 – 2010.

Adaptive thermal comfort paves the way for significant energy savings allowing a wider range of temperatures in naturally ventilated buildings. The adaptive comfort standard in ASHRAE (2010) applied a simple thermal index of operative temperature to characterize the indoor comfort temperature. This standard specifies the combinations of indoor space environment and personal factors that produce thermal environmental conditions, which is acceptable to 80% or more of the occupants within a space. The 80% acceptability limits are for typical applications and the 90% acceptability limits may be used when a higher standard of adaptive thermal comfort is desired (see Figure 2.1). The adaptive thermal comfort equation is calculated from the mean outdoor temperature and plotted on mean of the daily outdoor maximum and minimum temperatures to predict neutral indoor comfort temperature. Optimum indoor comfort in a naturally ventilated building equates to:

$0.31^{*}T_{mot} + 17.8^{o}C$ (T_{com} = 0.31 × Mean outdoor temperature + 17.8), whereas, the upper limit and lower limit can be calculated as illustrated in Table 2.1 (McGilligan et al, 2011). In order to determine the width of comfort zone, Figure 2.1 is showing the range of width comfort zone that is arising at the 80% of thermal acceptability band with the optimum ± 3.5°C, whereas the 90% acceptability band is ± 2.5°C of all the naturally-ventilated building (de Dear and Brager, 2001). The relationship between the desired indoor temperature and the range of outdoor temperatures shows whether, for instance, night cooling is likely to be a viable way to keep the building comfortable in summer, or to calculate whether passive solar heating will be enough in winter (Nicol and Humphreys, 2002).

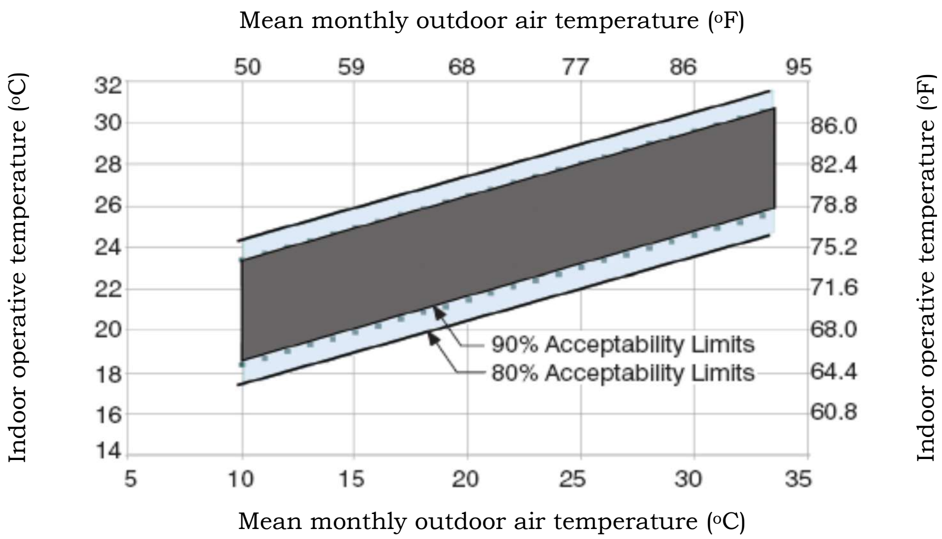


Figure 2.1: The adaptive comfort model used in ASHRAE standard 55 – 2010.

Table 2.1: Operative temperature limits of comfort zone adaptive standard (°C) in ASHRAE 55 (McGilligan et al, 2011).

Upper limit	$0.31 \times T_{mot} + 17.8 + x$
Lower limit	$0.31 \times T_{mot} + 17.8 - x$
	T_{mot} = *mean monthly outdoor air temperature, where* x = *2.5* °C *or 3.5* °C

Overall, the allowable operative temperature limits in Figure 2.1 may not be extrapolated to outdoor temperatures above and below the end points of the curves in this figure. If the mean monthly outdoor temperature is less than 10°C or greater than 33.5°C, this option may not be used, and no specific guidance for naturally conditioned spaces is included in this standard. The resulting Figure 2.1 indicates that adaptive thermal comfort that would be deemed acceptable to 80% of occupants extending from a minimum of about 18.5°C in winter to a maximum of about 28°C in summer. However, in a hot arid climate, where the average daily temperature is generally higher than indoor comfort conditions, a second approach tends to make use of thermal mass to reduce the extremes of day temperature and to enhance passive design concept (Farghaly, 2003). Moreover, an appropriate use of both insulating and conductive materials suitable for different elements of the building envelope can prevent heat gains as well as the potential of cooling the structure of the building; and their occupants can improve adaptive thermal comfort and indoor air quality by the form of convective cooling.

2.7 Adaptive Thermal Comfort Temperature in Ghadames

This study focused on naturally ventilated buildings that are the base of the Adaptive Comfort Model, implemented in ASHRAE Standard 55-2010. The methods for determining acceptable thermal conditions in naturally ventilated spaces need weather data of mean monthly outdoor air temperature. Thus the mean outdoor air temperature for each day of the field studies over the two seasons with starting dates were arranged in winter from 19th to 23th of January 2014 and in summer 21th to 26th of June 2014. This field study did not cover the whole months of winter and summer. Therefore, it was necessary to get recorded weather data from previous data that was recorded by Meteonorm (ten years of historical data 2000-2009) as shows in Table 2.2.

Table 2.2: Daily average of dry bulb temperatures °C from Meteonorm

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan
11.9	14.3	18.0	21.8	27.5	32.6	31.9	31.9	28.0	22.9	17.1	11.5	11.9

According to ASHRAE Standard 55-2010, the 80% bounds of acceptable operative temperature ranges for naturally ventilated spaces can be applied as a normative in this case study to determine comfort zone for Ghadames's homes, the 80 % acceptability limits are for typical applications and accepts ±3.5 °C around the comfort temperature. The equation of the adaptive comfort model implemented in ASHRAE 55-2010, the equation was:

$T_{in} = 17.8 + 0.31*T_{out}$

Where T_{in} is the indoor air temperature and T_{out} is the mean monthly outdoor air temperature.

1. In winter, Jan 2014

Upper limit $0.31 \times 11.9 + 17.8 + 3.5 = 24.4^{o}C$

Lower limit $0.31 \times 11.9 + 17.8 – 3.5 = 17^{o}C$

The comfort zone in winter ranged between 17°C ~ 24.4°C

2. In summer, June 2014

Upper limit $0.31 \times 32.6 + 17.8 + 3.5 = 31.4^{o}C$

Lower limit $0.31 \times 32.6 + 17.8 – 3.5 = 24.4^{o}C$

The comfort zone in summer ranged between 24.4°C ~ 31.4°C

2.8 Thermal Sensation Scale

Essentially, people want to live in thermal environments in which they feel comfortable. If the temperature drops due to changes of the weather or seasons, people want to stay in warmer environments, and if it rises, they want to stay in cooler environments (Ho Kim et al, 2013). Therefore, thermal sensation of humans is often calculated by human energy balance models, which are defined for steady state conditions, where the human thermo regulation system has been exposed to the same climatic conditions for a considerable period of time (Becker et al, 2003).

Accordingly, ASHRAE (2010) adapted thermal sensation scale, which was developed for use in quantifying people's thermal sensation, is defined as follows:

+3 hot

+2 warm

+1 slightly warm

0 neutral

-1 slightly cool

-2 cool

-3 cold

In addition, there are six primary factors are listed below:

1. Metabolic rate
2. Clothing insulation
3. Air temperature
4. Radiant temperature
5. Air speed
6. Humidity

These factors must be addressed when defining conditions for thermal comfort, and using the predicted mean vote (PMV) as the indices of thermal comfort sensation. However, to measure subjective responses of occupants in comfort, a questionnaire-based survey is used as one method of data collection. It evaluates the occupants' perception of thermal comfort in the houses and explores the occupants' preferences, in order to understand the thermal comfort rating scales, and also to highlight problematic questions between the questionnaire answers.

2.9 Bioclimatic Design and Thermal Comfort

"Bioclimatic" design is used to define potential building design strategies that utilize natural energy resources and minimize conventional energy use so as to achieve control of the microclimate of the indoor spaces (Visitsak et al. 2004). Lima, (1995) expressed the concept of bioclimatic design as *"... a disciplined approach to architecture that fosters the act of envisaging, defining, construction and appraising whole functioning buildings containing and including all environmental control systems in various combinations"*. However, this is an approach of the design to create a 'filter' between the people and the climate to achieve a better architecture for human beings which at the same time implies designing for the long-term and giving attention to sustainable use of natural resources (Jones, 1998).

In this case, understanding the bioclimatic design is related to the local climatic features and to the application of passive strategies. In a proposal about a comfort zone, Olgyay (1973) presented natural ventilation buildings in a systematic chart as in Figure (2.2). The method draws the conception of a structure that avoids extreme thermal fluctuations and keeps a balance close to comfort zone by using the coordinates of dry bulb temperature on the vertical axis and the relative humidity on the horizontal axis to define the comfort zone.

However, applying existing indoor temperature of the monitoring new house in Ghadames on Olgyay's chart shows that the range of temperature in summer between 21th June 2014 till 26th June 2014 are higher than the comfort zone. As well as, in winter from 19th ~ 23th of January 2014, the plotted indoor temperature are below the comfort zone as shown in chart in Figure (2.2).

In favour of bioclimatic chart, Givoni and Milne in Lechner (2001), illustrated a bioclimatic chart (see Figure 2.3), which is obtainable as appropriate passive strategies in specific boundaries of the passive cooling techniques, and also plotted on the chart presenting the relationship between the temperature amplitude and vapours pressure of the outdoor air in various regions. That indicates the ambient outdoor temperature and humidity conditions when falling within the designated limits of a control strategy, then the interior of a building designed to efficiently perform and remain comfortable. However, *"passive cooling techniques"* do not exclude the use of mechanical cooling when required, which means that it can be used to enhance the comfort. Consequently, the approach of bioclimatic design makes a distinction with sustainable design concepts.

However, according to Shawesh's (1993) study, the bio-climatic patterns of the houses presented in old and the new Ghadames town were dissimilar during the month of August 1991. In the old town, the bio-climatic pattern of houses reveals that the indoor climatic conditions of the vernacular houses are comfortable, because the air temperature and relative humidity are largely inside the comfort zone, the indoor air temperatures between 23°C ~ 28°C and relative humidity levels between 21% ~ 29%, while outside temperature varies between 24°C ~ 30°C and relative humidity levels between 22% ~ 27% in the morning and the temperature is between 33°C ~ 38°C and relative humidity levels between 12% ~ 18% in the afternoon. While during the evening period, the air temperature decreases in the old town to between 28°C ~ 33°C and relative humidity levels stay between 17% ~ 22%. On the other side, the bio-climatic pattern of the new houses is in comfortable range from morning to afternoon, when the indoor air temperatures is between 23°C ~ 29°C and relative humidity levels between 20% ~ 27%. While outside temperature varies between 25°C ~ 31°C and relative humidity levels between 21% ~ 27% in the morning and temperature is between 39°C ~ 47°C and relative humidity levels between 8% ~ 11% in the afternoon.

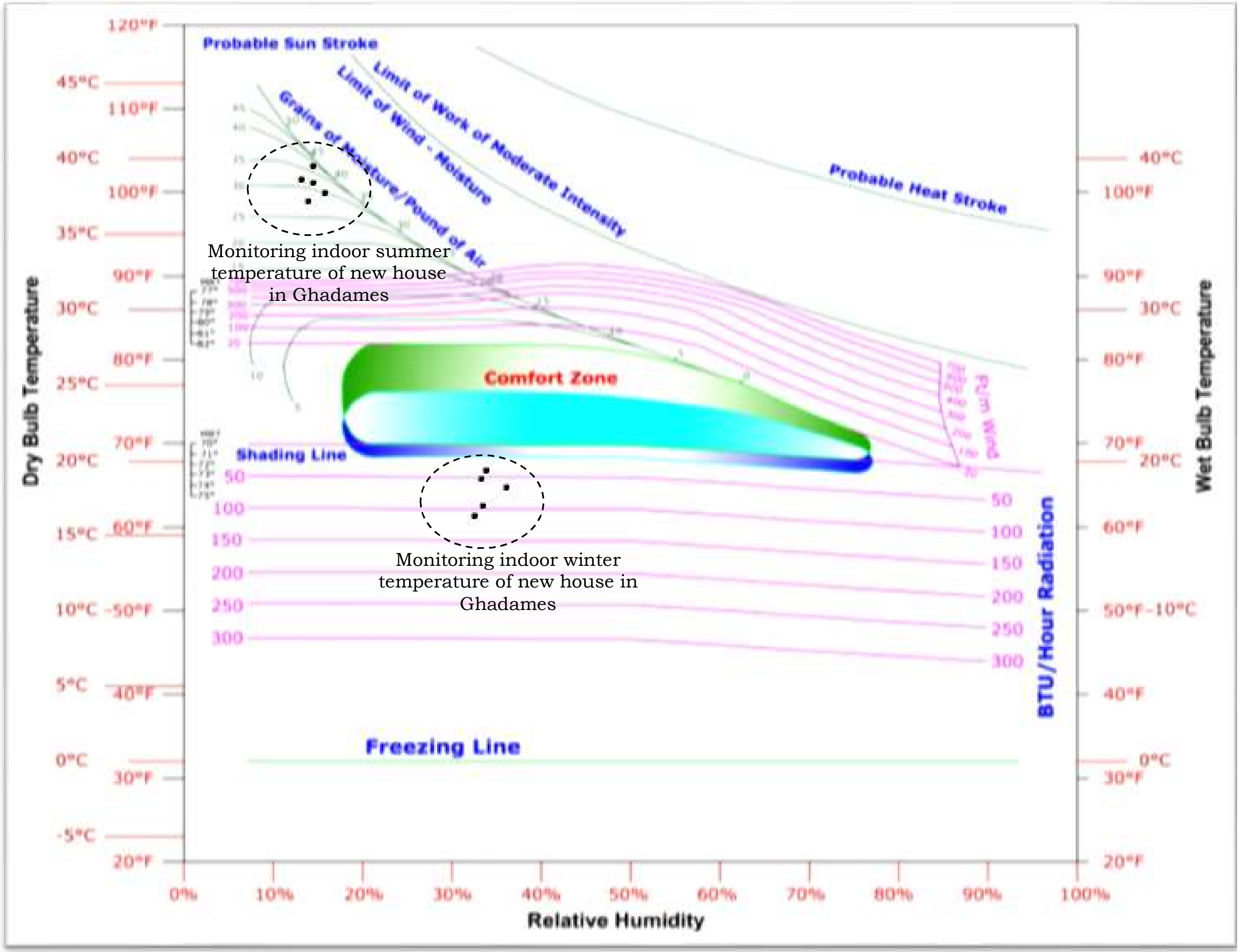


Figure 2.2: The range of indoor temperature of Ghadames' house in Bio-climatic chart (Olgyay, 1973), (winter from 19th till 23th of January 2014 and summer between 21th till 26th of June 2014). After (Nasrollahi, 2009)

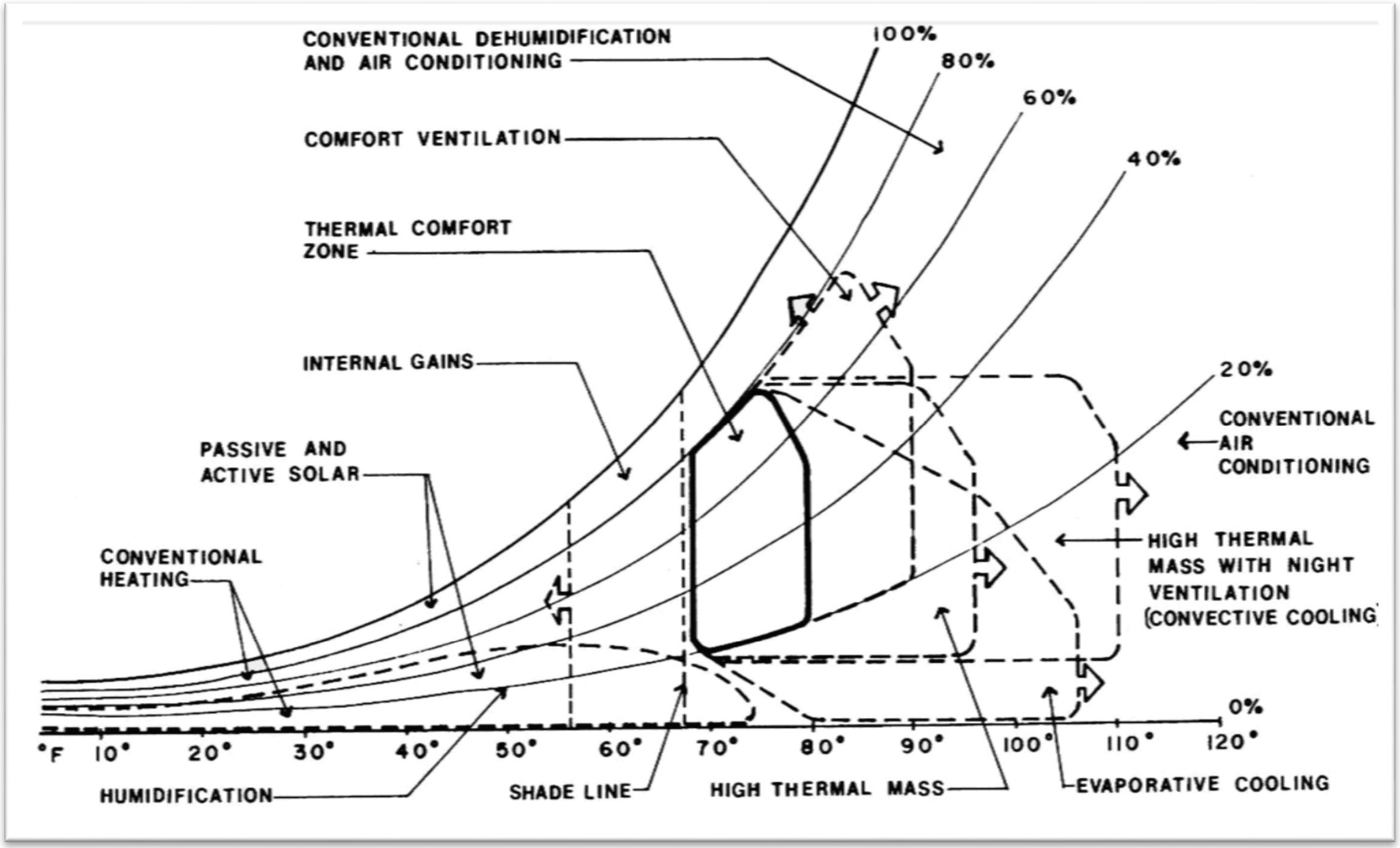


Figure 2.3: Bio-climatic chart, by Givoni and Murray Milne (Lechner, 2001).

However during the evening the bio-climatic pattern is mostly out of comfort zone whereas indoor temperature is rising over 30°C and humidity levels are between 20% ~ 26% in range and the outdoor temperature is between 41°C ~ 43°C and relative humidity is between 12% ~16%.

2.10 Conclusion

So far no studies have been attempted on the subject of reliable housing design with climatic requirements. Hence, efforts are yet to be made to upgrade development process taking place in housing areas, particularly in new settlements where conventional planning of old Ghadames City are not applied. However, from the review in this chapter, the arguments put forward by Shawesh (1993), Taki et al. (1999) and Ealiwa et al. (2001), show that building envelope design can minimise the discomfort for the residences. Where appropriate, designs should avoid simply excluding the environment, but should respond to factors like weather and occupancy, and make good use of natural light, ventilation, solar gains and shading, whenever they are beneficial.

Essentially, there are two different approaches to envelope design in relation to building energy performance. The first approach is to isolate the interior of the building from the external environment and the insulation is used extensively in all the envelope elements to reduce heat gain. The second approach is building energy design that referred to "passive" design. This approach supports the beneficial interactions between the building and the outside environment that reduce undesirable heat or cool gain without using mechanical system (Groth, 2007).

However, the building's site is the first line which has an obvious influence on natural ventilation to the building envelope that operates as a barrier between the external and internal environment. Therefore, the differences in the temperature and pressure of the internal and external air, due to the height of the stack and also the sufficient intensity of natural ventilation, are influenced directly by temperature, humidity and airflow (Dénes, 2003). The following chapter searches on the previous studies in Ghadames to illustrate the issues that can affect the thermal performance of modern houses towards extracting the points that can improve the thermal behaviour of the building envelope by using thermal simulation analysis and enhancing passive cooling design.

Chapter III

Previous Studies in Ghadames

3.1 Introduction

Objectively, in Ghadames, the current study highlights the main problems within the relation between modern buildings and their dwellers in terms of comfortable indoor climate against outdoor climates. This chapter presents the problem of discomfort in buildings which appears as a result of the architectural design that neglected the climatic factors. Therefore, it clarifies a number of previous studies showing that the thermal performance and thermal comfort in hot dry climate of Ghadames have been studied in different ways and have provided useful insights of the problems in the field. However, some of these studies investigated thermal performance, which were based only on field measurements during the summer time carried out by Ahmad et al. (1985), Shawesh (1993) and Chojnacki (2003). Some studies examined indoor thermal comfort based on field measurements and questionnaires, which were completed by Ealiwa et al. (2001). Another study by Taki et al. (1999) focused on the application of the adaptive comfort model based on field measurements and questionnaires.

3.2 Thermal Behaviours of Modern Residential Buildings

For an in-depth study of thermal performance in summer time, which is the most problematic season, the investigation was carried out by Ahmad et al. (1985), using thermo-hygrographs to record both the temperature and the relative humidity of the indoor atmosphere over time. The experimental observations showed that the summer ambient air temperature (Figure 3.1) varies from 20°C to 40°C with an average of about 31°C. On the other hand, the average indoor temperature in the new house is 35°C and ranges between 34°C and 39°C in July and August. However, the results highlighted the importance of U-value for building materials where high thermal resistance through walls and roof can reduce the swing of indoor temperature in terms of natural ventilation and bring more acceptability to enhance comfort zone.

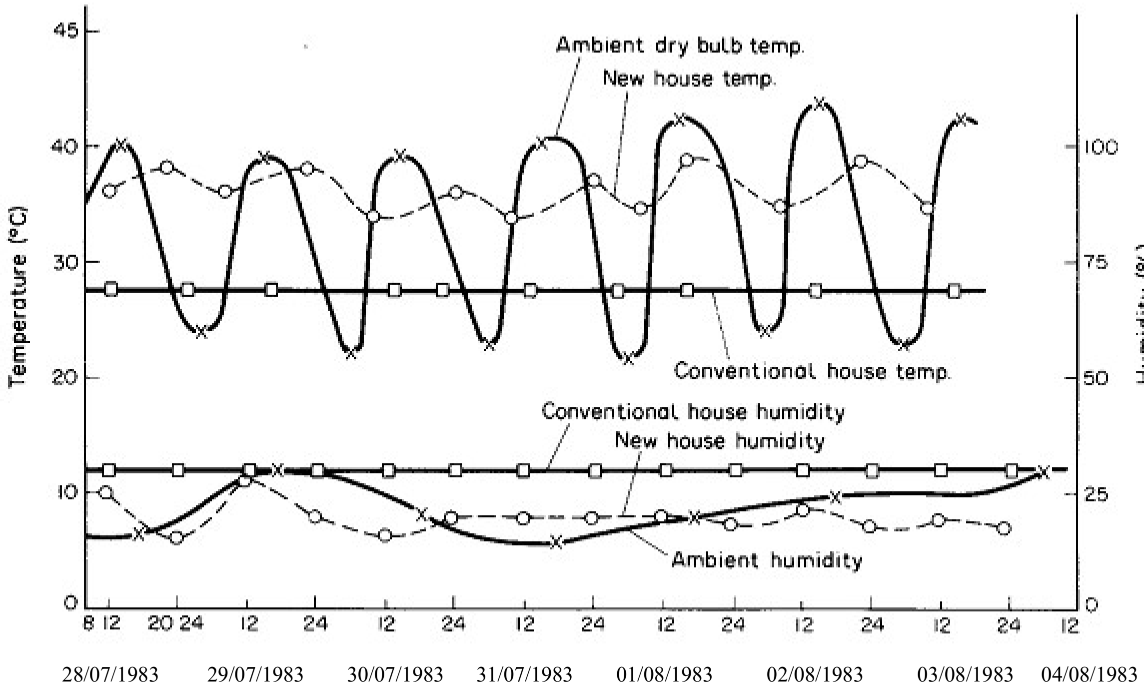


Figure 3.1: Temperature and relative humidity for old and new buildings in Ghadames: Source Ahmed et al. (1985).

In the examination of indoor thermal performance, an intrinsic study by Shawesh (1993) concluded that the modern houses are designed with no attention to the bio-climatic design where the new settlement is characterised by detached houses and wide open uncovered streets. Moreover, the modern houses have large unprotected glass windows on all four sides of the buildings. In addition, the use of modern materials with thin light weight walls and roofs which have quick time-lag for heat transfer contributes to the poor climatic adaptation of new housing. However, the results indicated that the indoor temperature in the new residential building recorded between 33˚C and 39˚C in August at afternoon periods, while between 26˚C and 34˚C during the evening time. As a result, the building envelope is not considered as a first defence line from harsh climate to promote a successful building design. Interestingly, the study conducted that 95 percent of the population in the new town were dissatisfied with their climatic condition. On the other hand, about 91 percent of the new town population prefer to live in the old town of Ghadames where the old town of Ghadames has responded to the local climatic conditions far better than the new town.

In the process of evaluating thermal performance of housing in Ghadames, Chojnacki (2003) portrayed that the new residential buildings in Ghadames do not provide adequate natural comfort in summer where the ranges of indoor temperature in the new house is between 34°C and 39°C in July and August, the reason lies in significant differences such as their location, relative positions, the way in which windows are designed and installed, and the building materials which, in the case of new houses, have less favourable heat transfer coefficient in general. However, the overall thermal performance of a building envelope in hot dry context is the result of a complex interaction between several factors, including the climate, the occupants and thermal characteristics of the building.

In assessing the indoor thermal comfort of hot dry climate of Ghadames, Ealiwa et al. (2001) have carried out full scale measurements by using radiation-shielded thermocouples (Type T, copper/constantan) for recording air temperatures in summer 1997, 1998 and also questionnaires were collected from the residents of 51 buildings: 24 old buildings that employ natural ventilation systems and 27 new buildings that employ air-conditioning systems where the indoor temperature was 33˚C. The questionnaire was based on six sections: background and personal information, social interaction, thermal environment and personal influences, occupants' perceptions of the environmental conditions in the whole building, occupants' thermal comfort, and people's general feeling and personal well-being. However, the overall thermal comfort sensation of the respondents in old naturally ventilated buildings and new air-conditioned buildings expressed the occupants' overall impressions of the building types in terms of their comfort conditions. Figure 3.2 illustrates that 54% of the respondents are feeling neutral (0) in the old buildings and only 15% of the respondents in new buildings are feeling neutral. In addition, 13% of people reported as being slightly cool (-1) in the old buildings compared with 0% in the new buildings, with 8% of them feeling hot (3) in the old buildings, and 33% feeling hot in new buildings. These results therefore suggest that the occupants have an overall impression of higher standards of thermal comfort in old buildings than in new buildings.

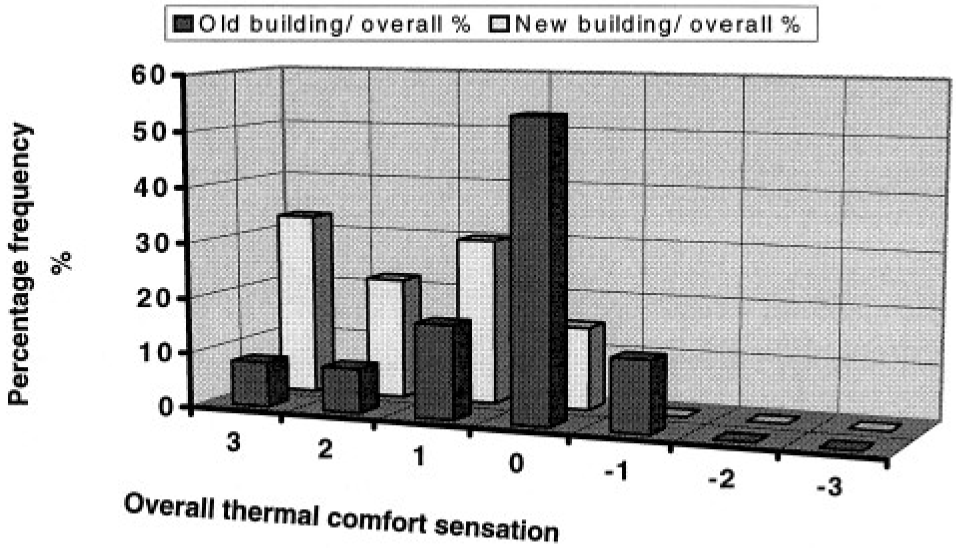


Figure 3.2: Comparison of the overall thermal comfort sensation for old buildings and new buildings: Source Ealiwa et al. (2001).

In their study of indoor adaptive thermal comfort of hot dry climate of Ghadames, Taki et al. (1999)'s investigations have covered full measurements to all environmental parameters: inside and outside air temperatures were recorded using radiation shielded thermocouples (Type T, copper/constantan) in the summer seasons from 20 to 26 of July 1998. These values were logged every 15 minutes and average values were calculated every hour, and also subjective data were collected from 88 subjects by the use of questionnaires distributed among the randomly chosen residents who were taking part in the survey (9 in the old buildings and 10 in the new buildings). The aim was to assess their actual mean vote (AMV) on the 7-point ASHRAE subjective scale. The interest was generally to find a temperature or range of temperatures and other environmental variables that people in that locality would consider neutral. However, the survey measures human thermal comfort and assesses the validity of the adaptive thermal comfort model. The relationship between the actual mean vote (AMV) of the subjects and the globe temperature in the new buildings are represented in Figure 3.3. It shows that when the air-conditioning system was in operation, the subjects were neutral at globe temperature values between 25°C and 31°C.

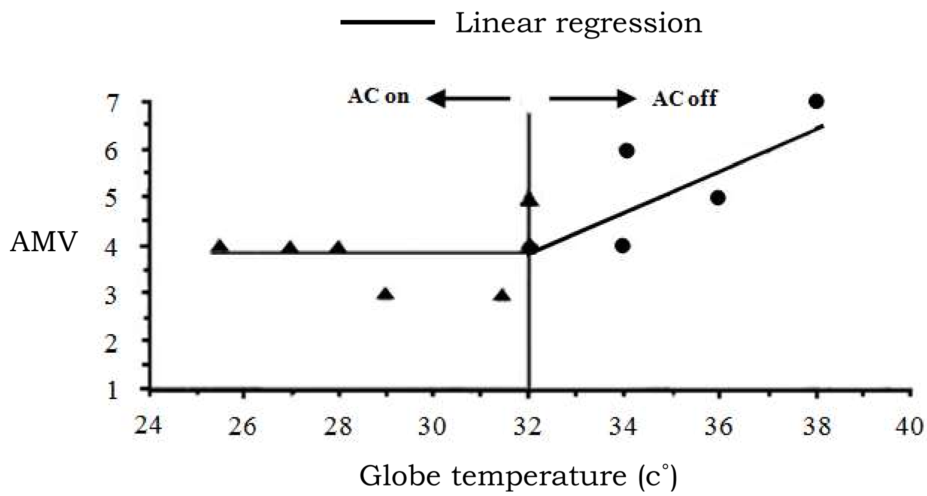


Figure 3.3: Responding of AMV of the residents in new buildings when air-conditioning turned off and on as a function of global temperature in Ghadames, 1997-98: Source Taki et al. (1999).

On the other hand, on disabling the air-conditioning system, the subjects expressed thermal dissatisfaction when the global temperatures exceeded values of 32°C. Subjects still felt comfortable or slightly comfortable (AMV =4 and 5) even when the global temperature reached 32°C. The results emphasise the adaptive effects on the behaviour of the residents, especially in new buildings, who rely more on the operation of air-conditioning systems and this became acceptable during prolonged warm spells, as people adapted their way of life to a new prevailing thermal environment.

3.3 Discussion

Firstly, the investigations reveal that the air-conditioning concept of the building and current envelope constructions cannot improve the behaviour of the buildings, concerning thermal comfort of the occupants and thermal performance. Secondly, employing the air-conditioning system concept cannot guarantee to maintain comfort boundary because thermal mass in the envelope design is not integrated between indoor and outdoor climate. Thirdly, the satisfaction with the indoor thermal conditions correlates strongly with control of the climate conditions by operating windows, doors and solar shading. Therefore, this enhances the interactions between the occupants and their surroundings in terms of natural ventilation. Fourthly, thermal comfort ratings are based on the entire summer season without the evaluation of the ability to enhance building envelope design. Lastly, the thermal performance of the building is affected by the increases or decreases in air temperatures during the whole year, especially in summer where very high ambient air temperatures with persistent heat waves and also in winter by low ambient air temperatures. Nevertheless, in general, current building design and material properties negatively influence the thermal performance and energy consumption for residential buildings.

Overall, the main findings from these previously completed studies are: the indoor temperature is around 33°C~39°C according to the varied outdoor temperature level. Hence this illustrates the huge reliance and use of air-conditioning as the outdoor temperature is high in summer and the building envelope is not a well-designed envelope to respond to the local climate. During the daytime, the indoor temperature is very hot comparing to the outdoor temperature but during the night the situation is reversed, the indoor temperature is much higher than the one outside. The use of air-conditioning concept instead of using the character of nature ventilation puts a big load on artificial energy use.

However, to improve the behaviour of the buildings, concerning thermal comfort for the occupants and thermal performance, this requires a thorough and straightforward optimization of the building envelope by using passive cooling design. Therefore, in this study, computer simulation technique can be used because it makes it possible to set up a model that generates relative performance data.

3.4 Conclusion

The subjective study by using a questionnaire and objective study by using an experimental method in Ghadames covered the physical issues related to the relation between the residence, buildings and climate, hence, this review shows that there is no need for an in-depth research in the field measurements and questionnaires of microclimate and thermal comfort in hot dry regions of Ghadames. Clearly, this reflective outline warrants further research and development on applying thermal building simulation as a direct research concerning adaptive comfort potential and its implication for building design. Evidently, it would thus seem possible that simulating existing building is another strategic design application for the changing scenarios relating to the potential for natural ventilation. However, in Ghadames, there is a lack of studies which dealt with the thermal behaviour, and therefore, improving building thermal performance in terms of design and construction is a burgeoning research area that requires greater emphasis. The following chapter explores the application of vernacular building methods in desert architecture in particular Ghadames that adapted the comfort for their occupants to bring integration of the past and present in terms of making it relevant to the modern design.

Chapter IV

Desert Architecture

4.1 Introduction

Traditional or vernacular housing provides a richness of design principles that *"...represented the result of many years or even centuries of optimisation in relation to the resources of materials and labour, the activities carried out within and around the dwelling, the social organisation of the household, and the climate"* (Evans, 1980). However, Evans spots a perspective of how vernacular form is "designed" and built with the very fact that it is not an architectural monument resulting in design. This indicates that vernacular architecture gradually improved along the times in response to the needs of their occupants. It privileges responses to the local climate as well as becomes well-fitted with their surroundings. Moreover, becoming a permanent phenomenon has historical roots to accommodate several factors approved through people's experience.

Nowadays, the polemical debate about practising the knowledge of vernacular architecture *"...has long been dismissed as accidental"* and ignored in existing modern architecture, therefore, *"...the result of rare good sense in the handling of practical problems"* (Rudofsky, 1981). However, the meaningful dimension to choose the solution from vernacular buildings and use them in today's architecture in a practical way is to draw application from these solutions, then combine architectural solutions taking into account cultural identity and local environment of different climate zones.

This chapter addresses the character of desert vernacular architecture. It seeks to answer the essential questions: *"How do vernacular buildings perform in terms of desert climate? What guidelines can be adopted from traditional building design of the hot arid climate?"* In addition, it reviews the wealth of vernacular Ghadames architecture representing knowledge and experience that is positively acquired through daily life and gained from our ancestors. It is worth considering the latter in this study to draw proper design in modern norms. Surely people choosing to live in modern domestic buildings in desert area intend to know how architects can extract the seldom experience from vernacular architecture, and also apply it in a way to enhance thermal comfort with a diversity of design treatments that provide useful insights in designing contemporary buildings.

4.2 Nature of the Climate

The Köppen climate classification provides a well-documented update of the world climate classification map using gridded climate data during 1951–2000 (Kottek et al., 2006). Based on this classification, Ghadames city is classified as a hot arid climate and is divided as (BWh) characterised by very hot, dry air temperatures and dry ground conditions) in desert climate. This climate classification was developed based on the empirical relationship between climate and vegetation (Chen et al., 2013). Figure (4.1) represents a map which is characterized by a seasonal temperature and precipitation that were calculated at each weather station and interpolated between stations using a two dimensional (latitude and longitude) (Peel et al., 2007), whereas, **B** means a dry climate, that is characterized by little rain and a huge daily temperature range, **W** means arid or desert and **h** means a dry hot weather with a mean annual temperature over 18°C.

4.3 Architectural Character in a Hot Climate

4.3.1 Urban Texture

The towns and cities of hot-arid regions consist of urban spaces, pathways, patios and buildings. Environmentally, the irregular shape of urban structure designed to integrate with the harsh climate and provide protection against undesirable winds from the south side sun radiation.

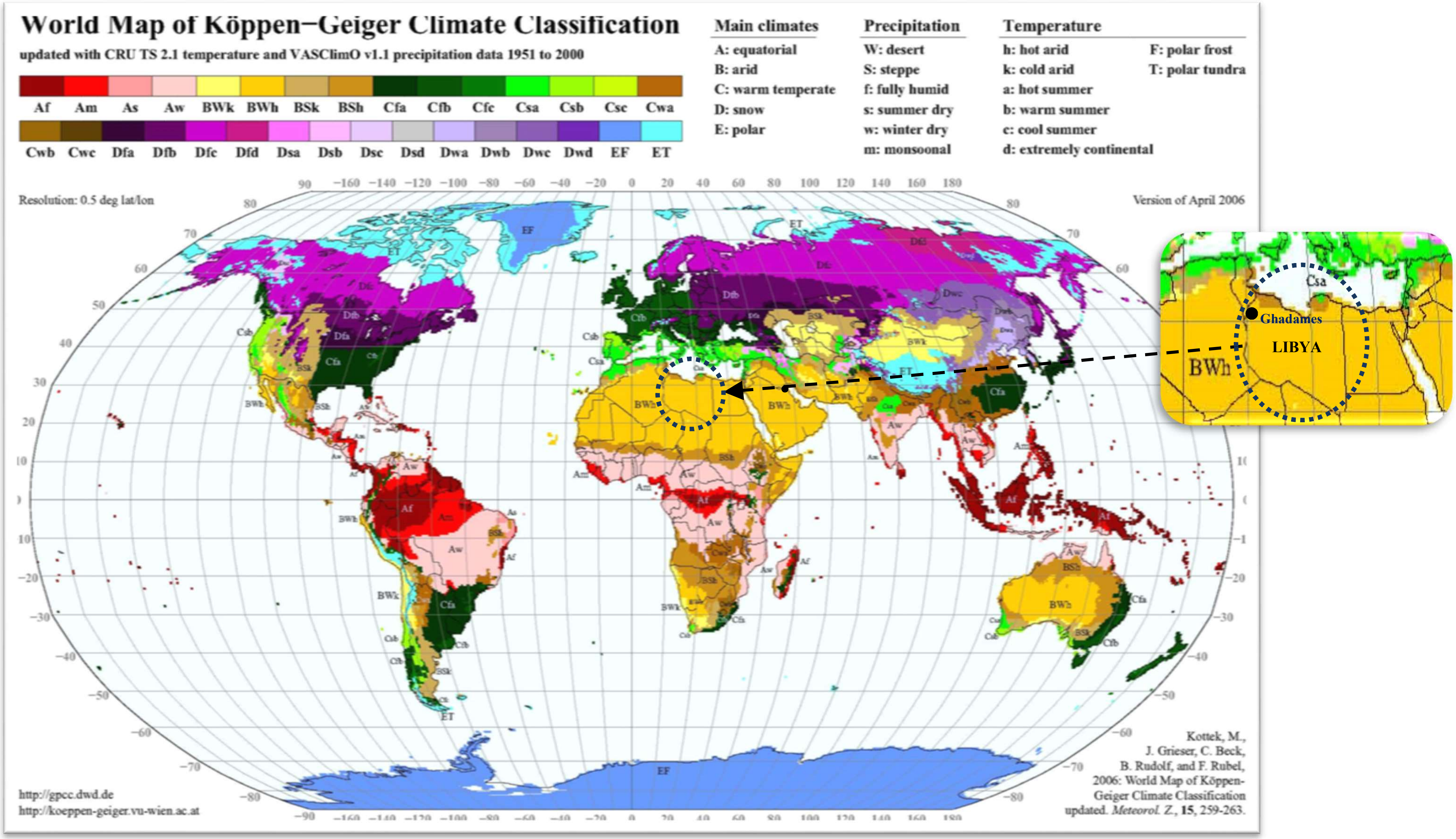


Figure 4.1: World map of Köppen−Geiger climate classification, Kottek et al. (2006)

However, traditional cities provide important lessons as a compact form of the urban texture, which *"... refer to a city that is concentrated and firmly unified with a consolidation of land uses in a close and tight physical relationship with each other and the structures within themselves"*.

The residential units in particular are arranged in a smaller space with un-equivalent size that provides enough suitable land, that has been saved adjacent to the cities for agriculture (Golany, 1996). Moreover, the compactness of urban texture in hot dry region*"...contributes to the thermal protection because the narrow winding streets are partially covered; the urban structure is usually a continuous pattern of courtyard building"* (Scudo, 1988), therefore the condensed and compressed urban texture allows the arteries of movement open in the direction of desirable winds and closed in the direction of undesirable winds and sand storms (A'zami et al. 2005). In addition, the compactness character of desert architecture is described as "*Defensive Architecture*" hence, the defensive wall system is formed by the blind rear walls of the houses in the perimeter of the village and the urban design becomes as a big compact fortress with concentric (De Filippi, 2006).

However, the important aspects of an urban texture that are harmonised with conditions of life and natural factors are the following (Maleki, 2011):

I. Dense urban built form the agglomeration and overlap of natural, social factors in the urban texture.
II. Urban spaces are completely surrounded by buildings that shaped the public squares for social gathering and pedestrian circulation.
III. Narrow, irregular and sometimes covered alleys provide shading and accelerate air flows that bring a desired protection from harsh climate and control over the outdoor environment.
IV. Buildings connected together compose the harmony and minimize the exposure to outdoor climate.

V. Buildings shaped by sun and wind direction contribute to buildings integrated to the harsh local climate.

In conclusion, traditional cities accumulated layers of experience for the enhancing thermal performance by designing the part as an essential to the whole and traditionally developed as compact settlements in practical response to the environmental stress. In other words, the compact city form reacts positively in its thermal performance to regions of harsh climate.

4.3.2 Buildings Design

Prominently, desert architecture is a vocabulary that governed the design concept of the traditional houses and highlights their distinctive characteristics solutions which can be traced in many of the existing buildings.

Importantly, the climate is a key factor determining its design parameters such as distance between buildings, building form, orientation and building envelope (walls, roof and fenestration). The design of every indoor and outdoor space such as courtyards, shading walls and enclosed spaces (rooms in different directions), gives a good choice for residents to change the living space for special hours of the day and night of cold or hot seasons in harmony with the region (Manioglu and Yılmaz 2008). The buildings in hot arid climate are shaped so as to allow natural ventilation in summer *“breezes and induce air movements”* through single and multiple courtyard system. The construction method has often used a high mass skin to counter the varying diurnal temperatures which occur from day to night (Kamel and Ibrahim 2004). According to the study by Croome, (2001), traditional architecture exhibits a variety of building design and construction that are suited to the respective climatic conditions. Hence, the structures are made of predominantly local materials such as the mud that can maintain fairly steady inside temperatures of desert regions in spite of the very high air temperatures and solar radiation. The physical measurements by the author between 21~26 of June 2014 have shown how the high thermal capacity of thick adobe walls and mud roofs give pleasant conditions of 24-30°C with midday external air temperatures of 40°C.

Fathy, (1986) highlighted the traditional architectural vocabularies representing building identity in hot arid region that meet the problems caused by excessive heat. Loggias, projecting balconies, and overhangs as well as wooden or marble lattices fill large openings to subdue the glare of the sun while permitting the breeze to pass through. Such arrangements characterize the architecture of hot zones and evoke comfort as well as aesthetic satisfaction with the visible endeavours of man to protect himself against the excessive heat. These vocabularies are not only a symbol for architectural identity, but successfully respond to their social, cultural, climatic features and effectively provided environmental design and sustainable key elements in buildings.

However, the appreciation of design quality needs developing links between contemporary architecture and vernacular architectural heritage by introducing an identifiable architectural character that would adequately belong to the local environmental conditions and to the behavioural patterns of the population of a locality.

In conclusion, vernacular architecture exhibits a variety of building designs suited to the respective climatic conditions. The orientation and arrangement of vernacular houses are designed in a way to have appropriate comfort for residents. Some types have courtyards and the architectural design of these types have porches and arches that providing shading zones admitting cooling breezes and protection against sun rays in the summer season, see Figure 4.2. Moreover, the patios zone provides natural lighting and ventilation and also benefit from solar radiation during the winter seaso 45 imately, construction materials of the houses that were traditionally used are mud brick, baked brick, white lime plastered walls and baked floor tiles. However, these materials are the important factors in hot-arid regions, where thermal resistance, high heat capacity and absorption of the sun radiation through their external surfaces are the positive character of local materials (A'zami, 2005) & (Salama, 2003) & (Scudo, 1988).

Figure 4.2: Arches in courtyards of traditional Moroccan home that provide shading zones allowing cooling breezes and protection against sun rays in the summer season, Fleisher, (2013)

4.4 Lessons from Vernacular Desert Architecture.

In principle, vernacular architecture is based on knowledge of traditional practices and techniques and reveals a high regard for craftsmanship and quality (Sundarraja et al. 2009). As well as represented as a composition of climatic adaptation that shows the strength of various settings (religion, culture, building techniques, etc.) where the natural harmony blends between architecture and people. However, this is a meaningful example to contemporary design of homes and much has to be learnt from their great history and development of city planning, building form and construction methods of the past.

According to previous review, indeed, there are many points can be derived from vernacular architecture, especially where extreme climates have stretched human ingenuity and may help to find appropriate concepts, if not models, to address problems. As a result, the performance of vernacular architecture has providing successful bioclimatic shelter results from a conscious design of microclimates both inside and outside the building, based on climatic responses as follows:

The first point regarding housing design is that the orientation of the building is the key to achieving thermal comfort. Orienting the openings is also very important, thus the best orientation requires that the building as a whole should receive minimum solar radiation in summer (Nayak and Prajapati, 2006).

The housing design in harsh climates has shown that the design of an effective envelope is vital. The windows are sized to minimize the penetration of hot air into the housing during the hot hours of the summer and of cold air during the winter, while allowing massive ventilation on cool summer nights (Okba, 2005).

The thick walls of materials like mud, mud-brick with high thermal capacity and adequate resistance will reduce external temperature, so that the temperature variation at the internal surface is only about 15 to 20% of the external air. (Evans, 1980).

Manipulating the geometry of the housing envelope is the most fundamental way where the ratio of the surface area to the volume of the building (S/V ratio) determines the magnitude of the heat transfer in the building (Nayak, J and Prajapati, A. 2006).

A dense pattern "carpet-planning" layout provides protection from solar radiation, glare and hot temperature by providing mutual shading where groups of buildings are close to each other (Gut and Ackerknecht, 1993).

The design of court-yards in some desert regions in the middle of houses is of great value. It also provides space for ponds, to plant grapes arbour and other plants, which, all in all, increases humidity in house environment and the mud-brick (Heidari, 2010).

Finally, all the arguments support the proficiency of building a sustainable context between vernacular architecture and local climate in terms of design response to climate, particularly in the context of purely passive environmental control. However, it is essential to take the wisdom of the past and evolve a built form which will be more humanized, more climate responsive and more environmental friendly for the buildings of tomorrow (Radhakrishnan et al. 2011).

4.5 The Case Study

The style of traditional Ghadamesian architecture in Libya has been built by people who were not schooled in any kind of formal architectural design. It is self-conscious to the human eye in buildings shape, choice of materials, arrangements and concept of passive techniques. It also demonstrates the principle of climate oriented architecture, which was a pragmatic remedy to the effects of harsh climate in arid region.

4.5.1 Location

Ghadames City is an agglomeration of Saharan oasis sited in Libya near the borders of two Arab countries. The City is about 340 metres above sea level and the site coordinates are 30°08' latitude North and 9°30' longitude East. It is located about 17 km from Tunisia and 14 km from Algeria, see Figure 4.3.

4.5.2 Foundation of Ghadames and Local Identity

In the 10th Century, Ghadames was an important commercial centre situated in the intersection between three countries that provided ancient transport routes for caravans trading between the Mediterranean and the interior of the African continent, (OWHC, 2016) & (Chojnacki, 2003). Historians record that Ghadames was inhabited (4,000) years ago. The town was shaped as symbol of *"... regional architecture ...* represented *an idiom* that *having a distinct identity and being associated with an identifiable group, and having this association used ... architectural elements to represent the identity of a group occupying a piece of land* "(Lefaivre and Tzonis, 2003).

Figure 4.3: Map of Libya showing Ghadames location and neighbours (Geology.com, 2014)[1]

Therefore, the decisive effect on the sections and the spatial development of Ghadames was built by seven nomad families who came from two tribes: Beni Wazit and Beni Walit. Those families took the land to create numerous habitable buildings in the form of continuous villages (EL-Agouri, 2004).

In 1969, when the first layout plan for old Ghadames was issued by the Architectural Planning Partnership, Copenhagen, the structure of the old town had not yet changed and it housed a population of 2.681 inhabitants in total, covering an area around of 15 hectares (Aalund, 1987).

[1]Geology.com provides information about geology and earth science founded by specialist Geology group in USA, http://geology.com/world/libya-satellite-image.shtml

4.5.3 Urban Fabric

Old Ghadames City is an *“Iconic City”* with a scarcity of natural resources in arid desert. It is divided into two parts: the old city with traditional architecture and the modern city with contemporary architecture, see Figure 4.4. According to a field study by Ghadames Municipality, (1980), the glimpses of urban scenes in Ghadames appeared to represent impressions of segregation, whereas the society itself claims to have unity, integrity and organization that can be patterned by a gradual shift from an urban texture to a building unit.

The Figure 4.5 shows the interpretation of the traditional city form that is mainly based on:

“Distinctive Design”, through the heritage of historical developments, compact urban pattern and local architecture style.

“Environment”, harmony with nature through understanding the site character and climate’s considerations.

“Constructions”, using traditional local technique with local natural materials that shaped the identity of Ghadames architecture.

“Life Context”, the social indoor life, culture dimension, religion effects and defence strategy is mainly important in eastern families, especially in harsh climate, where the control is led by the tribe.

Aforementioned factors support Ghadames' architecture of the traditional city, integrated into one complex structure with high-density in which it is hard to distinguish the individual houses in order to avoid the sharp sunlight during summer and protection against extreme temperatures and sand storms to minimize the thermal load on the buildings envelopes, especially houses (Al-Zubaidi, 2002).

Famously, the old town is described as the *“Pearl of the Desert”* [1] bordered by an oasis that is protected from the drifting sand and from the high air temperature of the surrounding desert by palm trees (see Figures 4.6, 4.7 & 4.8).

Inside the City boundary, the town extends in a continuous system of housing units, consisting of buildings, streets, pedestrian passages and squares which function as venues for meetings and resting places (Chojnacki, 2003).

The urban pattern of the old City is made of irregular blocks divided according to the tribes' distribution and each district has a centrally located communal meeting place and one major mosque, in addition to the local mosques (see Figure 4.9, 4.13), (Alund, 1987).

The shape of the City is a logical response to urban environment concerns, their relationship with natural features, an integration which demonstrates its aesthetic composition.

[1] http://whc.unesco.org/en/list/362

Figure 4.4: Arial photo for Ghadames town from Google earth, (2014).

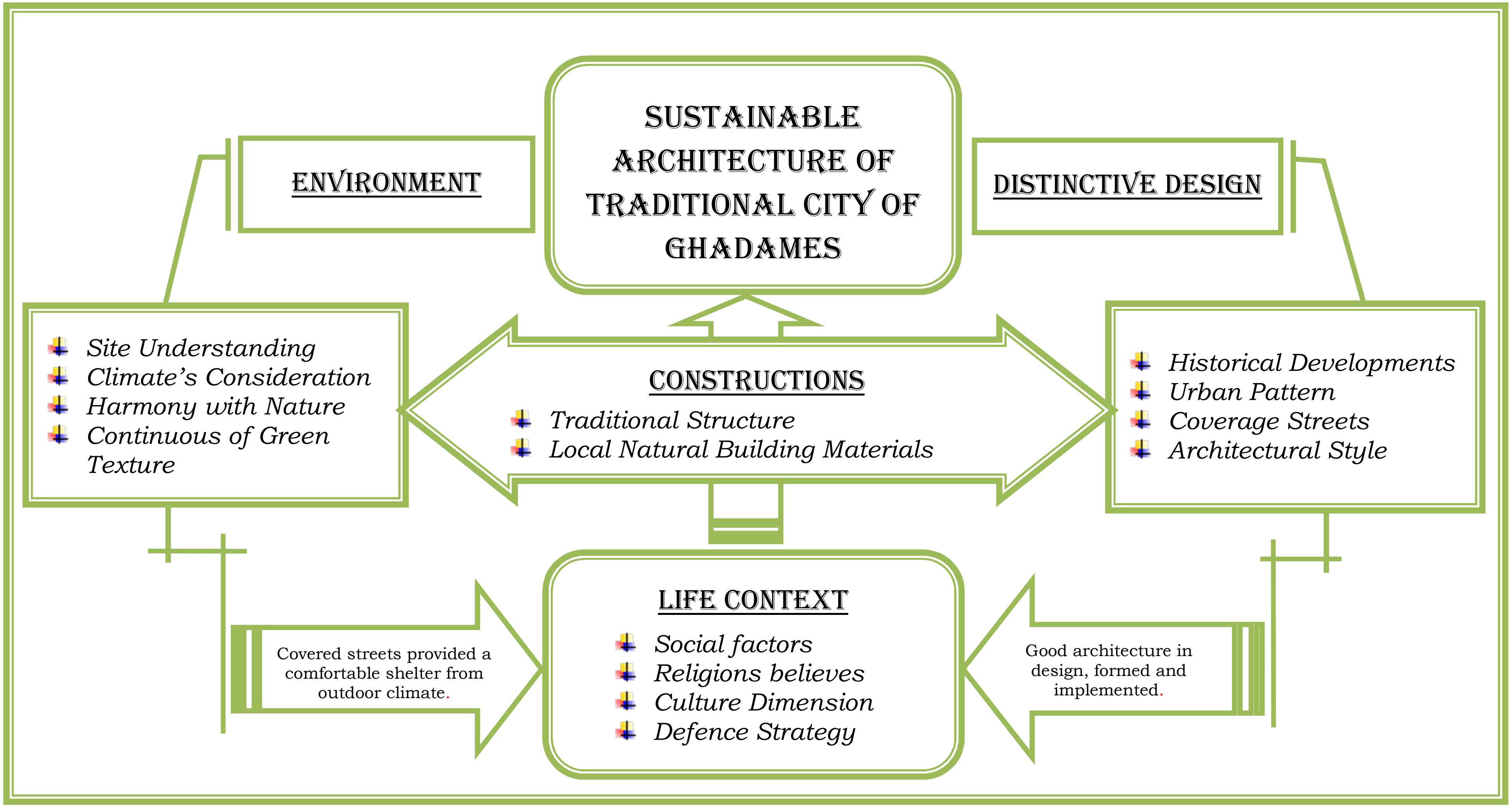


Figure 4.5: The main principles of sustainable design approach in old Ghadames town
(After Ghadames field study report, Libyan State, 1980)

Figure 4.7: Top view of the old City show respect of surrounding environment and unity of the city. Source: Site photographs by author, summer 2014

Figure 4.8: Tall buildings with less opening protect the city against the dusty desert winds and provide defence strategy. Source: Site photographs by author, summer 2014

Figure 4.6: Top panorama of the old City show the integration of the building with the greens. Image source from Google earth, (2014)

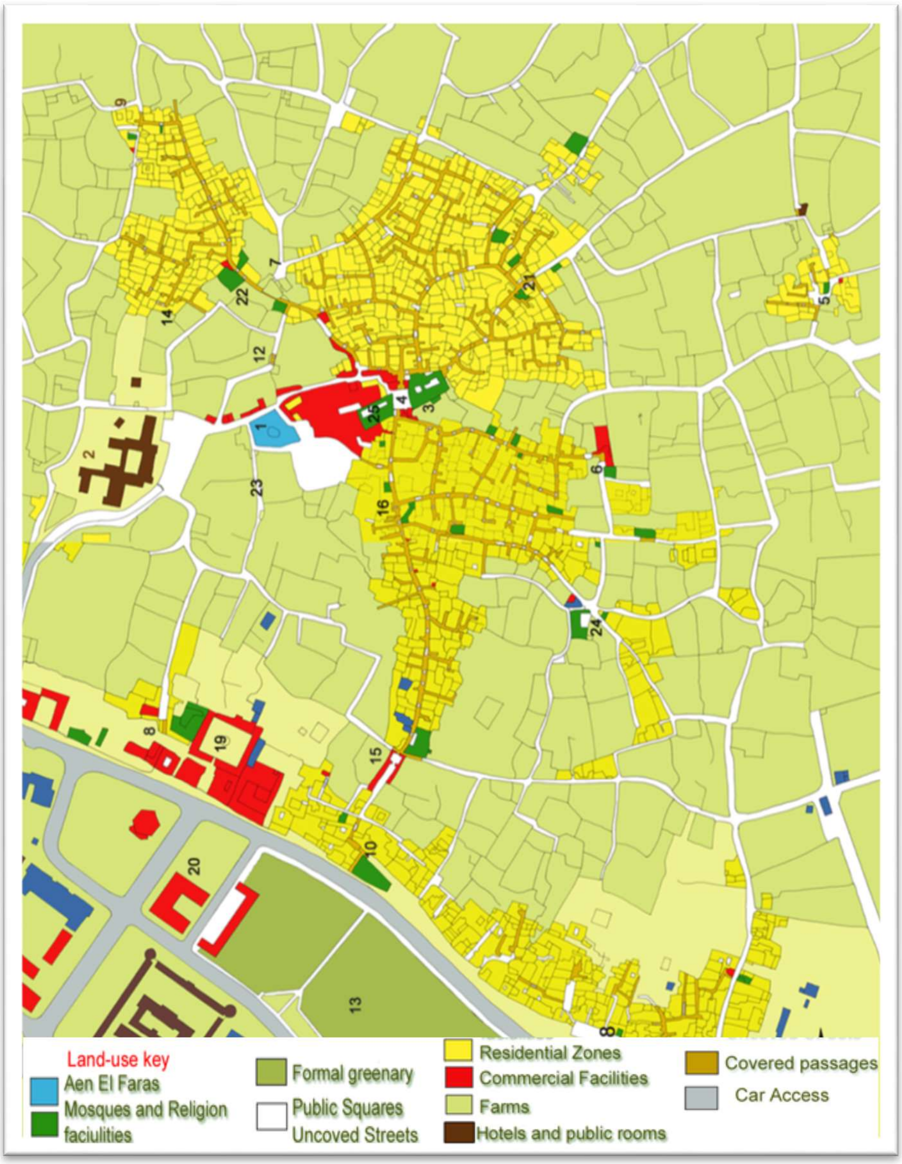


Figure 4.9: Old Ghadames land use plan. Map source (EL-Agouri, 2004)

Correspondingly, the old City shows a strong intimate connection of the urban form as an aggregation of covered cellular components. These components demonstrate the shape of private houses within a coherent urban fabric, thus meeting the essential social requirement and climatic solution, which is a pervasive logic in the urban pattern which is surrounded by farms.

Naturally, this concept is manifested in the City construction providing defence strategy *"Fortresses City"* to protect the City from enemies as well as save it from the harsh climate (Ghadames Municipality, 1980).

One noticeable and conspicuous aspect of urban structure is a continuous pattern of residential clusters that produce a cohesive urban form, (see Figure 4.9) which is connected by a network of dead-end alleys leading to a central area from major gates.

Structurally, the pedestrian network includes an almost unique system of covered lanes with formally arranged squares. It is based on a sophisticated hierarchical system and gradually leading from the more public to the more private areas (Azzouz, 2000). This system passes from major to manor alleys that reach the heart of the residential housing and the alleys generally are bordered by high building or walls and are mostly very narrow: about 1 - 2 metres (Libyan State report, 1985).

Interestingly, the urban texture provides a shelter from the harsh climate because the narrow snake streets provide shades and relatively well-lit areas from regularly spaced light wells each 15 metres that let cool air circulation deposited during the day sweep away partially through the buildings and main gates (see Figures 4.11, 4.12).

This causes air movement from high-pressure zones to low pressure ones, where the hot air is replaced with the cooler and humid air in the shaded passageways, thus regulating the internal temperature (Al-Zubaidi, 2002).

4.5.4 Architectural Composition

Architecture in Ghadames is shaped as an outcome of a successful mixture of geographical, historical, climatic solution, culture, and religion and construction techniques with specific materials (see Figure 4.5). Cumulatively, this development has been gained through ages, which distinguishes Ghadames itself in its architecture style that has been built in a friendship relation with the nature. Moreover, incredible aesthetics of the City skyline scale has been dominated by mud brick constructions that made a strong relationship between the surrounding landscape and the urban setting. Thus, the traditional buildings have been designed in such a fashion as being constructed entirely of local materials producing an attractive and harmonious architecture within the environment (Aalund, 1987).

Characteristically, the Ghadamesian houses are shaped according to the internal desires responding to the enclosed activities. The houses' designs have many shapes as the geometry of buildings is different according to land division of the City planning. So, this architectural composition represents a form that allows only a few visible facades rising in an almost fortifying manner to a height of about 10 metres and are composed of a number of areas extending on three floors, from the ground floor, through the central hall to the roof floor.

The ground floor, generally consists of an entrance to the houses opening to the street and is protected from the sun heat. The entrance leads to the main staircase of the upper floor as well as provides access from the entrance lobby to a store room at ground floor level for tools. Then the first floor consists of the family living room as a main space. Around this central space, other rooms are arranged in the second floor to include for instance the boys' room, the girls' room and the storage room. These rooms are a level higher than the living room and have access to them throughout the staircases (see Figures 4.16, 4.17, 4.18, 4.19). This distribution is common in all houses of Ghadames, i.e. following the same pattern. Ultimately, the top floor is reached by a winding staircase which is connected to the kitchen and storage room then to the terrace that is reserved for women only and where most of their activities are confined. Moreover, in the roof, a sky-light window is made to provide natural lighting to the living room (see Figure 4.14).

Furthermore, the roof provides freedom of movement and opportunities to meet each other as all terraces are linked by covering the lower streets.

Terraces are surrounded by small walls to ensure privacy and have been kept in this way for women especially when wanting to pay visit to their neighbours in any part of the town without contravening the traditional separation of the sexes (see Figure 4.15), (Libyan State report, 1985).

Figure 4.14: Roof window on the top to allow natural lighting and ventilation pass through building. Source: Site photographs by author, summer 2014

Figure 4.10: Show the concentrate of urban form decreases penetration the dusty wind moreover influence of hot sun radiation on the passageways. Source: Site photographs by author, summer 2014

Figure 4.13: The mosque is the dominate building in the city. Source: Site photographs by author, summer 2014

Figure 4.15: Women use the special paths built above the roof to keep the privacy. Source: Site photographs by author, summer 2014

Figure 4.11: The covered streets content sitting corners provide shades from harsh climate and are used mainly by men and children. Source: Site photographs by author, summer 2014

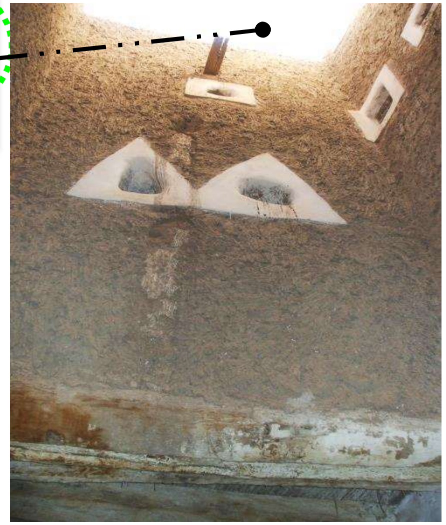


Figure 4.12: light well to provide natural lighting and ventilation on the covered streets. Source: Site photographs by author, summer 2014

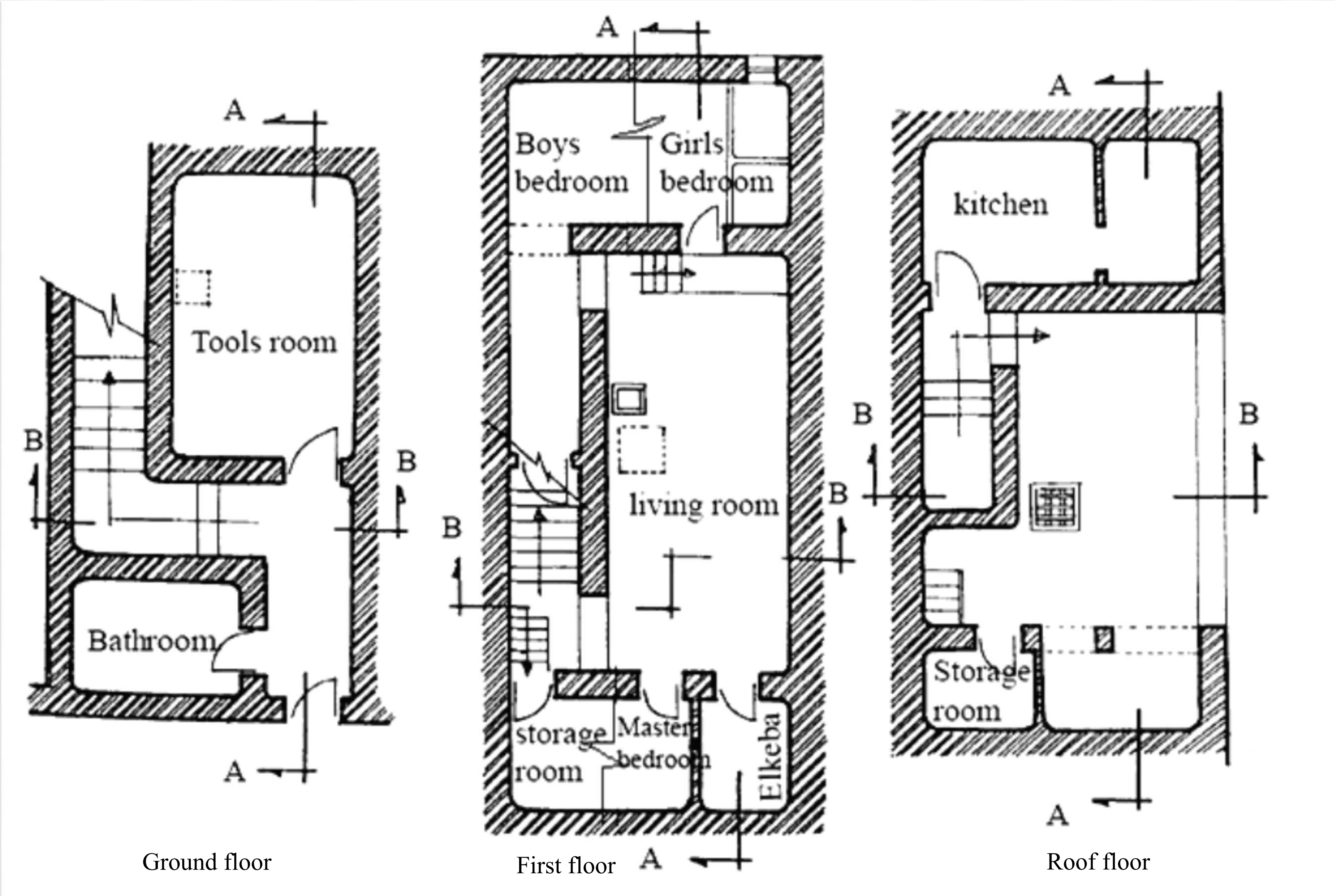
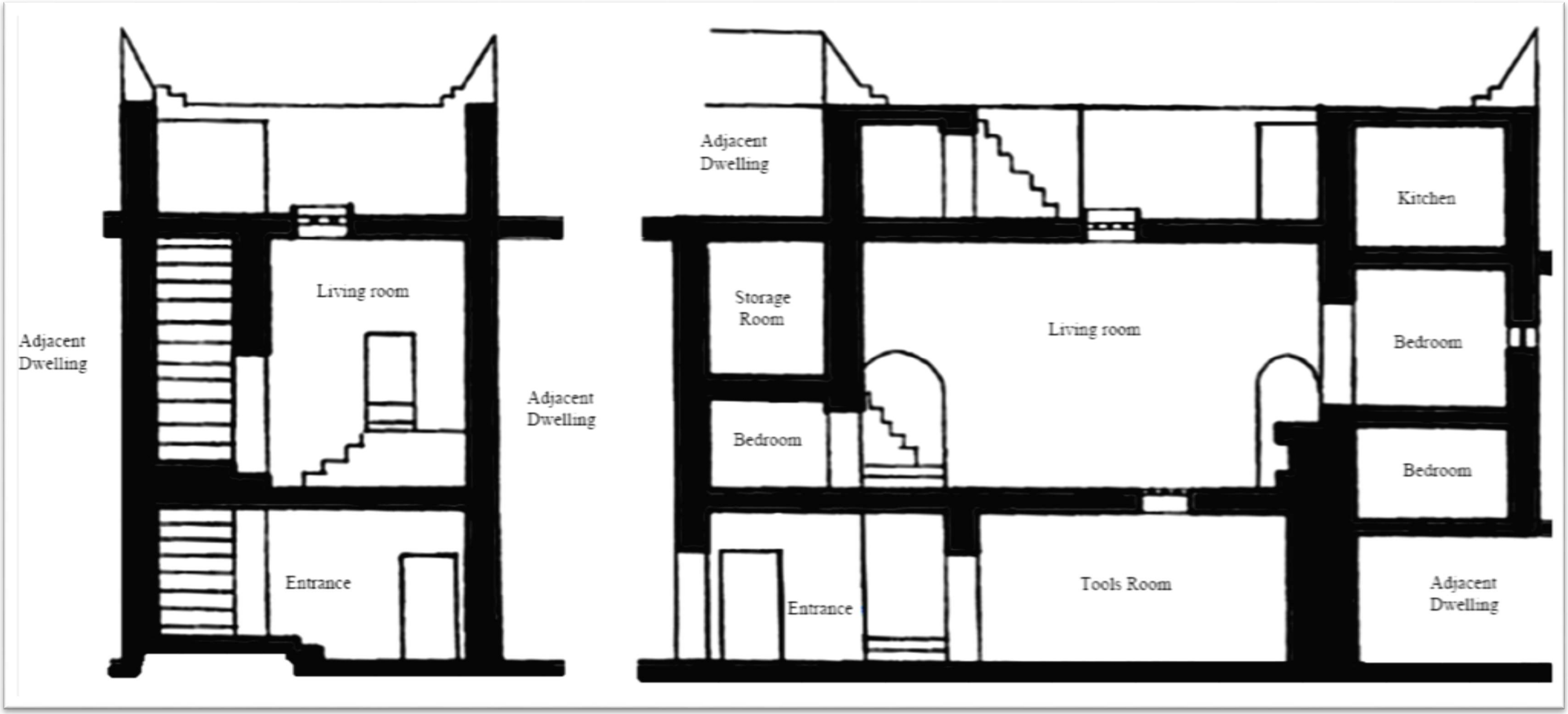


Figure 4.16: Vernacular house plan, (Type 1).

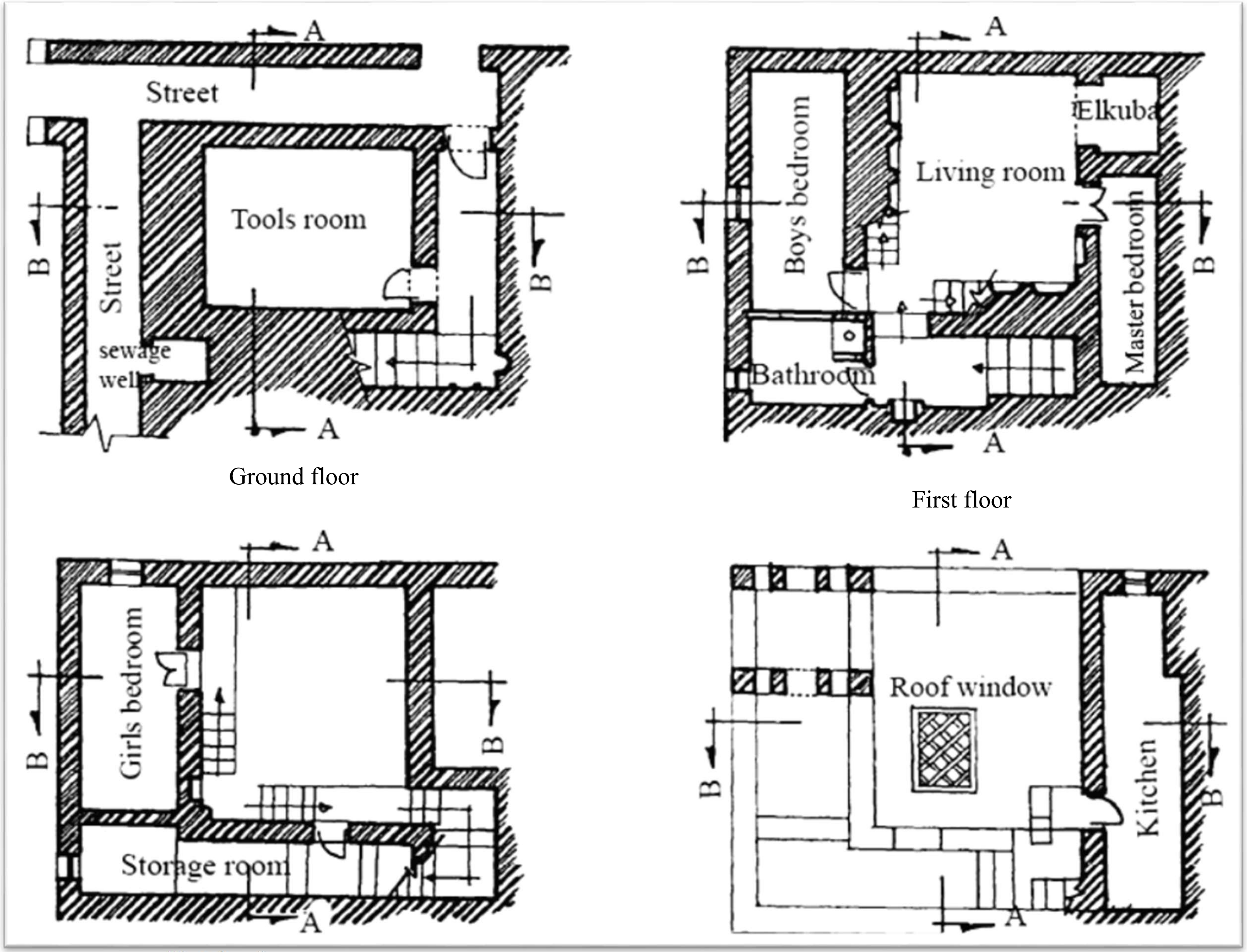


Section B- B

Section A- A

Scale 1:100

Figure 4.17: Vertical section (Type 1).



First level

Figure 4.18: Vernacular house plan, (Type 1).

Roof floor

Scale 1:100

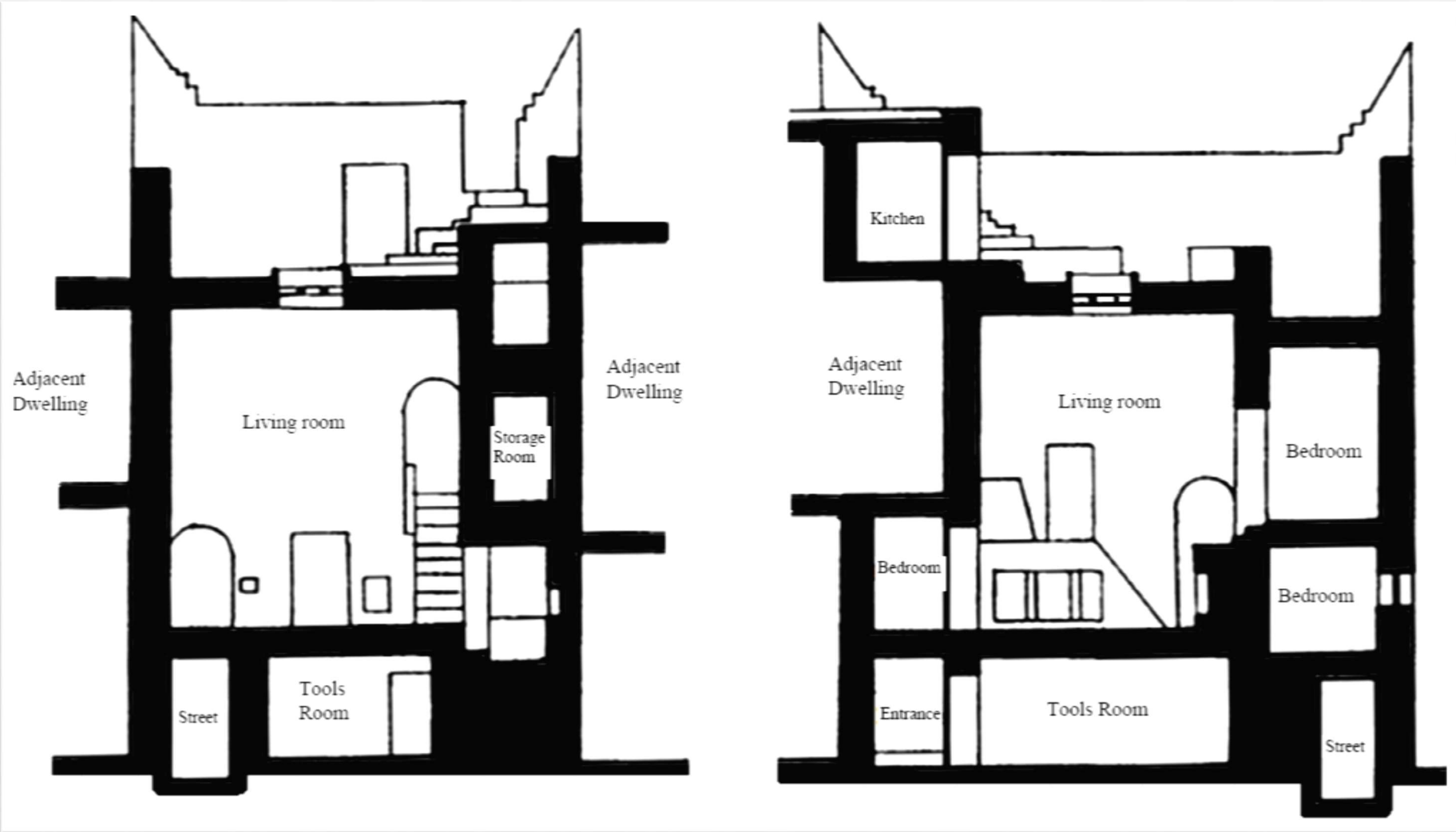


Figure 4.19: Vertical section (Type 2).

Architecturally, Ghadames is an extraordinary place of aesthetic design with rich and ingenious techniques which present a series of logical solutions for human comfort. In addition, the modes of ornamentation give a colourful interior embellishing the living room which is a dominant figurative place showing inspirations from the inherited cultural heritage (see Figure 4.20).

Figure 4.20: Traditional ornamentation embellished interior of living room. Source: Site photographs by author, summer 2014.

4.5.5 Natural Ventilation Strategy in Vernacular Houses of Ghadames

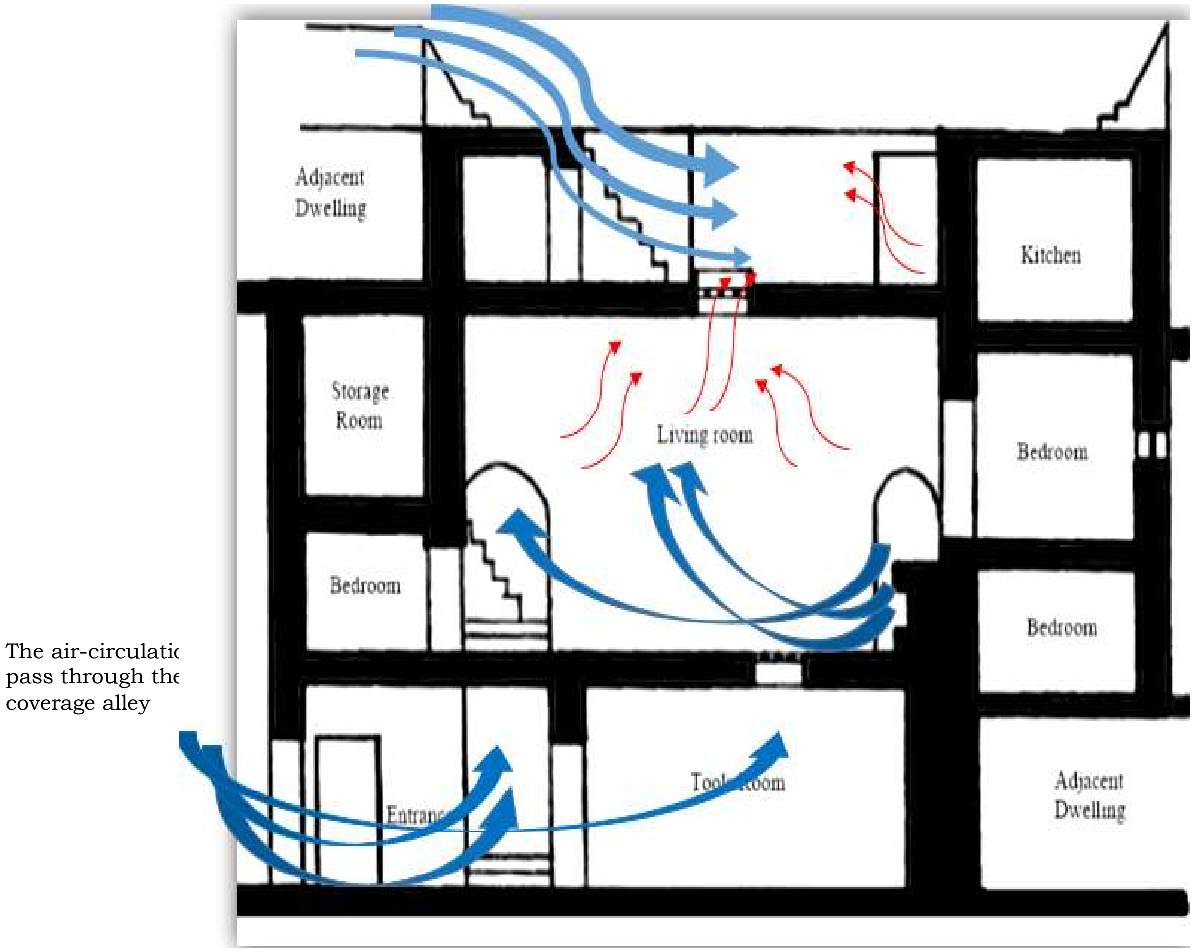
The natural ventilation system in vernacular houses was designed on the basis of stack ventilation. In summer, when the house's doors are left open in day time, the ventilation shafts lead down to the covered streets and lanes at ground floor providing natural ventilation to all rooms where the cool air supply enters, the houses of the lower part (main entrance) through the stairway and the air exiting from roof window. Hence, it is a simplified way of utilising the cooled air through covered streets by directing the air circulation vertically through the uppermost aperture (roof window) to decrease the amount of hot air that accumulates in the house (see Figure 4. 21). At night-time, when outdoor the air temperature decreases relatively, a reverse stack effect occurs when the main entrance is closed, a cross-flow of air ventilation enters the house from the rooftop through small voids located in different rooms. In harsh climate time, a shutter is used as a cover to shut or open the uppermost void, depending on outdoor climate conditions of the different seasons. (Evans, 1980) & (Shateh, 2002) & (Al Aabid and Taki, 2014).

4.5.6 Building Technique and Materials

The valuable experiences of local builders has been exposed through their finger print on building design and construction that visually has shown the unity of the housing fabric which is composed of local materials.

Subtly, construction system built from mixed organic elements such as mud brick, stone, sun dried hot baked in the walls and also the structure of ceilings and roofs constructed by bisected and smoothed trunks of palm tree as first cover. The second cover, mainly made of ribs of palm leaves are left in water for three months before plating the mat, providing support for the floor slab. Later on, the last cover consists of stones and clay with a gypsum mortar. Lastly, gypsum plaster used to cover the walls surface and applied to lime paint in thin layer as a final coat (see Figures 4.22, 4.23), (Al-Zubaidi. 2002) & (Mohamed et al. 2006).

Basically, the construction system of the houses is constituted of load bearing walls of sun-dried clay bricks on a foundation of stones where the thickness is diminishing from bottom to top from (0.75 - 0.60 - 0.50 m) for structural durability.



(Fresh air comes through ventilation walls in the coverage streets that assist to cool the air down through pass over shadows areas to the main entrance of the houses to the living room , then warm air rising-up through convection).

Figure 4.21: Section illustrates the circulation process of natural air ventilation in vernacular houses of Ghadames

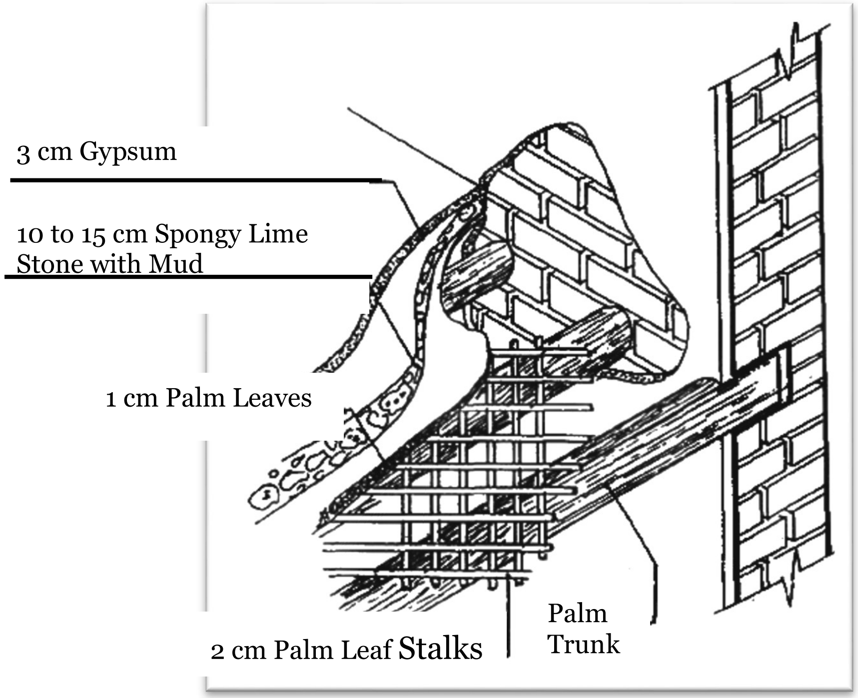


Figure 4.22: Perspective section in the roof construction of traditional building (Ghadames report, 1980).

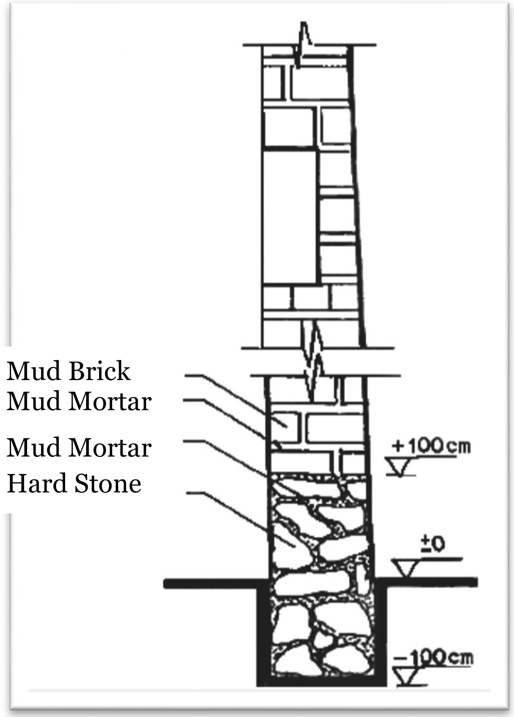


Figure 4.23: Section in the wall and foundation of traditional building (Ghadames report, 1980).

The size of the bricks is different corresponding to wall thickness, measuring (0.60 x 0.40 m) in the ground floor, (0.50 x 0.40 m) at first floor and (0.40 x 0.40 m) at top floor (Al-Zubaidi, 2002).

4.5.7 Contemporary City

The trend of modernization and urbanization affects the social life in Libyan cities, especially Ghadames. In the early 1970's the economic transformations after oil has been discovered and exported in the beginning of the 1960's. The housing sector acquired considerable care especially after September 1969 Revolution, when the revolutionaries tried to gain public support after they attempted to solve the problems which touched peoples' life directly (Sheibani and Havard, 2006). Accordingly, the priorities for the new town are highlighted as adapting the changing needs and a growing demand for living opportunities.

Libya's planning and building regulations established rules that led to modern neighbourhood configuration and street patterns that changed from the 1969's. In contradiction, as one moves away from the old town, the new urban growth becomes discontinuous with the old town and more diffuse as the contrast extends further. The extension of the new City is relocated towards the South, although there is no evidence of the reasons of choice the relocation. However, the new City is surrounded to the North by the old town and the oasis, and to the East, South and West by the desert (see Figure 4.24). Realistically, according to the master plan of the new City in Figure (4.25), there is no buffer zone considered to isolate the new built environment from the surrounding desert. Whereas unattractive landscaping surrounded the new City as well as become stand-alone City confronted to the extreme climatic conditions manifested by high temperatures and heat, low humidity and sandstorms. The case study area showed the grid patterns of wide streets through necessary set-backs and site-coverage limits (see Figure 4.26).

This resulted in promoting the construction of free-standing villa type buildings.

Recently, the new housing zones in the town optimized within the blocks of buildings (see Figure 4.27, 4.28, 4.29, 4.30), split by a street hierarchy that gives a wide and straight network allowing public passage for pedestrian movement and traffic. Different types of housing are shaped and arranged in blocks of semi-detached or terraced in one and two storey buildings. The urban street network provides huge open spaces for the sun heat during the daytime as the streets do not offer any shading and they heat up faster than the narrow lanes in the old district (Givoni, 1998).

According to Mohamed et al. (2006) study, recent residential buildings in the local Ghadames context are designed without giving due importance to the parameters that are responsible for enabling thermal comfort, so the people can express their social behaviour and identity. Various forms of housing are shaped from rectangles and squares to optimize the use of space and personal needs in the town. However, the housing designs and structure type are not concerned with the local context of Ghadames City: this is also a typical style common in other Libyan cities. The structure consists of reinforced concrete, cement block and cement-mortar plaster; and the concrete buildings have a modern architectural style. However, the urban patterns are entirely different from the old town image that considered the climate in a traditional way (See Figure 4.31, 4.32).

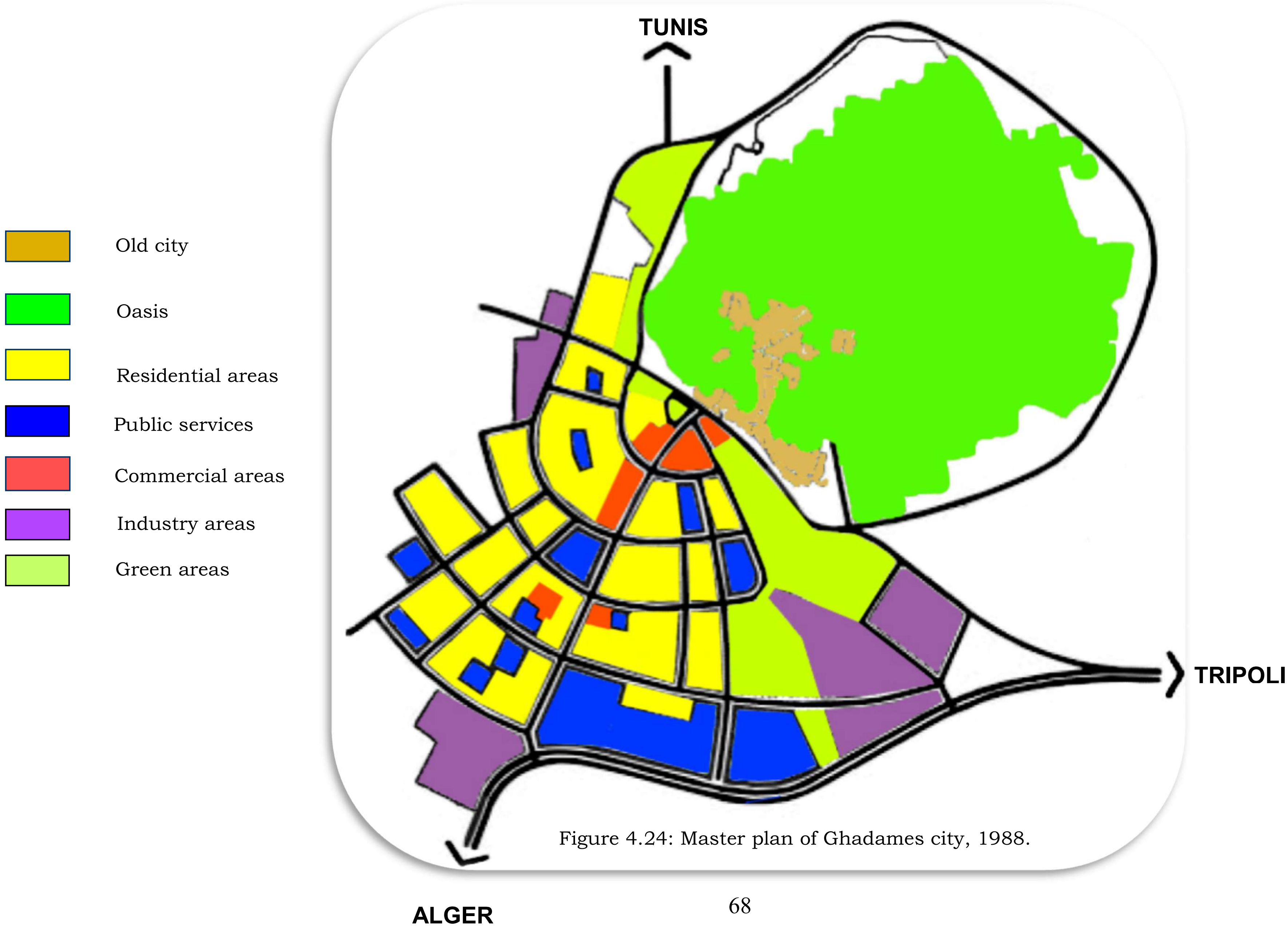


Figure 4.24: Master plan of Ghadames city, 1988.

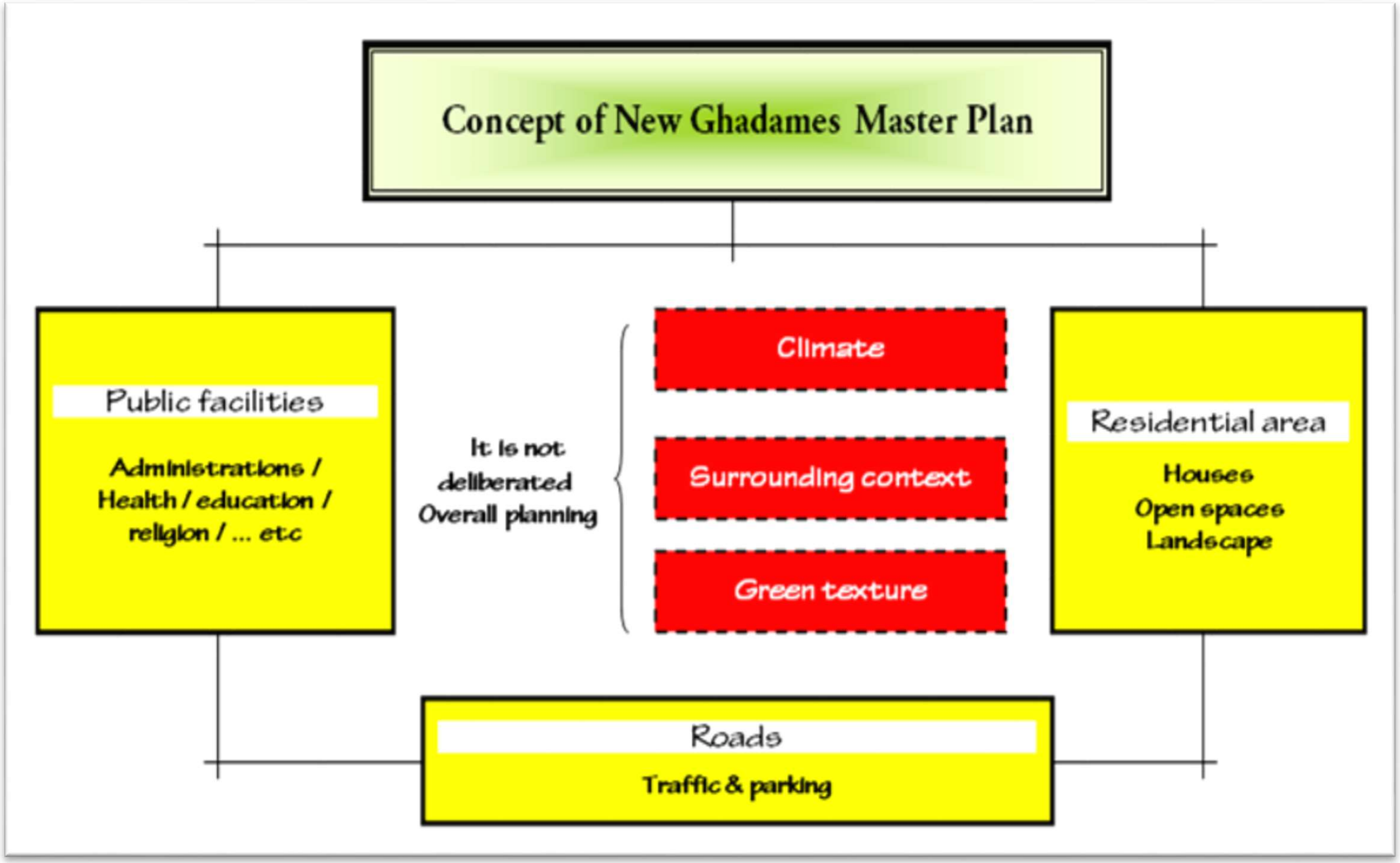
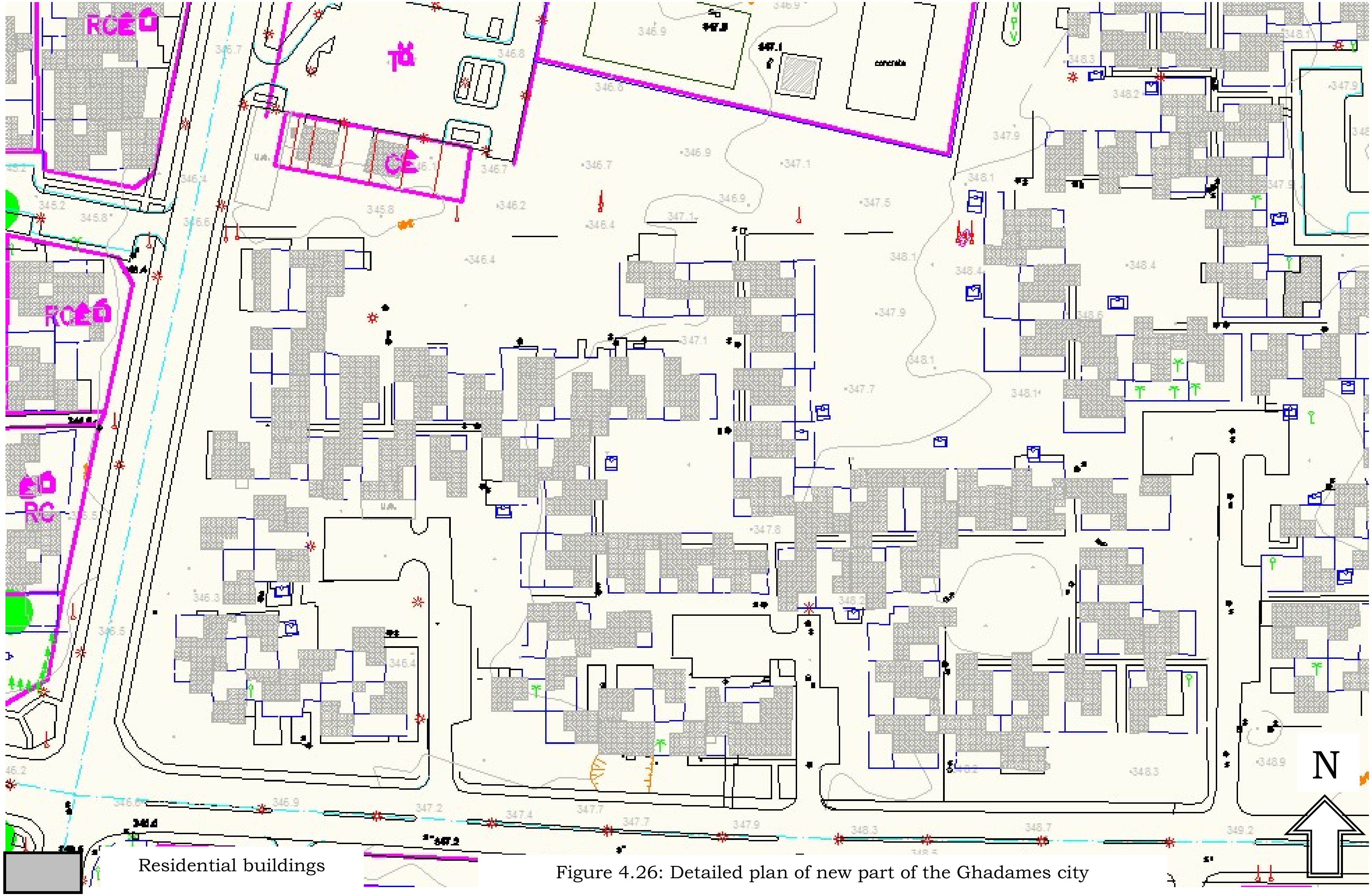


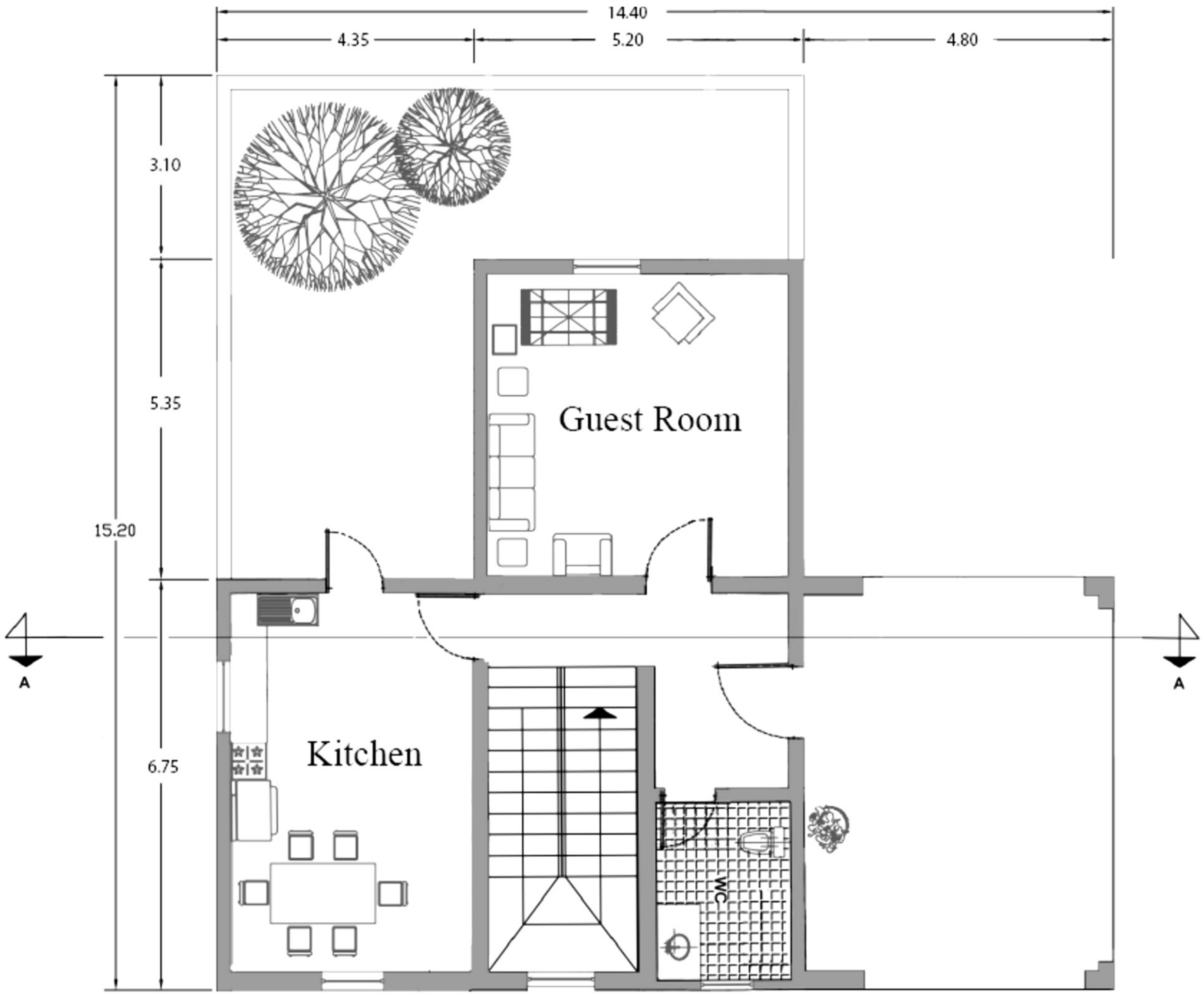
Figure 4.25: Designation of existing concept of master plan.



Residential buildings

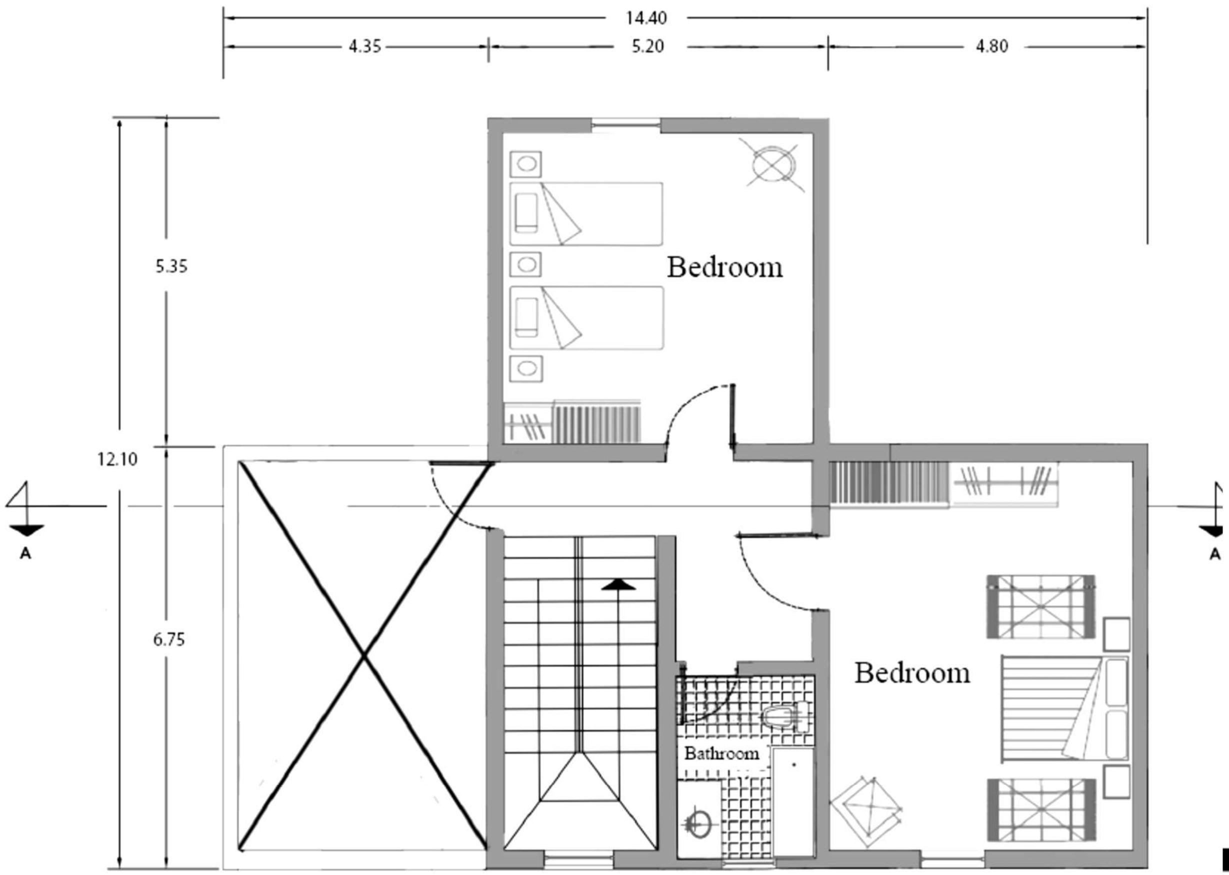
Figure 4.26: Detailed plan of new part of the Ghadames city

Scale 1:1000



Scale 1:100

Figure 4.27: Modern villa type / Ground floor.

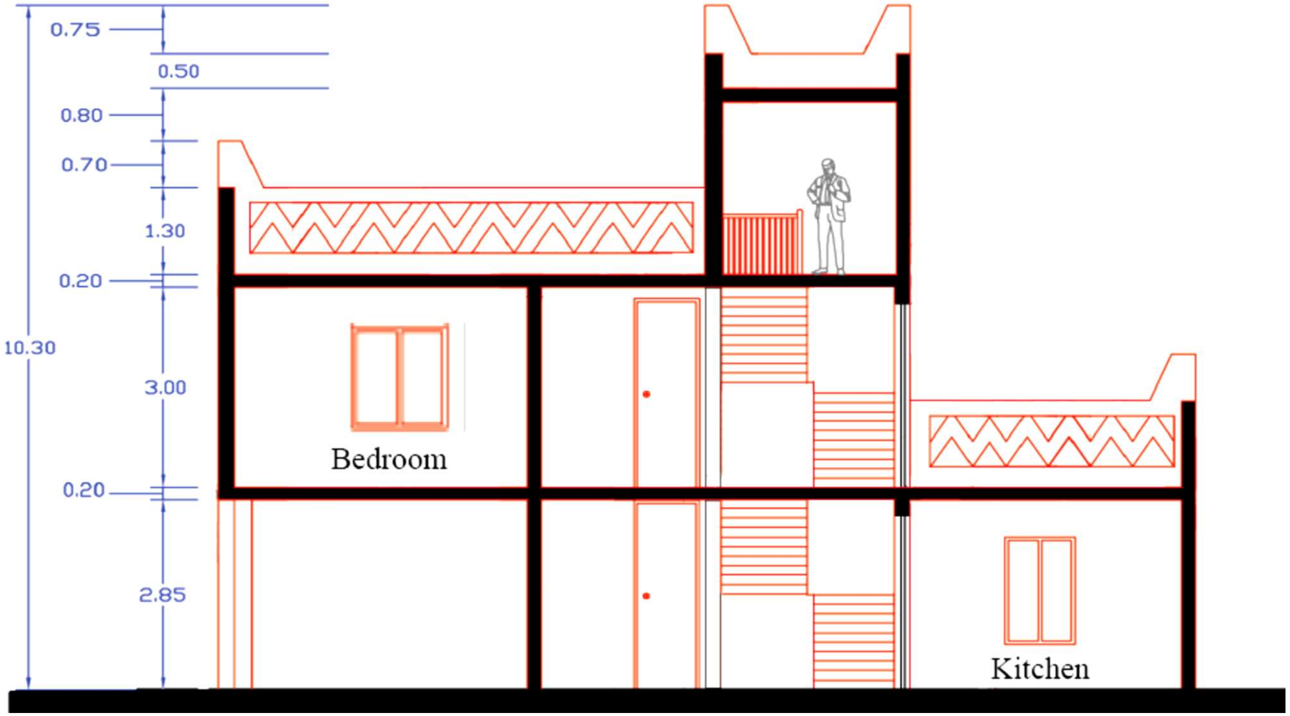


First Floor

Main Facade

Scale 1:100

Figure 4.28: Modern villa type / First floor & Main facade.



Scale 1:100

Figure 4.29: Modern villa type / Section A-A.

Figure 4.30: General view of the modern City. Image source from Google earth, (2014)

Figure 4.31: Modern houses types. Site photographs by the author, summer 2014

4.6 Conclusion.

Positively, in Ghadames, the rationale solutions which consider issues regarding the prevailing local microclimate highlighted the old town of Ghadames as a best example that shows the integration between the climate and the building design. They shaped and dominated the urban character with building forms to secure large comfortable zone that integrated the indoor with the outdoor for the residents' life. The vernacular houses are the key to many solutions that can be considered in the new buildings, so much so that these houses are an example of sustainable structure and materials produced with sensitivity to local climate.

The previous studies in Ghadames by Taki et al. (1999) and Ealiwa et al. (2001) as portrayed in Chapter 3, illustrate that, in the existing environment, old houses possess greater thermal comfort than new houses. However, the major lessons should be to consider the potential of the vernacular architecture such as the building envelopes which are the first line of defence from the harsh climate. Moreover, building envelopes can provide more than shelter and beauty, thus they can be an integral part of a building that responds to the weather by nurturing the occupants and the organizations within. At the same time they are part of an integrated design process which will identify the interaction of envelope choices with other building systems and the ultimate performance and comfort of the building in terms of natural ventilation.

However, according to Chojnacki, (2003), contemporary housing is poorly adjusted to the local conditions and also fails to meet the expectations of the dwellers, remaining in stark contrast to vernacular housing. Added to these factors are the poor adjustment of contemporary solutions to the conditions imposed by the natural environment and the inability to achieve proper microclimatic conditions without using products of advanced technology. This means the people who are living in the modern houses are suffering from the harsh desert climate. They can neither satisfy their poor environmental conditions in the long term nor can they think of the idea of going back and living in vernacular houses, which is impossible in view of the new requirements imposed by modern life.

However, the need actually, is not for the replacement of contemporary houses by vernacular houses or by imitating a copy of the vernacular sector in a new modern style. Nevertheless, the aim should be to employ the essential principles of traditional design such as use of thermal mass, enhancing natural ventilation to generate contemporary solutions that can meet urgently the housing requirement to avoid the total use of air conditioning to achieve comfort conditions. In Chapters 5, Fieldwork survey carried out the investigation of the existing climate conditions in Ghadames.

Chapter V

Fieldwork Survey

5.1 Overview

This fieldwork survey is based on objective study and subjective study where the data collection is serving the aim of this thesis. Therefore, the fieldwork survey divided into two parts: the first part is on-site measurements by using sensors monitoring the climate to use this acquisition data in the simulation analysis and the second part mainly consists of obtaining the data from the questionnaire survey to the case study and the interviews in order to use it in statistical and comparative analyses.

5.2 On-site Measurements of Microclimate of Ghadames

In this stage, two types of measurements were used. Firstly, meteorological stations were used to measure air temperature, humidity and wind speed simultaneously in Winter from 19^{th} to 23^{th} of January 2014 and in Summer 21^{th} to 26^{th} of June 2014. Secondly, at the same time, the monitoring of the indoor climate of residencies building to measure air temperature, humidity is carried out. All the weather data that is measured is applied in the simulation analysis to validate the results and to optimize the thermal performance design inside the residence buildings in Ghadames.

5.2.1 Existing Modern Housing Projects in Ghadames

According to the Ghadames housing report (2014) and the Libyan State report (1985), modern Ghadames has two major planning developments. The first development inside the city was in 1973 where 616 of housing units were constructed and the second recent development in 2007 where 1440 housing units are still under construction in suburbs of the City (The project was suspended as the Libya become unsafe country after the recent up-rising in 2011).

Referencing to separate interviews by the author in January and June 2014 with the Administration of Development of Ghadames, the overall comments on the previous housing construction and the recent housing construction do not meet the Ghadamesians' requirements, they described as imported projects sponsored by the Ministry of Housing in the capital City of Tripoli. Whereas the climatic solutions, the traditional treatments and the architecture style of Ghadames is a special one, different from those of other cities in Libya. Moreover, electricity interruptions as a result of civil war for long time the cause for inconveniences to the indoor environment in summer without using air-conditioning system.

In this study, the selection of the case study area representing the common construction dominated the general sense of modern Ghadamesian home. It also targeted the high population density zone in Ghadames. The analyses covered terraced houses for big families as a typical unit of public housing that has been sponsored by the Libyan Ministry of Housing in Ghadames between 1973–1980. This project considered six types of residential buildings where 40% are designed for the big families representing the high population density zone that has the largest portion in public housing, a total of 248 units from the overall 616 residential units.

5.2.2 Climate Measurement Methods

Firstly, constructing outdoor weather data is an essential requirement to run the simulation analysis stage to build a model of the actual indoor climate in order to understand and improve the climate of indoor environment. Therefore, the measurements and observations of the weather need to gather real weather data from the Libyan Meteorological Office as an official climatological observer or alternatively to run the Meteonorm software to get statistical weather data from the ten years of historical data (2000-2009). Unfortunately, the researcher could not manage to obtain the weather data from the Libyan Meteorological Office as the civil war was spreading everywhere around the capital City of Tripoli. Secondly, the Meteorological station in Ghadames Airport has been destroyed during the same civil war in Libya in 2011. In addition to this, the use of analogue station does not have a storage system for historical data. Thirdly, Meteonorm software gives an average of data of ten years which did not match the reality due to global warming. However, the researcher decided to install a small weather station to get real outdoor weather data. After searching online, the researcher found EasyWeather station, which is a simple weather station showing the general behaviour of the climate which, nevertheless can plot the results.

Lastly, monitoring indoor climate is necessary to evaluate the actual performance of natural ventilation of residential buildings and to validate the output simulation results to confirm the accuracy of the simulation outcome. HOBO data loggers for monitoring the indoor climate variables inside the houses and for measuring indoor thermal environment were taken on the first floor inside the master bedroom and on the ground floor inside the living room.

A. Outdoor Monitoring

The EasyWeather station version 6.2/2010 provides a full data of micro climates of Ghadames City and delivers an accurate climatological situation of local climate in the City. It collects the data time scale based on the set time interval between readings: this means an actual time stamp is assigned to each reading in the memory from the base station and can be downloaded onto the PC. In addition the weather monitoring system has multiple sensors. It displays and records of the weather data from internal as well as external sensors. Besides the internally measured values for indoor temperature, indoor humidity and air pressure, the outdoor sensors will take data for temperature and humidity, wind, rainfall and barometric pressure. The operating of these units is by wireless transmission to the Display Console. The following specifications provide information about the EasyWeather station efficiency (User Manual of EasyWeather, 2010).

Outdoor data:

Transmission distance in open field 100m (300feet)

Temperature range -40°C ~ +65°C (-40°F to +149°F) - Accuracy+/- 1°C

Measuring range relative humidity10%~99% - Accuracy +/- 5% 1%

Wind speed 0-160km/h (0~100mph) (show - if outside range) +/- 1m/s (wind speed < 10m/s) - Accuracy +/- 10 % (wind speed > 10m/s)

Measuring interval thermo-hygro sensor 48 sec

Indoor data:

Measuring interval pressure / temperature 48 sec

Indoor temperature range 0°C~50°C (32°F to +122°F) (show — if outside range) - Accuracy +/- 1

Measuring range relative humidity10%~99% - Accuracy +/- 5%

Measuring range air pressure - Accuracy 300-1100hpa (8.85-32.5inHg) - Accuracy +/- 3hpa under 700-1100hpa

B. Weather Station Setup

First of all, the setup area was in the new Ghadames City and the building was chosen as described at the beginning of this chapter. The weather station was assembled and verified to make sure that all of the components of the weather station were in working order, and then on the top of the roof of the building as the highest point, the weather station was installed as a first step (Figure 5.1). Secondly, the weather station was placed in the windiest location so that the higher point is far from any obstructions, such as buildings or trees which could significantly impact the location to get accurate measurements.

Figure 5.1 EasyWeather Station placed at the top of the selected building.

The field study was arranged to take place in two seasons; at the beginning of winter which is in January and at the beginning of summer which is in June. Moreover, there is an ongoing civil war which is a real fact on the Libyan ground that affected the choice of the dates selected as the issue of security was the main reason for arranging travel from Benghazi Airport to Tripoli, and then to Ghadames.

Basically, starting dates were arranged in Winter from 19th to 23th of January 2014 and in Summer 21th to 26th of June 2014. The outdoor data were logged at 30 minutes and the wireless LCD monitoring screen kept inside the measured house of this study to save the data and to be downloaded later to the computer through installation of the "EasyWeather" software.

However, the character of the vernacular City is different in planning and architecture as it is built in lowland area of Ghadames which is about 307 meter above sea level whereas the modern City was built in highland area in Ghadames which is about 351 meter above sea level. Moreover, the streets were covered to provide shading and breezy air around the buildings. They were surrounded by oasis and tall palm trees are as described in Chapter 4. Therefore, it was not possible to fix multiple weather stations in multiple locations to understand the micro climate around the buildings in the vernacular City. Instead, a single location has been selected which was a representative location in between buildings for supporting on-site monitoring and measurements to ensure that micro climate conditions of this site are recorded accurately in the vernacular City.

The area selected was the middle part of the City that has still residents living, i.e. some families especially in the summer season. A single HOBO logger was placed within a roofed street where there was a small gap in the wall as shown in Figure 5.2 to monitor the micro climate of the City and to compare the differences between the micro climate of the urban vernacular City and the urban modern City. Ideally, the HOBO sensor should be sited out in the open and away from objects that may affect measurement accuracy. However, the researcher was not able to put the HOBO sensor in a free place to avoid any significant heat transfer through the building envelope. Therefore, it was sited on the wall, the main reason the narrow passageway , the busy padestrian movement and the sitting arrangement places in both sides of the passageway.

Figure 5.2 HOBO placed inside the vernacular city as shown in the red circular.

C. Indoor Monitoring

The aim of the indoor site monitoring was to establish a database for the indoor air temperature and relative humidity levels in order to verify the building thermal performance and to evaluate the thermal condition of the indoor living. DesignBuilder thermal simulation software will then be used to produce thermal modelling and thermal analysis of the residential building as described in Chapter 7. The HOBO U10-003 is a two-channel Temperature/Relative Humidity Data Logger with 10-bit resolution and capacity for 52,000 measurements. The logger uses a direct USB interface for launching and data readout by a computer. The following specifications provide information about the HOBO U10-003 efficiency (Onset, 2012).

Specifications

Measurement range

Temperature: -20° to 70°C (-4° to 158°F)

RH: 25% to 95% RH

Accuracy

Temperature: ± 0.53°C from 0° to 50°C (± 0.95°F from 32° to 122°F)

RH: ± 3.5% from 25% to 85% over the range of 15° to 45°C (59° to 113°F)

Response time in airflow of 1 m/s (2.2 mph)

Temperature: 10 minutes, typical to 90%

RH: 6 minutes, typical to 90%

D. HOBO Setup

The HOBO data loggers covered indoor climate data for two seasons: cold winter from 19th to 23th of January 2014 and hot summer 21th to 26th of June 2014. The monitoring targeted two rooms for every 30 minutes, the bedroom in the first floor and the living room in the ground floor of the modern residential building, as well as the living room in the vernacular house. The software HOBOware pro Version 3.3 was used to connect the computer to the HOBO, loading manually indoor temperature and relative humidity from the logger and saving the data (Figure 5.3).

Figure 5.3 HOBO U10-003 data logger.

5.2.3 Climatic Conditions of Ghadames

The Ghadames climate classification is a BWh zone (Köppen−Geiger, 2006), which is specified as a hot dry climate of desert, characterized with little rain as described in Chapter 4. The field measurements in the urban climate using local weather station showed the character of the climate in winter and summer as two important seasons in Ghadames. In winter between 19/01/14 to 23/01/14, the Figure 5.4 has shown the maximum average of temperature as recorded where it reached about 20°C in day time and minimum average of low temperature of about 3.3°C at night time. The humidity average was between 55% ~19% increasing at night time and decreasing in the day time.

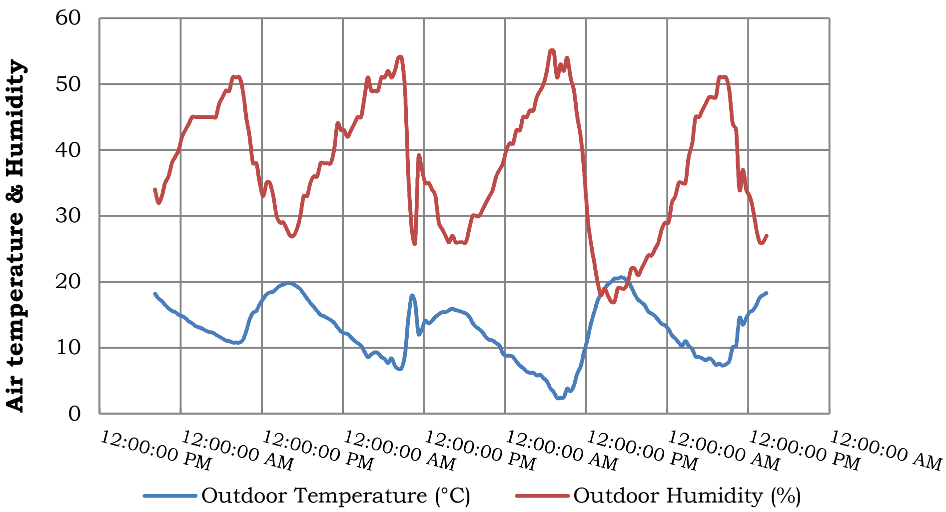


Figure 5.4 Winter outdoor monitoring recordings from 19/01/14 to 23/01/14.

In Summer between 21/06/14 to 26/06/14 as shown in Figure 5.5, the maximum average temperature recorded reached about 47°C in day time and the minimum average low temperature recorded was about 26°C at night time. The humidity average was low but increased slightly to 15% at night time and decreased to 11% in the day time. Overall, the temperature patterns recorded from the local weather station indicated that warm air temperatures in day time and cold air temperatures at night time in the Winter, whereas in Summer the air temperatures change quickly between very hot in day time and warm at night time.

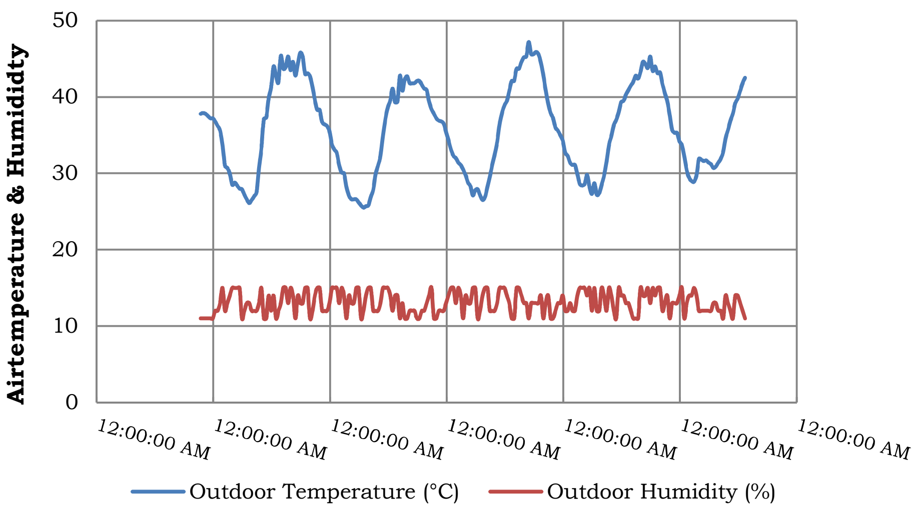


Figure 5.5 Summer outdoor monitoring recordings from 21/06/14 to 26/06/14.

Supportively, the author contacted the administration of Ghadames Airport Met Office in January 2014 to have weather data but the digital station was destroyed during civil war in 2011. Therefore it was impossible to have recorded weather data for that 24 hours. However, they offered a sample data that was recorded manually for 10 hours from 8:00 AM to 18:00 PM on the 22/01/2014 for one season only, which was used for comparison with local weather station forecasting.

Figure 5.6 shows the weather patterns and their rate of change between local urban climate and airport temperature which was located 20 kilometres away from the City of Ghadames, and generally, the flow of data has the same curve pattern with small variations. The general weather is often cooler at night time in the airport as it is located in an open area of desert with no shelters while the presence of the surroundings has urban mass shaped with weather factor and characteristic significantly affecting the climate in Ghadames City. Overall, the data from the local weather station provided good indication and the maximum difference showing 1.6°C with the airport weather station data as the characteristics of the two sites are dissimilar.

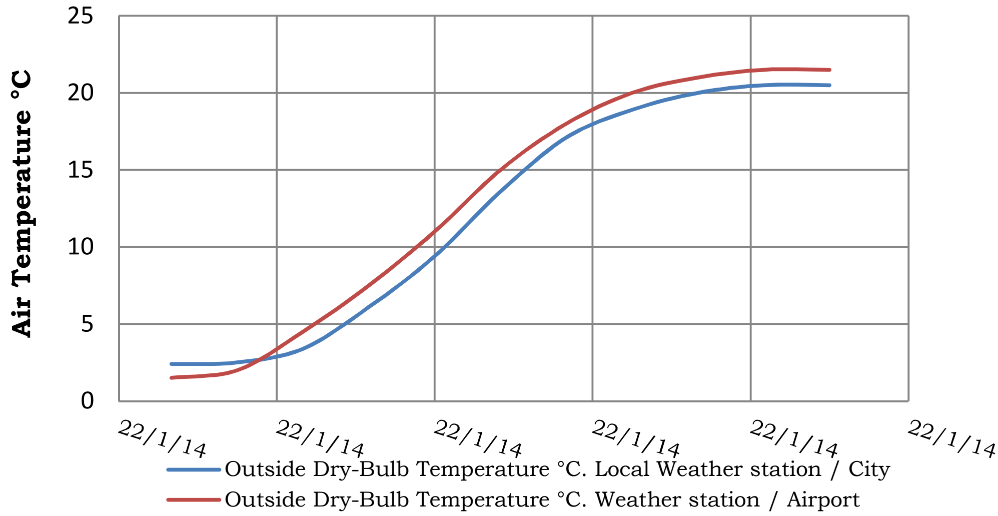


Figure 5.6 Comparison of the weather data between the Airport Station and the local weather station placed in Winter.

Linking with the vernacular City, in winter, urban climate of the vernacular City is showing the air temperatures as less than outdoor air temperature of the new modern City. The reason is that urban patterns are enclosed and the streets are covered which provide shading from direct and reflected sun radiation during the day, allowing the air to pass through the wells in the shaded pathways and causing low temperature as the outside temperature is lower. Therefore, the air temperatures ranged from 14.3 to 13°C whereas in the modern City, they ranged from 20.5°C to 2.4°C (Figure 5.7). Nevertheless, the variation of air temperature is less than 1°C in the vernacular City while the variation in the modern City is higher, i.e. about 18.1°C.

Similarly, during the summer, the air temperatures in the vernacular City ranged between 28°C to 33°C whereas the urban climate conditions under control as the characteristic of urban patterns are enclosed to indoor activities and movement. In the modern City, the air temperatures fluctuated among 25.8°C to 47°C (Figure 5.8), then again, the variation of air temperatures is about 5°C in the vernacular City whereas the variation in the modern City is higher, i.e. about 21.2°C.

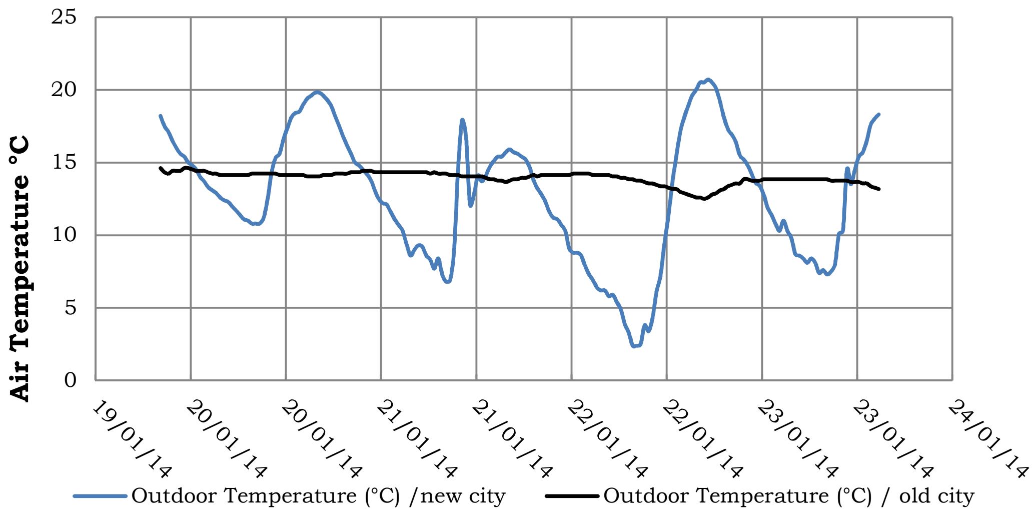


Figure 5.7 Comparison of outdoor air temperatures between urban climate of the modern and the vernacular Cities in Winter.

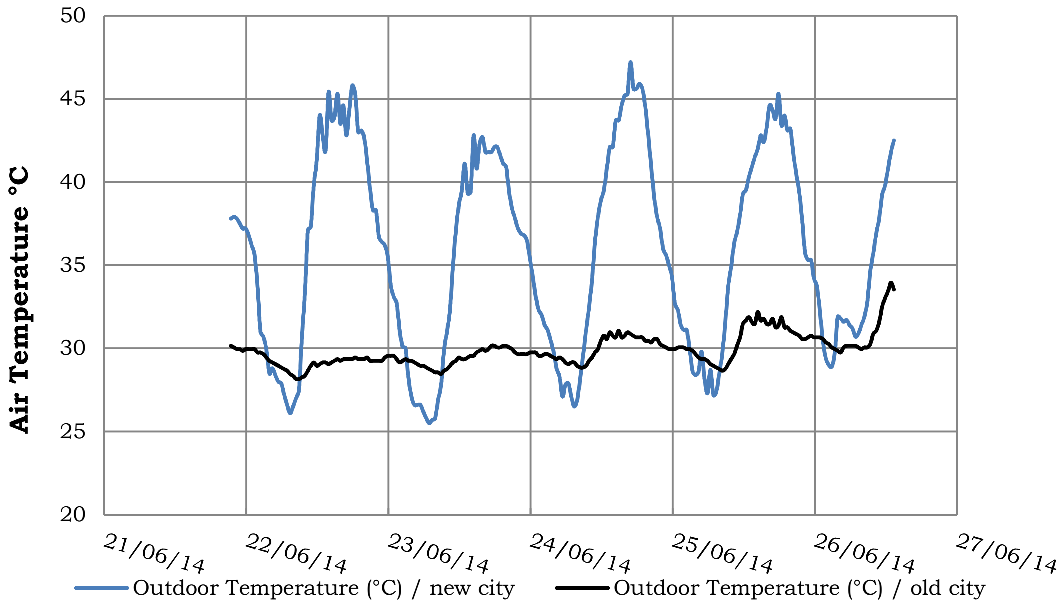


Figure 5.8 Comparison of outdoor air temperatures between urban climate of the modern and the vernacular Cities in Summer.

However, the air temperature in the vernacular city is a steady state, cooler in Winter while warmer in Summer but much cooler than the modern City as the City is shaded, protected from direct sun rays and other climate factors by roofed alleys. Therefore, for the sun rays to penetrate into the vernacular City was only just through the light wells, which is totally opposite for the modern City where the physical elements of the City can be divided into three categories: pathway networks, buildings and open spaces with no shelter form the most important climate factors.

5.2.4 Outdoor Weather Condition in the Simulation of Base Model

First of all, generated weather file before running the simulation of the terraced house is the first step, in DesignBuilder thermal simulation using EnergyPlus weather file (EPW). Therefore, the weather data file was partially synthesised by using an EnergyPlus Weather Converter after modifying the original weather file (EPW) of Ghadames using CSV excel file, and then entering a specific data that was collected from the local weather station. Relevant parameters of winter season from 19th to 23th of January 2014 and summer season from 21th to 26th of June 2014 were replaced with values obtained from monitoring recordings (dry bulb temperature, relative humidity, wind speed, wind direction and barometric pressure). After revising the CSV excel file with new weather data, EnergyPlus Weather Converter was used to change the CSV excel file to a new format (EPW) weather file based on information derived from the monitoring data.

Secondly, to make sure that weather file is running correctly and applying the measurement data in the DesignBuilder simulation, EPW file was imported into DesignBuilder weather file, after running the simulation in the same dates of monitoring, the results were quite stable in corresponding with actual monitoring data of the two seasons. Figure 5.9 and Figure 5.10 show the simulation performance of outdoor climate of base model in winter and summer periods where smaller performance gap can be noticed in coordination with the actual performance of weather data monitoring.

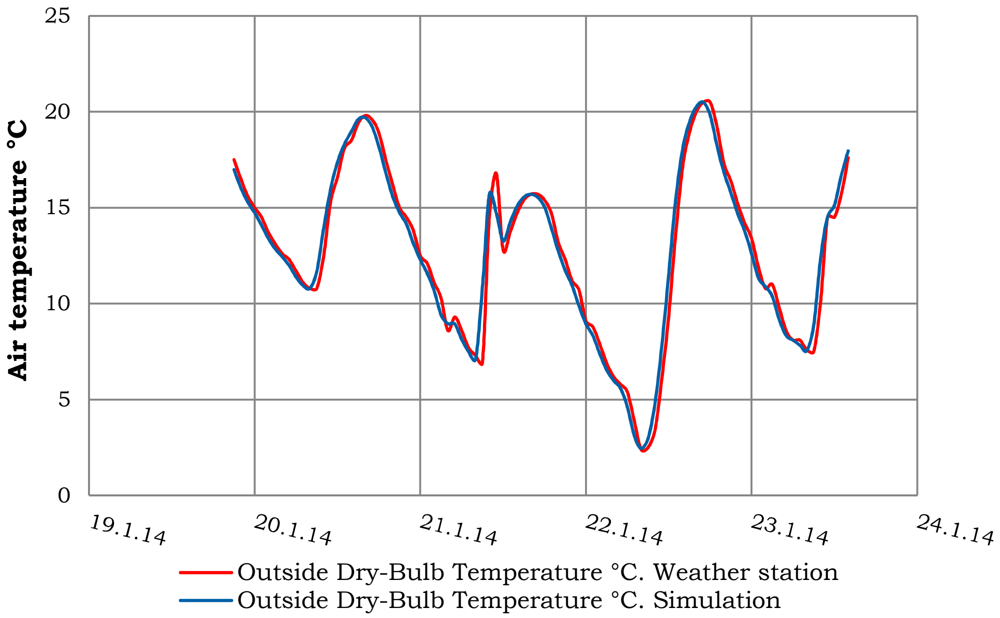


Figure 5.9: The relation between predicted outdoor temperatures from simulation and monitored in winter.

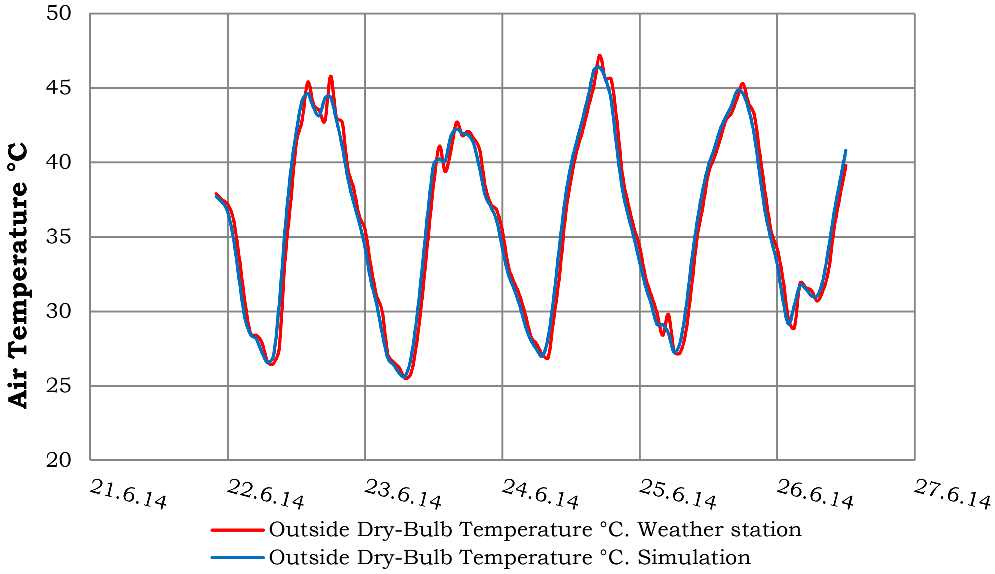


Figure 5.10: The relation between predicted outdoor temperatures from simulation and monitored in winter.

In order to assess how close the predicted site data (i.e. the monitored data) from DesignBuilder simulation, a root mean squared error (RMSE) is a frequently used to measure the differences between values predicted by a model and the values actually observed.

Fundamentally, RMSE represents the sample standard deviation of the differences between predicted valu 86 nd observed values as defined in the following equation (Bowler, 2008).

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(fi - vi)^2}$$

Where "N" is the number of data, "fi" is simulated and "vi" is actual

However, RMSE shows the differences of temperatures between the simulation predicted and the monitored during the period between 19th to 23th of January 2014 which was 0.83°C, then, the RMSE between the simulation and the monitored temperatures during the period between 21th to 26th of June 2014 was 1.01°C.

Undoubtedly, on this basis, simulation appears to be very accurate with a smaller performance gap and aligned to outdoor monitored data. However, another validation of the indoor simulation outcome to the base model with physical indoor monitoring of the case study will be explained in Chapter 6.

5.2.5 Conclusion

As a result, urban climate is affected by their physical built environment (urban geometries, materials and surfaces) because of the lack of vegetation and shading areas. While, indoor building effected from this sever condition as the housing design was not modelled in coherence with such climate. In this thesis, the passive cooling ability of the existing terraced houses would likely differ much under the influence of urban climate; therefore, further considerations will be given in the analysis in Chapter 7. The following point is considering the questionnaire-based surveys to obtain a general overview of thermal performance assessment in the residential building.

5.3 Questionnaire-based Survey

The field survey carried out using a questionnaire as a survey instrument. In order to achieve the objectives of the research, the questionnaire was translated into respondents' native language to facilitate the respondents' clear understanding of the questions and to encourage them to co-operate with the researcher in order to elicit the required information. The participants' information sheet and consent form were attached to the questionnaire explaining the purposes behind the survey and seeking respondents agreement. This is to encourage the respondents to fill out the questionnaire voluntarily. Moreover, highlighting the purposes of the research was enhancing respondents' acceptance and permission for the researcher to administer the questionnaire and to use the data under anonymised responses.

5.3.1 Purpose of the Questionnaire

Building occupiers are interested in what to look for and to ask about in new premises and strategies for operating and improving existing ones (Cohen et al, 2000). In this study, one of the main aim is to understand building occupiers interests in strategies for operating and improving existing ones to obtain a general overview of the residences thermal satisfaction and thermal preferences with various clothing values in cold winter period and hot summer season that are drastically changing in the coldest and hottest periods in the whole year. The improvement of thermal performance inside the houses will result in increasing the comfort and physical relaxing and good state of mind of the residents during the living and sleeping hours. Moreover, the questionnaire provides two types of data: firstly qualitative data to reveal the perception of the existing situation and describe aspects of difficulties that face the indoor residents living in such climate, and secondly, quantitative data by using numeric values in terms of quantity to precisely provide more in- depth information about the image of indoor life to reflect in simulation design analysis. However, the question of comfort has always been examined by tests with people in order to include subjective votes and to correlate them with measured climate parameters. While standards on thermal comfort were exclusively based on laboratory tests for a long time, the demand for field studies gradually arose (Gossauer and Wagner, 2007).

5.3.2 Target Survey Area

The field survey targeted contemporary buildings, i.e. modern (new city), and therefore, the survey planned to select a representative sample of people who experienced living in residential buildings that represent different locations in modern Ghadames, and typical types and sizes of buildings that are common in modern Ghadames (Figure 5.11). The selection covered a group totalling 350 inhabitants who live in the surveyed houses and with an average occupancy of 5.8 per person in a house.

Figure 5.11: Typical example of this type

The subject study adopts qualitative questions with quantitative questions in a form of a questionnaire-based survey on specific information to reveal the actual answers from different opinions about indoor building sufficiency. In order to evaluate indoor comfort condition and to enhance the thermal performance of the residential building, the questionnaire was circulated to 60 households in the Ghadames City, Libya in the Summer of 2014.

5.3.3 Structure of the Questionnaire

The questionnaire structure assists and encourages respondents to fill the questions in an interesting way with the sequence of the questions being self-evidently attractive to the respondents in a logical stream and groups. Questions on the same topic grouped in the same section, with regard to section ordering made as simple as possible and avoiding complexity, questions which were tested again and again beforehand.

However, the form of the questions was developed in a form of five-points to measure the respondents' attitudes. The first types of questions were to be answered by a 'Yes', or a 'No'; the second type is multiple-choice questions; the third type, there were a series of propositions; the fourth type is open-ended questions describing the current situation in a sentence or so. Lastly, the fifth type of questions were used to gather information about the construction type and percentages of opening doors and windows, number of people and occupancy hours in each room, and the best orientation. These data have been used as variables for thermal simulation input.

In general, the whole questionnaire included 58 questions which were structured into five main parts, and printed on four pages excluding the cover page (a copy of questionnaire is attached in appendix 1).

Part (1) is designed to provide general information about the respondents including: name, length of stay in the house, house type, location, number of family members and family age category.

Part (2) is designed to provide information about the housing including: the floors number, number of rooms, hours of occupancy in the building, number of bedrooms, users in each individual's room, sleeping hours and sleeping time, and occupancy hours in the living room.

Part (3) included information of building construction focusing on type of construction and building materials.

Part (4) is divided in two sections investigating the ventilation and thermal performance inside the house to understand the viewpoint that covered ventilation type and air conditioning system, quality of construction and building materials to recognize the level of influence of the possible issues that negatively affect indoor climate.

Part (5) is designed to gather information about the clothing types that are usually worn by the respondents for different seasons.

At the end, space for additional comments by the respondents have been added for their expression in all five parts in the questionnaire in order to obtain more information that may help to extend the depth of analysis and understanding the current issue of indoor thermal performance.

5.3.4 Questionnaire Administration

In order to start distributing the questionnaires in field survey, it was necessary to translate the questionnaire to respondents' native language; in this case from English version to Arabic version as the Arabic language is the native language of Ghadames' population. Translation from English to Arabic language was a main premise where two languages are fundamentally different in vocabulary, in structure, and in meanings, accordingly, after all translating the questionnaire will ask the same questions. Therefore, the translation to Arabic language began after the questionnaire has been designed and completed in wording which became clear and understandable and also have the same meaning for all the respondents. Generally, the translation was worded in simple unequivocal terms which have the same meaning for all members of the target population.

However, the questionnaires were managed via personal contact (face-to-face). The researcher personally issued questionnaires via handing them to the respondents together with three staff from administration of Development of Ghadames City. The researcher prepared a short session to the team who are involved in the project, before starting to hand the questionaires. While distributing the questionaires, general instructions were provided to the respondents. The description of the contents of the questionnaire and the purpose of the survey were also explained plainly. The distribution was organized by four people to minimize the effort required to give out this questionnaire and at the same time, the questionnaires were collected by the same people within a target time.

5.3.5 Coding of Questionnaires

Once the data collection was completed, the next task was the coding process for each question before inputting the data into the 'Statistical Package for Social Sciences' (SPSS). This stage was necessary because numerical values are needed representing answers for questions on the questionnaire for SPSS to analyse the data. The processing of the survey data into the computer started by entering all parameters of the questionnaire for variable view in the SPSS software where they were classified into the three main measure categories: nominal, ordinal and scale.

5.3.6 Methods of Analysis

Improving indoor environment is a big challenge. Therefore designing a building thermally acceptable is a significant issue whereas it is possible to expect an indoor thermal environment different from the outdoor.

The main focus of this study is to investigate thermal environment in residential buildings and to explore the potential reasons of discomfort in winter and summer. In order to predict and reflect the occupancy interpretations with regard to the indoor environment, the analysis has been carried out by using the SPSS software. However, most of the field survey questions were designed to be measured in three different types (58% nominal / 8% ordinal / 34% scale). Accordingly, the application of non-parametric techniques were applied for data that have non-numerical interpretation and regression method for numerical interpretation, both of which are adopted for analysing the collected data.

The results concentrated on multiple views such as predicted occupancy pattern in a graphical representation and also appraisals of seasonal effects as discussed below.

A. Descriptive Analysis

1. Family size

The survey showed the average of people who are living in the study area of Ghadames, categorized in three groups as shown in Figure 5.12. In total, small family household size is between two and four members that represented 31.50%, the majority of family household size is between five and eight members who represented 50% and large number of family household size is between nine and twelve members that represented 18.50%. The survey covered gender and age. Most of the subjects were between the ages of 20 to 50 years which accounted for 45% of the subjects. This is followed by those aged 51 to 65 years representing 27%. The next group is those between the ages of 6 months to 20 years at 18%. The least is represented by those over 65 years at 10%.

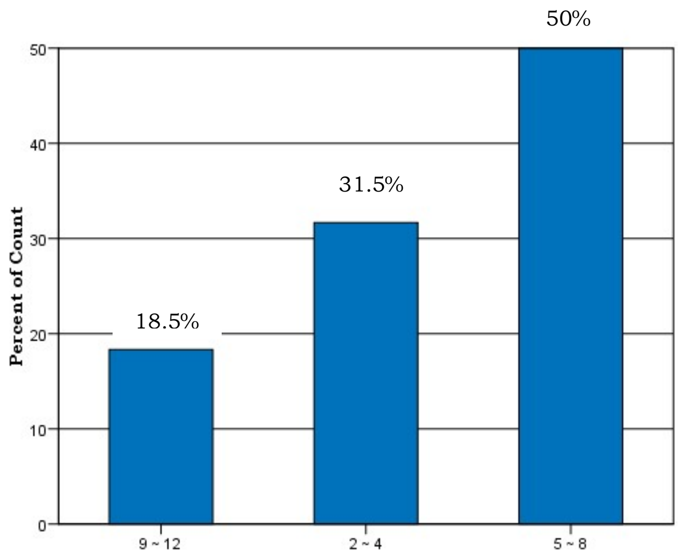


Figure 5.12: The average number of people who are living in the study area

2. Construction Materials

The questionnaire results showed that 100% of the physical building characteristics are made of the same construction method that is most common in modern Ghadames City. The reinforced concrete structural system is very prominent in Libya and in particular Ghadames. The structural skeleton is primarily made from reinforced concrete; basically consisting of vertical elements (columns, staircases and walls) and horizontal elements (beams and roof). Columns are vertical elements in a structural system and used to support reinforced concrete slabs; the roofs are made of flat reinforced concrete slab made by shuttering the area with wood; inserting steel reinforcing and then filling the area with poured concrete mix of cement, sand, aggregate and water. Wall materials constructed from hollow concrete blocks with standard mix of cement, sand and coarse aggregate; the size of the block used is 250 x 200 x 400 mm for external walls (see Figure 5.13) or 150 x 200 x 400 mm for internal walls.

Figure 5.13: Thickness of external wall

3. Thermal Environment

The main focus of this study is the thermal environment, which is a major part between the other indoor conditions. Therefore, thermal performance was investigated to analyse the reasons of discomfort in summer and winter in the selected houses. The findings are discussed and presented in the following.

a. Natural Ventilation.

In the morning (5:00 am – 9:00 a.m.), as shown in Figure 5.14, 40 percent of occupants are using natural ventilation for cooling while the whole night and morning (8:00 pm – 9:00 am) as a single period, the percentage of occupants using natural ventilation for cooling decreased gradually by reaching to 36.7 percent. However, using natural ventilation during the evening, night and morning (5:00 pm – 9:00 am) for cooling accumulated 16.7 of the total percentage of occupants whereas it started to drop steadily to 3.3 percent during the night-time (8:00 pm – 5:00 am) and also 3.3 percent during both the evening with night (5:00 pm – 5:00 am) as a single period.

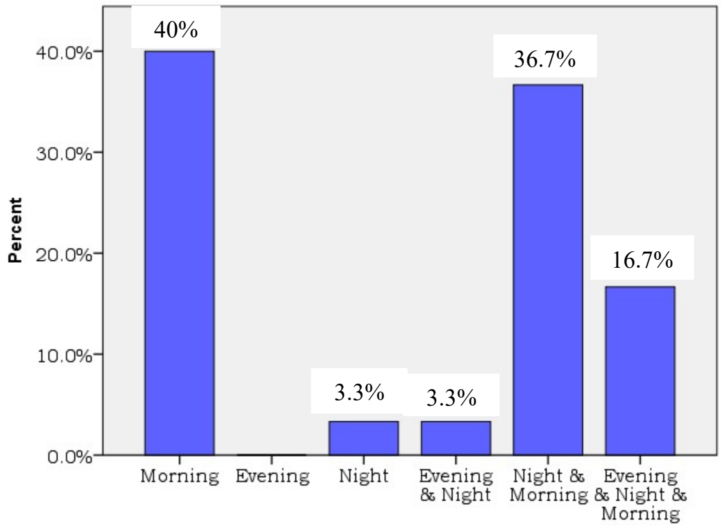


Figure 5.14 Favoured hours of using natural ventilation in summer.

b. Mechanical Cooling.

In summer where the outdoor temperature arising over 50°C, the use of air conditioning is inevitable where the building constructions are not resistance to outdoor climate. The pilot surveys by questionnaire in Figure 5.15 has shown that 46.7 percent of occupants are using air conditioning system where 45 percent of occupants are using mixed mode (air conditioning & electric fans). However, using electric fans plotted 8.3 percent as a lower percentage of occupants to circulate indoor air. Overall, respondents to the questionnaire are presenting various times in the usage of mechanical cooling. Accordingly, the Figure 5.16 is showing that 15 percent of occupants using mechanical cooling during the night period where this increased to 46.7 percent in the evening and night time as a single period. However, using mechanical cooling in the entire day by occupants represented 20 percent whereas in the evening this only represented 13.3 percent of using mechanical cooling. Interestingly, the percentage of using mechanical cooling almost decreased to 5 percent during the morning, meaning that only a small number of occupants use it.

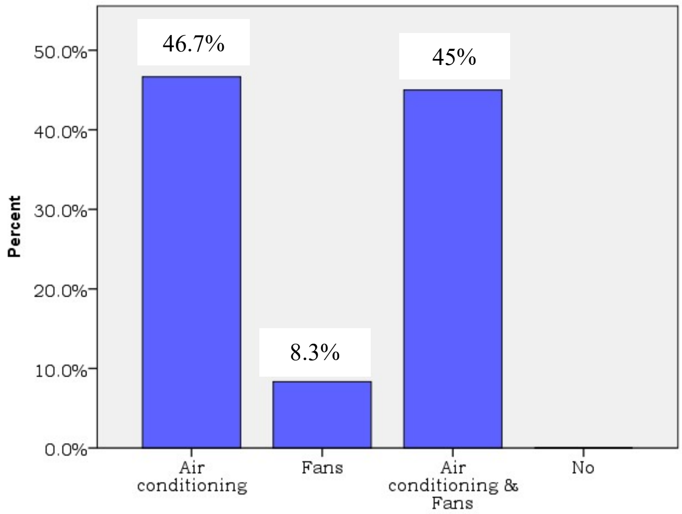


Figure 5.15: The type of mechanical cooling used in summer.

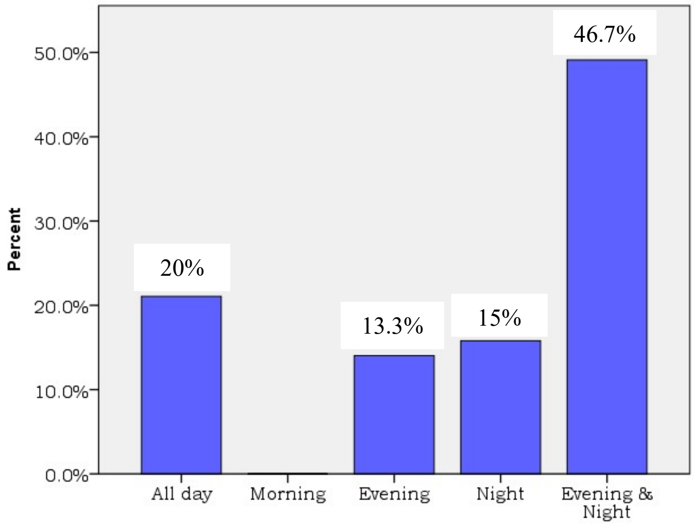


Figure 5.16 The time of use of mechanical cooling in summer.

5.3.7 Satisfaction with Indoor Thermal Conditions

Remarkably, the comforts vote predictions from the questionnaires in Figure 5.17 shows that the occupants have different assessments of indoor climate, especially when 100 percent of occupants supported the indoor climate by using mechanical cooling.

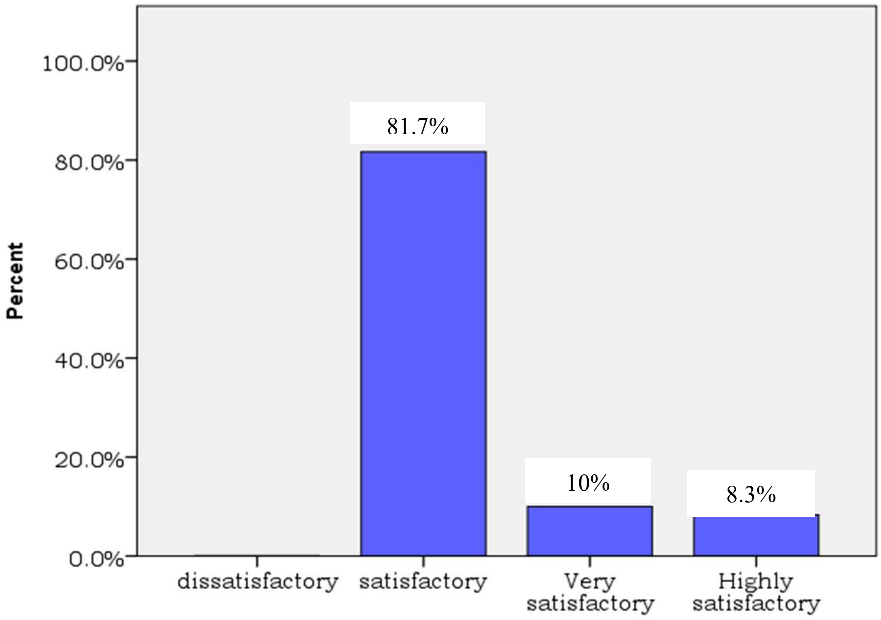


Figure 5.17: Indoor comfort assessment using mechanical ventilation in summer.

However, the result of the questionnaires showed that occupants are significantly more satisfied with their thermal environment in terms of using air conditioning. However satisfactory feeling regarding indoor comfort represented 81.7, as a high percentage from the occupants whereas very satisfactory feeling is showing 10 percent and highly satisfactory feeling is showing, 8.3 percent.

5.3.8 Residence Responses of Thermal Sensation

Based on the questionnaire, the study targeted two seasons, winter and summer whereas the thermal sensation of the occupants was designed to have an idea of the indoor air temperature that felt by the people who are living in the houses. According to ASHRAE Standard 55-2010 (Thermal Environmental Conditions for Human Occupancy), PMV (Predicted Mean

Value) scale is considered to measure peoples' thermal sensations. The scale is divided between two levels from -3 to +3 where +3 indicates hot, +2 warm, +1 slightly warm, 0 neutral and also -1 slightly cool, -2 cool and -3 cold. These seven points offered an evaluation of occupants' satisfaction and the thermal quality of indoor environment to investigate the reasons of discomfort both in winter and summer. The following results indicated that indoor thermal environment during winter and summer is not comfortable without the use of heating in winter and again mechanical cooling in summer.

1. Winter Comfort Vote

In modern Ghadames (new city), the field weather measurement by EasyWeather station during the period 19 Jan 2014 to 24 Jan 2014 is shown in Figure 5.18 where the outdoor temperatures in winter ranged between 2.4°C ~ 20.5°C.

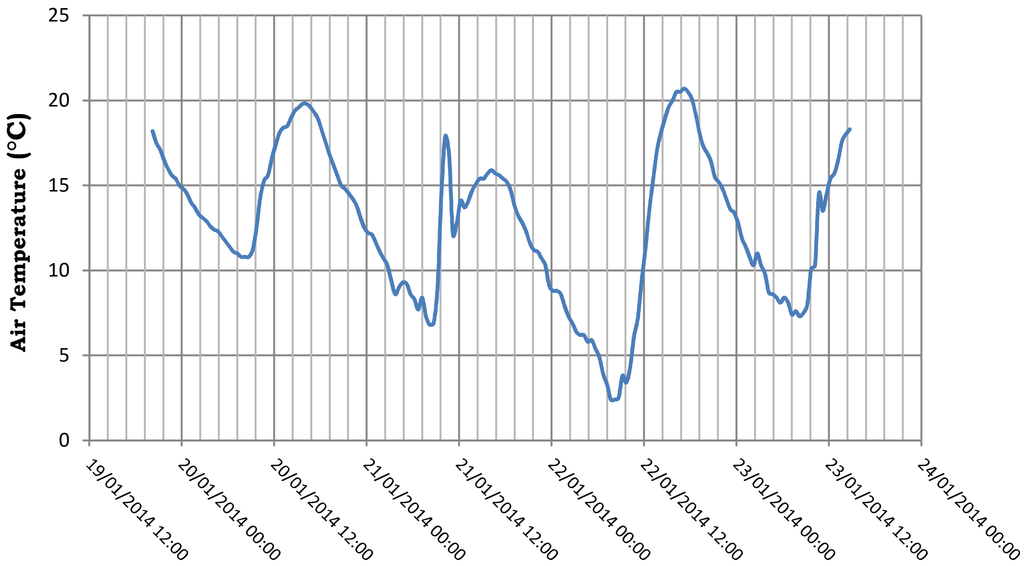


Figure 5.18 Outdoor filed measurements of air temperature in winter season in modern city.

These measurements indicate that the winter weather conditions in modern Ghadames slightly cold in day-time and cold in night-time, thus matching the character of the desert climate. The following assessment further explains the situation of comfort in each floor.

a. Ground floor

Figure 5.19 indicates that the level of the indoor temperature is between 16.9°C ~ 22.9°C in terms of using electric heating when the outdoor temperature is cold, especially in the night time. Therefore, Figure 5.20 shows the overall result of the thermal preference votes in terms of no electrical heating use: it can be seen that 65% of the occupants were feeling slightly cool while 35% were feeling cool during the winter season. However, the neutral levels are not achievable with indoor climate as the building envelope is not integrated with outdoor climate.

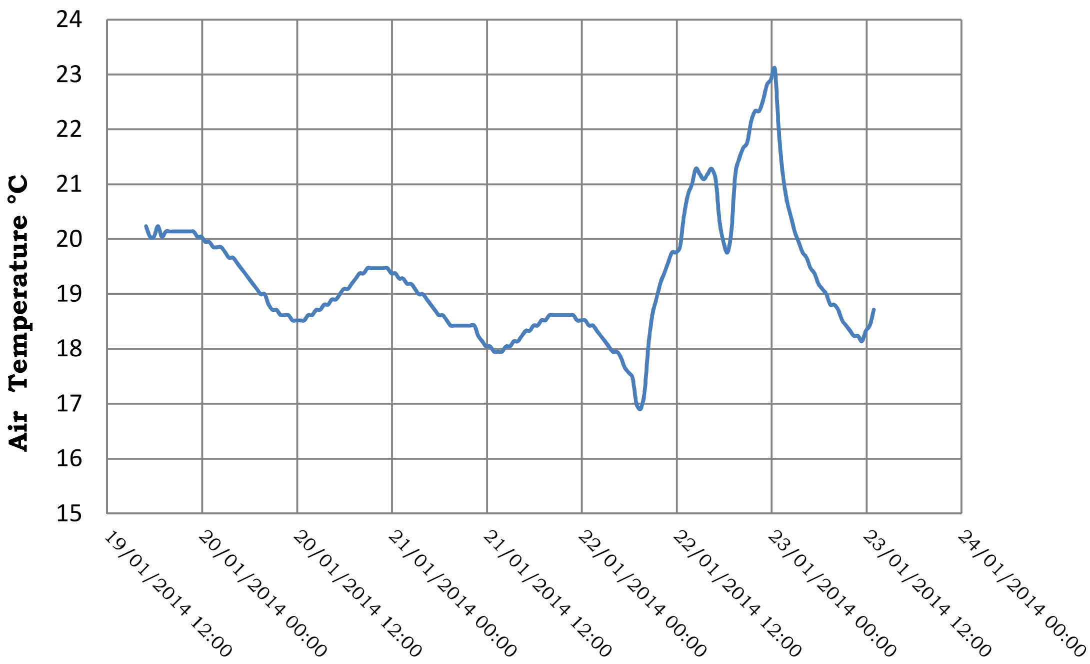


Figure 5.19 Indoor HOBO measurements of air temperature in setting room / ground floor.

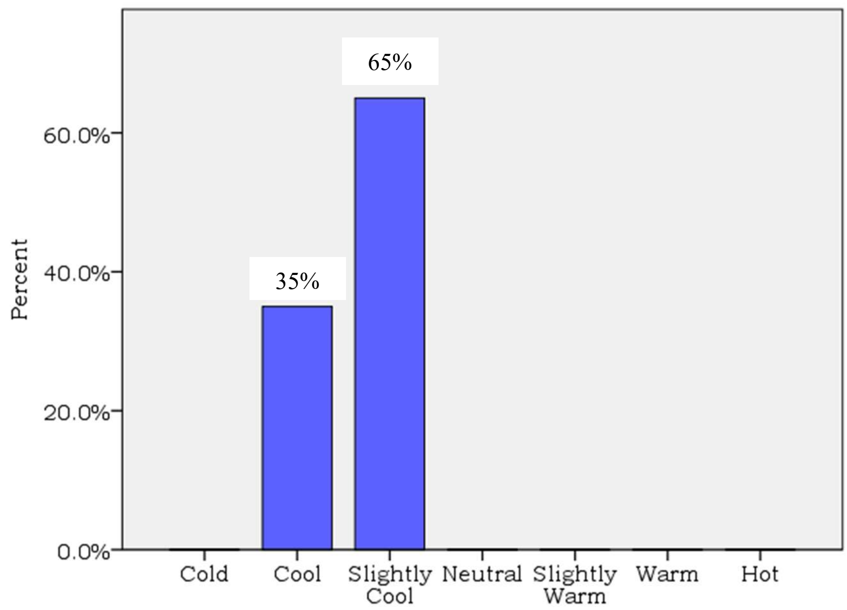


Figure 5.20 Histograms of sensation votes in ground floor (Jan 2014).

b. First floor

It is observed from Figure 5.21 that indoor temperatures in first floor ranged between 15.5°C ~ 21°C in terms of using electric heating. Accordingly, in terms of no electric heating, the result of thermal preference votes by occupants in Figure 5.22 demonstrate that 73% of occupants were feeling cool where 27% others were feeling slightly cool.

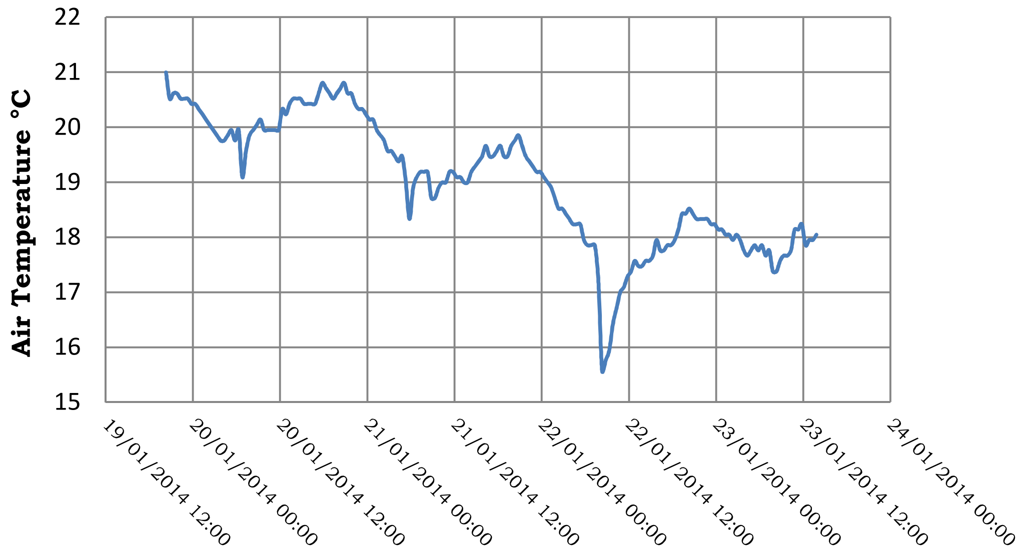


Figure 5.21 Indoor HOBO measurements of air temperature in bedroom / first floor.

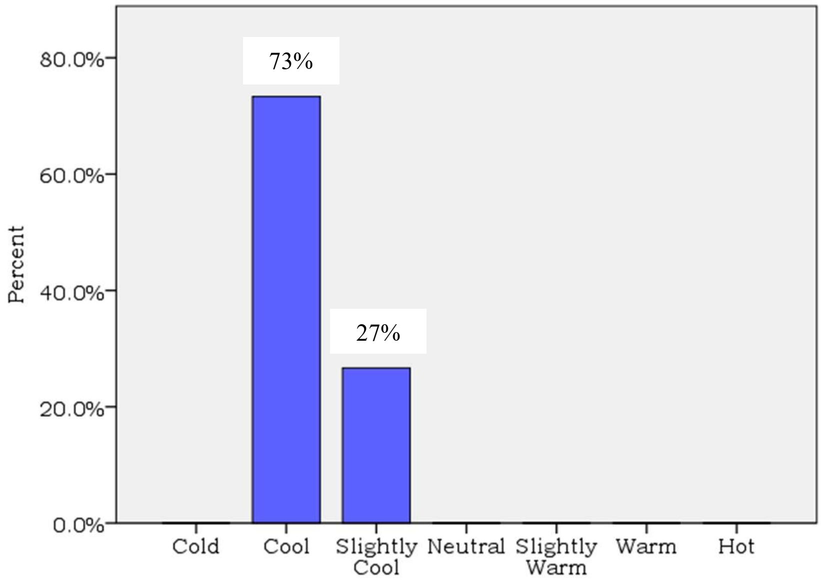


Figure 5.22 Histograms of sensation votes in first floor (Jan 2014).

2. Summer Comfort Vote

The field weather measurement by EasyWeather station during the period from 21 June 2014 to 26 June 2014 is shown in Figure 5.23 where the outdoor temperatures in summer ranged between 25.8°C to 47°C.

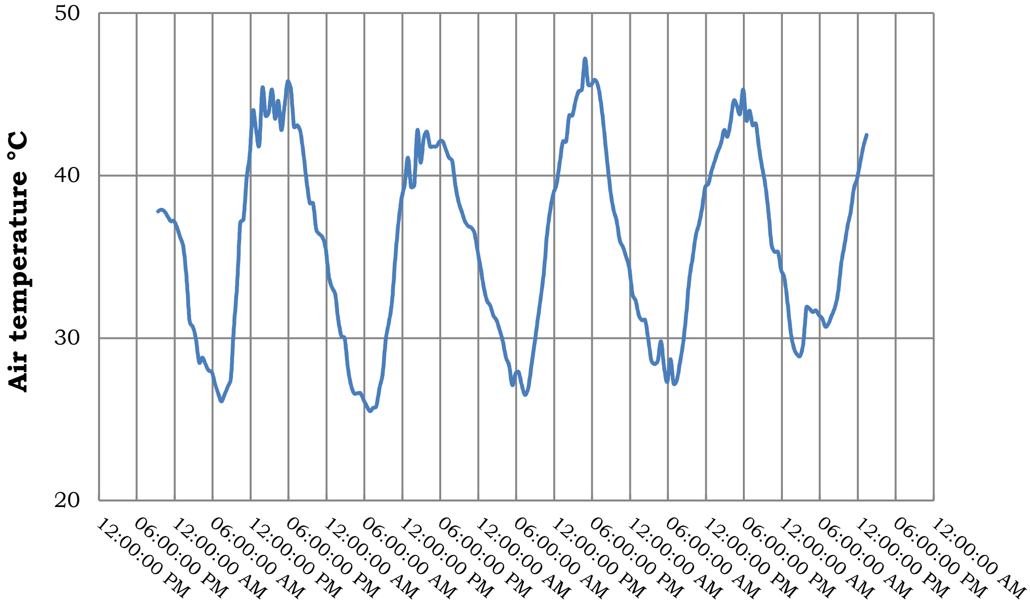


Figure 5.23 Outdoor field measurement of air temperature in summer season in modern city.

a. Ground floor

The indication of indoor temperature in Figure 5.24 fluctuating between 31.6°C ~ 36°C where the outdoor temperature was very hot, in terms of using natural ventilation. Figure 5.24 presents the effect of high outdoor temperatures in summer on occupants' thermal preference votes in terms of using natural ventilation. Figure 5.25 revealed that 38% of occupants were feeling slightly warm and 48.5% were feeling warm while 13.5% were feeling hot. However, the character of the building envelope design does not resist against heat gains effects the indoor environment which also becomes uncomfortable.

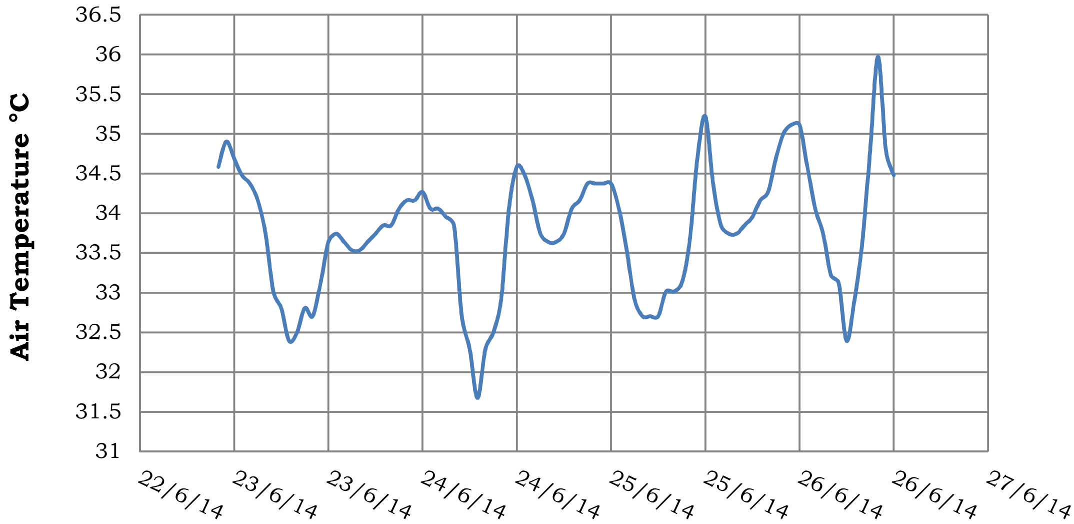


Figure 5.24 Indoor HOBO measurement of air temperature in setting room / ground floor.

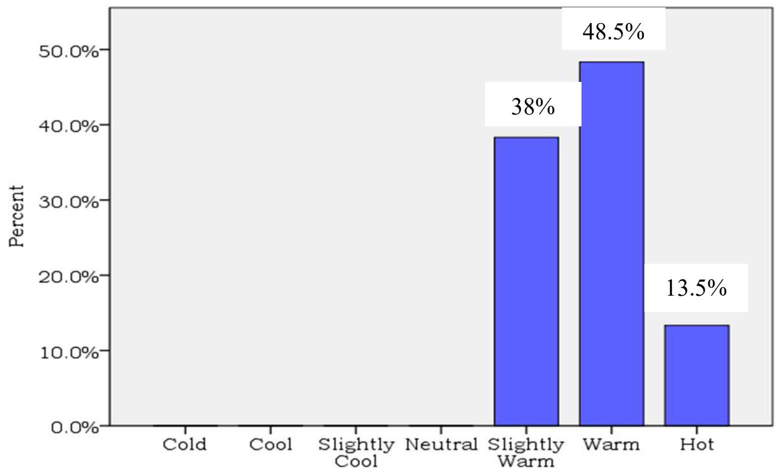


Figure 5.25 Histograms of sensation votes in ground floor (June 2014).

b. First floor

It is observed from Figure 5.26 that indoor temperature in first floor is ranged between 36.3°C ~ 40.6°C, especially during night time when the thermal mass releases the storage heat out. Figure 5.26 presents the effect of high outdoor temperatures in summer on occupants' thermal preference votes in terms of using natural ventilation. Figure 5.27 revealed that 41.7% of occupants were feeling warm while 58.3% were feeling hot.

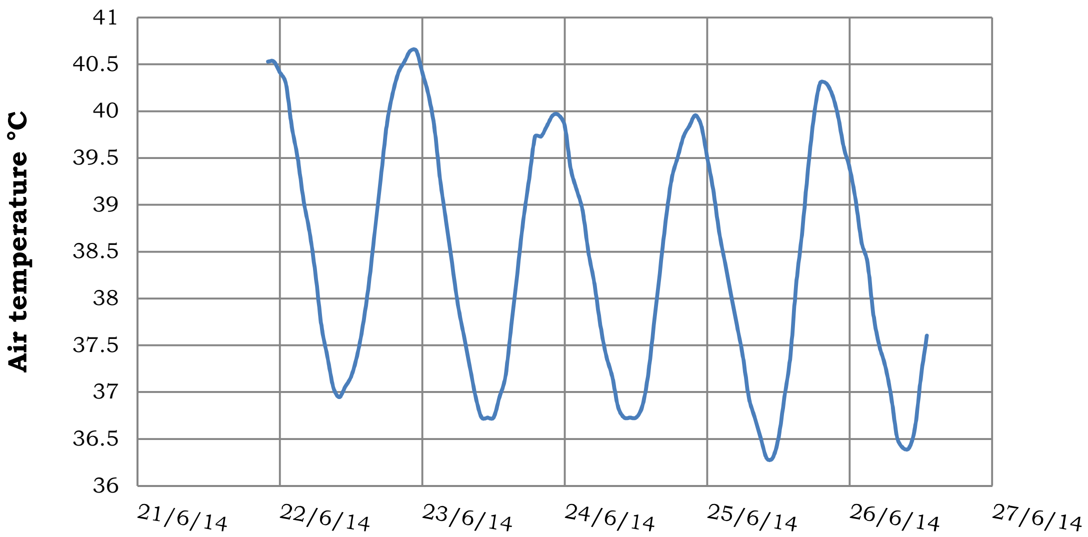


Figure 5.26 Indoor HOBO measurement of air temperature in bedroom / first floor.

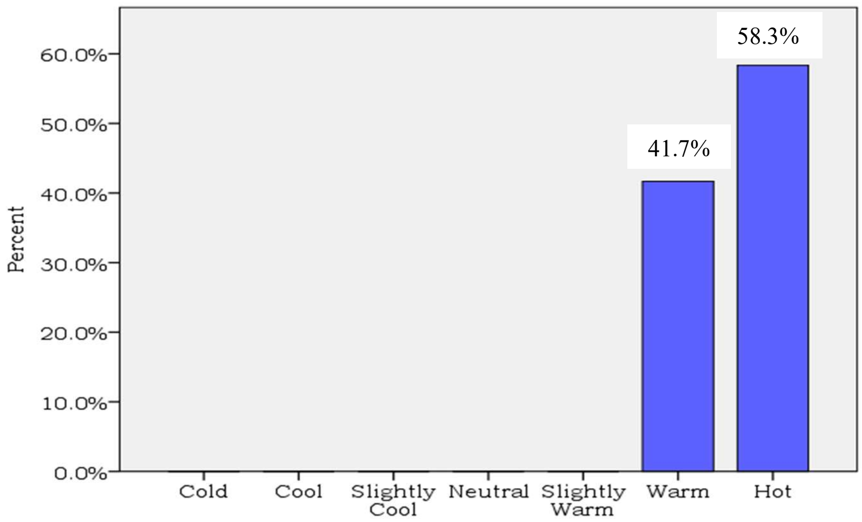


Figure 5.27 Histograms of sensation votes in first floor (June 2014).

However, the first floor gains too much of heat from the roof and walls, as the insulation and building thermal mass was not considered in envelope design. This floor becomes hotter than the ground floor according to occupants' impressions.

5.3.9 Conclusions

Overall, the impression by people who participated in the field survey stated that the residential building in the new City are not comfortable in the winter season when the outdoor temperatures are very cold and in summer when the outdoor temperatures are very hot. The living in the building cannot be comfortable without the use of electric heaters in winter and mechanical ventilation in summer. However 100% of occupants covered by the questionnaire survey agree that the vernacular bindings in the old City are more reliable and comfortable in all seasons of the year. On the other hand, dwellers in new City no longer live permanently in the old City and all the houses became unoccupied as they adapted the modern City and, keep their old houses in vernacular City as relaxing place and sign for their family's originality at Ghadames. As a result of that, the researcher could not be able to consider a full objective study and subjective study in the old City to have an actual prospective of the thermal performance.

By comparing the outdoor temperatures of the old City with the new City, a difference can be noticed in which the impact of urban area design in each city influences the local climate as described in Chapter 5. Overall, the temperatures in the old City have constant fluctuations while in the urban area, the design is carried out in such an organic way: all the streets are protected from sunray by the covering of light wells in order to provide natural lighting and ventilation and the city itself is protected by oasis from all directions. All these features help to provide low temperatures surrounding the buildings whenever the buildings can benefit from low temperatures, beside the good character of the building envelope design that is made from local materials. However, the range of temperatures in the new and modern City of Ghadames has large fluctuations between day and night in winter and summer whereas the urban area in the new City is designed in such a modern way that it neglected the character of desert climate such as is in the design of the old City. Additionally there are wide streets and different types of buildings with less green areas form the character of the new City of Ghadames. The following chapter will consider the introduction to thermal simulation assessment.

Chapter VI

Building Simulation, Calibration and Validation

6.1 Introduction

In recent times, *"Computer simulation is more pervasive today..."* where *"...Engineering and Science involves the use of computer modelling simulation to solve mathematical formulations of physical models of engineered and natural systems",* which become *"...tools for building performance evaluation* (Glotzer et al. 2009 and Augenbroe et al. 2004).

According to the definition by Oden et al. (2006), Simulation *"... refers to the application of computational models to the study and prediction of physical events or the behaviour of engineered systems."* However, advances in computer simulation offer rich possibilities that are essential to ensure the building can satisfy the needs of residents.

In principles of simulation, Oden et al. (2006) portrayed that the state of simulation as built in *"Advances in mathematical modelling, in computational algorithms, and the speed of computers and in the science and technology of data-intensive computing* have increased the ... *productivity* of quality design and become vital in predictive of building behaviour to achieve the optimum performance as proposed by their designers. Moreover, "... *unprecedented improvements* in building design have brought ... *the field of computer simulation to the threshold of a new era".*

In a large simulation exercise, the progress in technology has allowed simulation to become more extensively available, with building energy simulation tools such as DesignBuilder, Airpak, ESP-r, ECOTECT, TAS, EnergyPlus and ApacheSim that are now widely used. These programs have a wide range of capabilities and can help designers compare various design options and lead them to more optimal and energy saving designs, as well as helping engineers define the energy saving potentials and evaluate the energy saving effects. However, the verification of any simulation model is necessary and important to give confidence in the accuracy and the reliability of software.

In order to get a better architectural design, it is essential to consider all environmental factors that affect the performance of the building. On the other hand, building energy simulation has offered a greater support in building design, operation, analysis, commissioning and assessment of buildings in the last two decades.

Generally speaking, the using of building simulation in hot dry climate is important to recognize how much heat is gained from the various components of the building envelope (walls, roof, and fenestrations). On top of that, how natural ventilation can reduce heating loads from building envelope or the internal gains? And also, is the top floor more comfortable than the ground?. However, in the simulation, the outcome results need several parameters pertaining to the building design and usage to be identify in the improvement of the thermal performance along with recommendations for energy conservation measures.

6.2 Building Design and Simulation Environment.

Traditionally, the building design process can be seen as a dynamic process of generating ideas that involve specific strategies and technologies and then estimating and evaluating their performance with respect to the various performance considerations within the specific design context (Hien et al. 2003).

At the moment , the simulation environment has been used extensively in a large number of projects in conjunction with architects and engineering organisations to provide insight to sustainability in the designs throughout all stages of the design process (Tang and Kim, 2004).

Tang and Kim (2004) described the building simulation environment as a "*…technology that can be used to answer the type of 'what if' questions that clients, design teams and users that have always wanted answered. It is able to provide integrated information on the performance of the design to enable the design team to actually 'see' and 'feel' the building before it being built"*. However, "*…the capabilities of the building simulation* *program will lead to a completely new building design philosophy and methodology..."* (Majali et al. 2005).

In benefit of dynamic building simulation tools, Hensen et al. (2004) and Pfluger, (2005) stated that *"...building concepts relies more and more on the results of the computer-aided simulation for the thermal behaviour of buildings ..."* as well as the "... *simulation is much more effective when used for comparing the predicted performance of design alternatives, rather than when used to predict the performance of a single design solution in absolute sense"*. However, producing indicative results provide general directions for the architect, whereas simulation tools have evolved in terms of their details and applicability, which assist to consider various domain analysis and calculations to represent the behaviour of buildings and thereby to produce better designs (as can be seen in Figure 6.1).

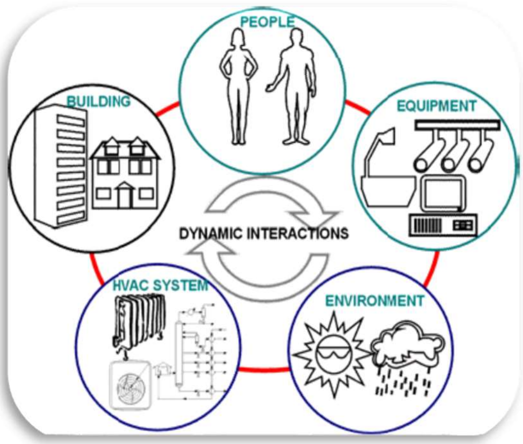


Figure 6.1: Dynamic interacting sub-systems in a building context (Hensen, et al. 2004)

In addition, the purpose is to make it easier to consider different performance aspects (comfort & energy) at different levels of resolution in terms of time and space (region, town, district, building, room, construction element) (Hensen et al. 2004).

In support of capability of simulation environment, Augenbroe and Hensen, (2004) stated that the *"...deal with the resulting complexity of* *scale and diversity of component interactions has gained building simulation a uniquely recognized role in the prediction, assessment and verification of building performance."* However, this results not only in a responsible attitude towards energy but also on how successful the designer has been applying the technology and the energy analysis tools during the design process (Hui, 1998).

Definitely, building simulation is an *"...approach to allow a designer to better understand the interrelation between design and performance parameter"* to predict the energy performance of a given building and thermal comfort for its occupants (Clarke and Maver, 1991). However, understanding of how given buildings operate according to certain criteria and enabling comparisons of different design alternatives that *"... identify potential problem areas, and so implement and test appropriate design modifications"* (Maile et al. 2007 and Clarke and Maver, 1991).

Altogether, the simulation environment represented *"...the importance of a well conceived problem abstraction"* and "*...appraise options for change in terms of relevant issues such as human health and comfort, energy demand reduction and sustainable practices"* (Clarke, 2001).

6.3 Evaluating the Capability of Building Simulation.

In the earlier stages of a design process, building energy simulation programmes are tools which can be used to predict and to optimize energy performance and comfort in buildings. From the Loutzenhiser et al.'s (2007) point of view, evaluating the capability of building energy simulation programmes is an important component in the development and modification of models and algorithms implemented in the software; successful application of a programme requires careful and thorough validations. Nevertheless, integrated simulation offers building designers a range of new analysis possibilities, applying hypotheses for correctly selecting simulation which can help to produce accurate models for precise simulations of the interactions between a building and outdoor climate.

In a framework review of the characteristics of different simulations software, Crawley et al. (2005) produced a report that provides a simple method for the evaluation and comparison of the features and capabilities of twenty major building energy simulation programmes including BLAST, BSim, DeST, DOE-2.1E, ECOTECT, Ener-Win, Energy Express, Energy-10, EnergyPlus, eQUEST, ESP-r, IDA ICE, IES <VE>, HAP, HEED, PowerDomus, SUNREL, TAS, TRACE and TRNSYS. However, Crawley et al attempts are based on information that is provided by the program developers in the following categories: general modelling features, zone loads, building envelope, day-lighting and solar, infiltration, ventilation and multi-zone airflow.

In the survey Table 6.1, Crawley et al. pinpoints EnergyPlus as a high capability, according to the summary by Crawley et al. (2001) EnergyPlus is a new building energy simulation programme that builds on the strengths of BLAST and DOE-2. It is being written in Fortran 90 with structured, modular code that is easy to maintain, update, and extend. Still, EnergyPlus, not only combines the best features of the BLAST and DOE-2 programmes, but also represents a significant step forward in terms of computational techniques and program structures. Connectivity and extensibility are overriding objectives in the design and development process (Crawley et al. 2001).

Technically, according to Crawley et al. (2001), EnergyPlus consists of three basic components: a simulation manager, a heat and mass balance simulation module and a building systems simulation module, as shown in Figure 6.2. The Building Loads Analysis and System Thermodynamics BLAST form a system of aggregation program to predict energy consumption and energy system performance and cost in buildings. So, BLAST's heat balance method is based on actual thermodynamic equations and produces better results than its counterpart in DOE-2.

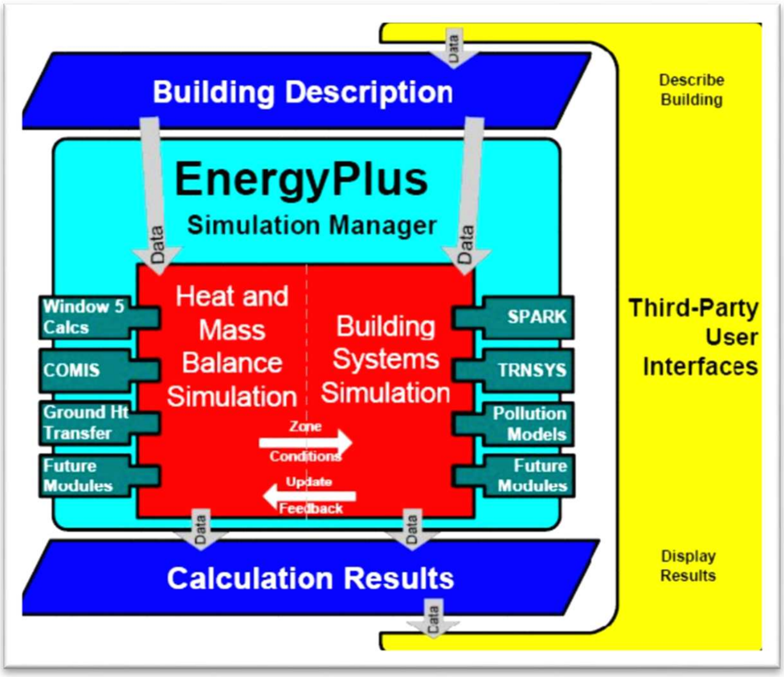


Figure 6.2: Overall EnergyPlus structure. Crawley et al. (2001)

EnergyPlus includes links to the multi-zone air flow engine COMIS and SPARK. COMIS is a nodal air flow and containment distribution engine that enables the integration of air flow in EnergyPlus simulation as occurring in naturally ventilated buildings. SPARK allows the user to build simulation models of complex physical processes by connecting equation-based calculation modules from an object library. Its link to EnergyPlus enables the creation of user defined HVAC components based on SPARK's object library.

Lastly, EnergyPlus is based on ASHRAE standard that is reliable for the hot climate and has documentation that is experienced in hot climate for many decades, as well as a number of developments that have been made to improve its performance.

Table 6.1: Contrasting the capabilities of building energy performance simulation programs (Crawley et al**.** 2005)

Zone Loads	BLAST	GBSim	DeST	DOE-2.1E	ECOTECT	Ener-Win	Energy Express	Energy-10	EnergyPlus	eQUEST	ESP-r	IDAICE	IES<VE>	HAP	HEED	PowerDomus	SUNREL	Tas	TRACE	TRNSYS
Interior surface convection ■ Dependent on temperature	X	X					p		X		X	X	X		X	X	X	X		X
■ Dependent on air flow	X						X		p		X		X		X			X		E
■ Dependent on surface heat coefficient from CFD									E		E		X							
■ User-defined coefficients (constants, equations or correlations)		X	X	X	X				X		E	R	X		X	X	X	X		X
Internal thermal mass	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X
Automatic design day calculations for sizing ■ Dry bulb temperature	X	X	X	X	X	X	X	X	X	X		X	X	X	X	p		X	X	
■ Dew point temperature or relative humidity			X	X		X	X		X	X		X	X	X				X	X	
■ User-specified minimum and maximum			X	X			X		X	X		X	X	X	X			X	X	X
■ User-specified steady-state, steady-periodic or fully dynamic design conditions			X			X						X	X	X				X	X	

Building Envelope, Day- lighting and Solar	BLAST	GBSim	DeST	DOE-2.1E	ECOTECT	Ener-Win	Energy Express	Energy-10	EnergyPlus	eQUEST	ESP-r	IDAICE	IES<VE>	HAP	HEED	PowerDomus	SUNREL	Tas	TRACE	TRNSYS
Outside surface convection algorithm ■ BLAST/TARP	X								X											
■ DOE-2				X					X	X	X								X	
■ MoWiTT	X					X		X	X				X		X				X	
■ ASHRAE simple			X						X		X	X	X			X		X	X	X
■ Ito, Kimura, and Oka correlation									X		X	X						X	X	
■ User-selectable																				
Inside radiation view factors		X	X						X		X	X	X				p	X		
Radiation-to-air component separate from detailed convection (exterior)		X	X						X	X	X	X	X				X	X	p	X

X (has capability) / **P** (partially implemented) / **O** (optional) / **R** (research use) / **E** (expert use) / **I** (difficult to obtain input data).

Solar gain and day- lighting calculations account for inter-reflections from external building components and other buildings		p			X				X		X		X			p				X

Infiltration, Ventilation, Room Air and Multi-zone Airflow	BLAST	GBSim	DeST	DOE-2.1E	ECOTECT	Ener-Win	Energy Express	Energy-10	EnergyPlus	eQUEST	ESP-r	IDAICE	IES<VE>	HAP	HEED	PowerDomu s	SUNREL	Tas	TRACE	TRNSYS
Single zone infiltration	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Automatic calculation of wind pressure coefficients		X	P						p				X				X	X		
Natural ventilation		X	P						X	P	X	X	X			X	X	X		O
Multi-zone airflow (via pressure network model)		X	P						X		X	X	X				X	X		O
Hybrid natural and mechanical ventilation		X	P			X					I	X	X			X		X		O
Control window opening based on zone or external conditions			X			X			X		X		X			p	X			O
Displacement ventilation									X		X	X	X					X		O
Mix of flow networks and CFD domains			X								E									
Contaminants, mycotoxins (mold growth)		p									R					p				

X (has capability) / **P** (partially implemented) / **O** (optional) / **R** (research use) / **E** (expert use) / **I** (difficult to obtain input data).

In the context of this research, Table 6.2 is built to show a range of available software tools for analysing thermal performance. Through the review of the tools that are described in Table 6.2, it can be observed that DesignBuilder tool has been specifically developed around EnergyPlus allowing all of the EnergyPlus fabric and glazing data to be inputted. Databases of building materials, constructions, window panes, window gas, glazing units and blinds are provided.

In reference to DesignBuilder simulation, the basic concept of sequential simulation is to facilitate the analysis of this research provided by DesignBuilder Documentation (2011) as significant parameters:

Functionality: The multi-zones approach to modelling allows flexibility in both the types of system that can be modelled and the level of detail. The modeller can describe a building and its systems abstractly and then add more detailed zone descriptions as required. For example, the most basic energy simulation would involve only one domain in a model e.g. the geometry and fabric of the building. If more functionality were required, the model could be augmented with air flow, CFD and HVAC.

Separation of engine and interface: DesignBuilder interface allows simulation engine to work in mainstream of allowed input-output data without the need for request redesign of the models. Hence, while the model can be constructed from many different and diverse zones, the zones of the building model are connected together and they form a consistent mathematical description of the building.

Integrated simulation: DesignBuilder performs a comprehensive simulation. A typical model of a building consists of a number of coupled polyhedral zones that describe the geometry and fabric of the building envelope. Augmenting these zones are a series of networks, each of which describes an individual zone: heating, air conditioning plant and air flow.

Table 6.2: Building simulation software

Program	Source	Capabilities	Comments
eQUEST	**www.doe2.com/equest**	Performs an hourly simulation of the building based on walls, windows, glass, people, plug loads, and ventilation. DOE-2.2 also simulates the performance of fans, pumps, chillers, boilers and other energy-consuming devices.	The building creation wizard walks a user through the process of creating a building model within eQUEST, DOE-2.2
TRNSYS	**http://apps1.eere.energy.gov/buildings/tools_directory/software.cfm/ID=58/pagename=alpha_list**	Analysis and sizing HVAC, Multi-zone airflow analyses, electric power simulation, solar design, building thermal performance, analysis of control schemes, differing levels of complexity, extensive documentation on component routines, including explanation, background.	Useful for research applications and industry cases where a new or innovative system model is required.
EnergyPlus	**http://apps1.eere.energy.gov/buildings/tools_directory/software.cfm/ID=287/pagename=alpha_list**	EnergyPlus engine that is based on DOE-2, BLAST, and COMIS software. Time-steps less than an hour, modular systems and plant integrated with heat balance-based zone simulation, multi-zone air flow, thermal comfort, water use, natural ventilation, and photovoltaic systems.	EnergyPlus is a complicated program in which to develop or adjust building models.
ECOTECT	**http://apps1.eere.energy.gov/buildings/tools_directory/software.cfm/ID=391/pagename_menu=pc/contacts_landing.cfm**	Thermal energy, lighting, shading, acoustics, Tools for climatic analysis.	Real-time animation features are provided along with interactive acoustic and solar ray tracing that updates in real time with changes to building geometry and material properties.
TAS	**http://www.edsl.net/main/**	Dynamic thermal performance of buildings and their systems, accessing environmental performance, conducting a natural ventilation analysis	
ESP-r	**http://www.esru.strath.ac.uk/Programs/ESP-r.htm**	An integrated energy modelling tool for the simulation of the thermal, visual and acoustic performance of buildings and the energy use and gaseous emissions associated with associated environmental control systems.	Useful for research applications where high degree of accuracy is required
Energy-10	**http://www.nrel.gov/buildings/energy10.html**	whole-building analysis, evaluating the energy and cost savings that can be achieved by applying energy-efficient strategies such as day lighting, passive solar heating, and high-performance windows and lighting systems, Natural Ventilation	The simulation software is suitable for examining small commercial and residential buildings that are characterized by one or two thermal zones.
DesignBuilder	**http://apps1.eere.energy.gov/buildings/tools_directory/software.cfm/ID=486/pagename_menu=united_kingdom/contacts_landing.cfm**	EnergyPlus Engine that is based on DOE-2, BLAST, and COMIS software. Calculates CO2 emissions, solar shading, comfort studies, CFD, HVAC, naturally ventilated buildings, buildings with day lighting control, facades, advanced solar shading strategies.	The DesignBuilder approach to natural ventilation allows detailed models of natural ventilation air flows.

This multi-zone modelling approach is efficient in terms of both the complexity of the model and the numerical solution. The requirements of a particular simulation will dictate time-steps from 15-minutes to 1-hour. In conclusion, the selection of DesignBuilder is based on:

Capability: DesignBuilder is an interface to dynamic thermal simulation engine that based on DOE-2, BLAST, and COMIS software and being combined into a new program called 'EnergyPlus' (Majali et al. 2005). It is the most recent building energy simulation program for modelling building calculating internal heat gain generated through building envelope, solar radiation through windows and glass facade elements. Additionally it calculates heating, cooling, lighting, CFD, natural ventilation and also other energy flows and sizing of HVAC equipment and systems. Moreover, it includes many innovative simulation capabilities such as time steps of less than an hour, modular systems and plant integrated with heat balance based on zone simulation, multi-zone air flow and thermal comfort.

Credibility: DesignBuilder encompasses all building parameters and properties and a fairly accurate depiction of energy use within the structure. The framework starts with the selection of a location and the corresponding weather through a weather file (EPW format), building geometry representing a definition of the geometry needed for the simulation of the building's thermal performance. Moreover if one imports DXF files as footprints for the creation of a geometric model, DesignBuilder provides a variety of country or region specific templates for selection of parameters (materials and constructions).

Feasibility: DesignBuilder has a good accessibility and information of control interface, a digital rendering of the final model can also be developed and imported into Google's drawing program Sketch Up (Parke et al. 2010), and better graphical representation of simulation output, simple navigation and flexible control. It also integrates the design by creating a specific thermal building model geometry with the integrated CAD interface and interoperability of 3D building model.

Resources: The latest ASHRAE worldwide design weather data and locations (4429 data sets) are included with the software and about 1258 EnergyPlus hourly weather files are available free using the DesignBuilder.

Broadly speaking, using DesignBuilder simulation to test the thermal performance of the houses needs various stages for accurate prediction. Nevertheless, actual outdoor weather data can manipulate certain variables to predict the effects of changes on the house characteristics which lead to reshaping the model parameters that can create a design that exactly fits the needs of each simulation.

6.4 Modelling Process and Simulation in DesignBuilder

Depending on the application and the level of detail required, in DesignBuilder, a simulation model includes a building context that is composed of thermal zones which have geometric, operational and constructional elements; as well as more technical networks and control systems within a model. Material properties are available for building characteristics e.g. walls description, composition and surface properties that assist in understanding all model data within an evaluation for an entire building.

As the case study is determinate, building inputs encompasses information linked to building characteristics and their context, which clarify the nature of the model as well as the patterns of boundary conditions outside dry bulb temperature, humidity, solar radiation and wind speed. The following information is the framework that led to the evaluation phase as shown in Figure 6.3.

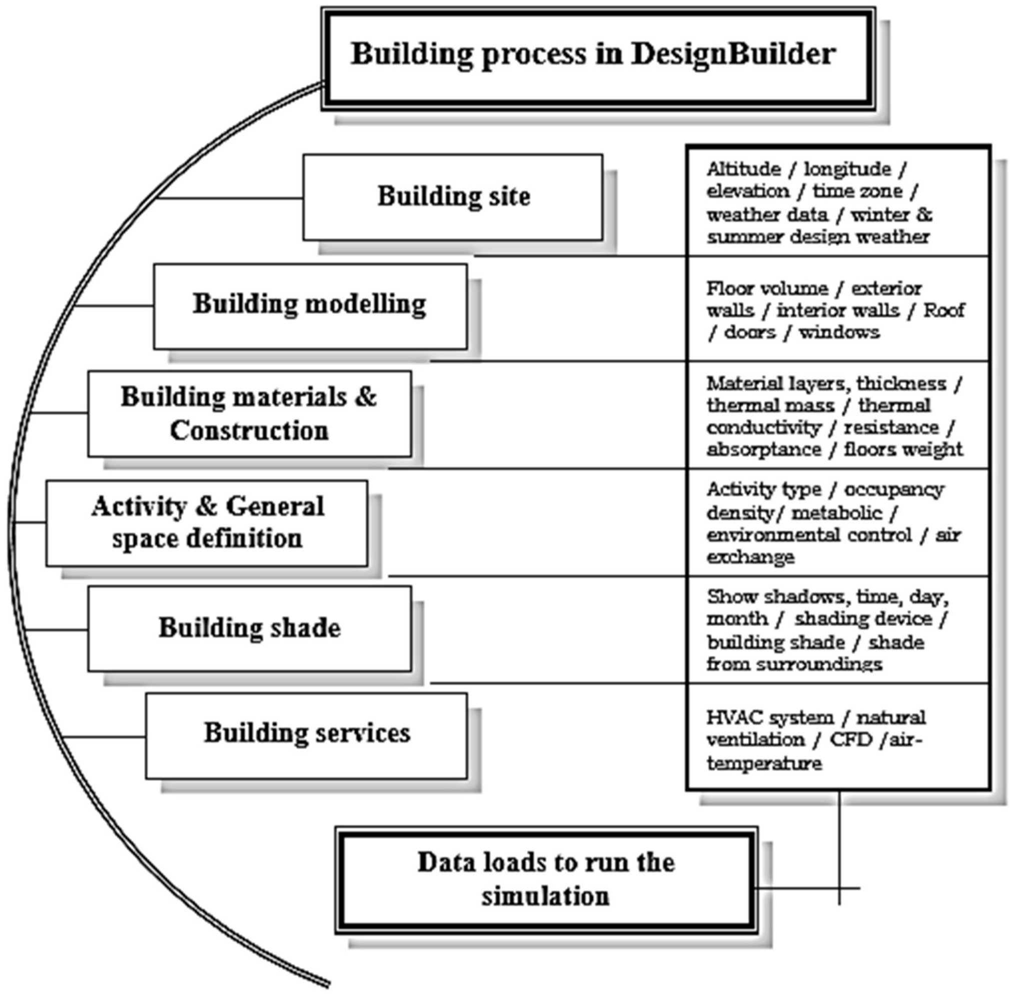


Figure 6.3: Basic concept of sequential simulation in DesignBuilder

Building site: it represents information about the site including: The latitude (in degrees) of the site and the longitude (in degrees) of the site and time zone reference. Elevation above sea level defines the altitude of the site relative to sea level and is passed directly to EnergyPlus. Simulation weather data in DesignBuilder uses EnergyPlus weather file format, also known as EPW, as hourly weather data for simulations (heating and cooling design calculations use much simpler weather data design).

Building modelling: 2D drawing is a key in the building production process so it draws exterior walls, interior walls and identifying the Roof, doors that are linked to 3D model which illustrate the floor volume.

Building model data can be entered at building, block, zone and surface levels.

Building materials & Construction: building fabric is described in terms of orientation, area, material thickness, density, conductivity, specific heat capacity, vapour diffusivity, surface shortwave absorptivity and long-wave emissivity to enable calculation of heat and moisture.

Activity and general space definition: the Occupancy model data defines the total occupant density for the space and the times of occupancy; the metabolic rate determines the amount of heat gain per person in the zone under design conditions and defines the clothing levels of the occupants for summer and winter periods.

Building shade: Showing the patterns of shading on external surfaces caused by obstructions and surroundings as well as it can design the shading device; at this stage it can determine the building shadows at specific time in any day time of any month.

Building services: once the base model has been created within the DesignBuilder, the room/zone templates are created. Each room/zone type has an individual template which allows activities, temperatures, HVAC systems, lighting, occupancy, internal gains and ventilation to be set for each.

6.5 Weather Data

Weather data requirements consist of representative time-series of hourly values of climate factors and cover a representative heating season and cooling season. In this research, the DesignBuilder programme was used to investigate the thermal performance of the residential building. However, in DesignBuilder, the weather files database don't have Ghadames weather data. Therefore it was necessary to create a new weather file with all climatic data for Ghadames.

The weather data was collected from outdoor monitoring by EasyWeather station as described in Chapter 5, and then saved in CSV (Comma-separated values format) excel format. EnergyPlus weather converter 8.1.0 was used to convert weather file CSV format to epw format which are defined by DesignBuilder. EnergyPlus weather (EPW) file is a database of hourly weather data to define external conditions during simulations; the weather parameters in EPW format contain detailed values of Ghadames City in solar time and local standard time. The parameters of EPW weather data file include:

Thermal data (Dry- bulb temperature / Dew-point temperature / Relative humidity / Atmospheric pressure).
Solar data (Global horizontal solar radiation).
Wind data (Wind speed and direction).

The case study of a residential building was modelled in DesignBuilder simulation programme while the validation of the weather data file for Ghadames used in the simulations was presented in Chapter 5.

6.6 Modelling of the Case Study Building

The selected house for modelling is one of the typical single family houses sited in an occupied urban residential area in the new modern City as a contemporary building. The case study residential building is a prototype building which was constructed of similar building materials including reinforced concrete structures and brick walls representing the typical residential buildings in Ghadames that also expressing the common poor performance of climatic solutions in new houses.

The geographical location of the base model followed that of the actual house (latitude: 30.12153 North and longitude: 9.49217 East at an altitude of 351m above sea level) that were monitored between 19/January/2014 to 23/January/2014 and 21/June/2014 to 26/June/2014 in the two seasons of winter and of summer where indoor temperature fluctuations are undesirable and hence affect the residents' living conditions.

Weather data was measured on site throughout the field survey in the same period as described in Chapter 5. The preliminary design approach for simulation was defining the model geometry and determining the building dimensions from a hard copy in two steps (AutoCAD design-DesignBuilder modelling). In order to enter the information for the simulation of the thermal comfort performance of a building, DesignBuilder imported AutoCAD (DXF) drawing file that is employed for constructing the building using the DesignBuilder graphic interface. The AutoCAD drawings in Figures 6.5, 6.6, 6.7, & 6.8 used for modelling have to be exported to the building configuration CAD drawings and to be imported into the simulation software. In Figure 6.4, the idea of modelling the building on DesignBuilder where mass design of building shows the outer envelope shell of the model and contains the rest of the building's aspects that consist of external and internal walls, floor and roof as in Figures 6.9. In addition, the description of the materials is supported by libraries of standard components and combinations of components that helped to edit and create new materials.

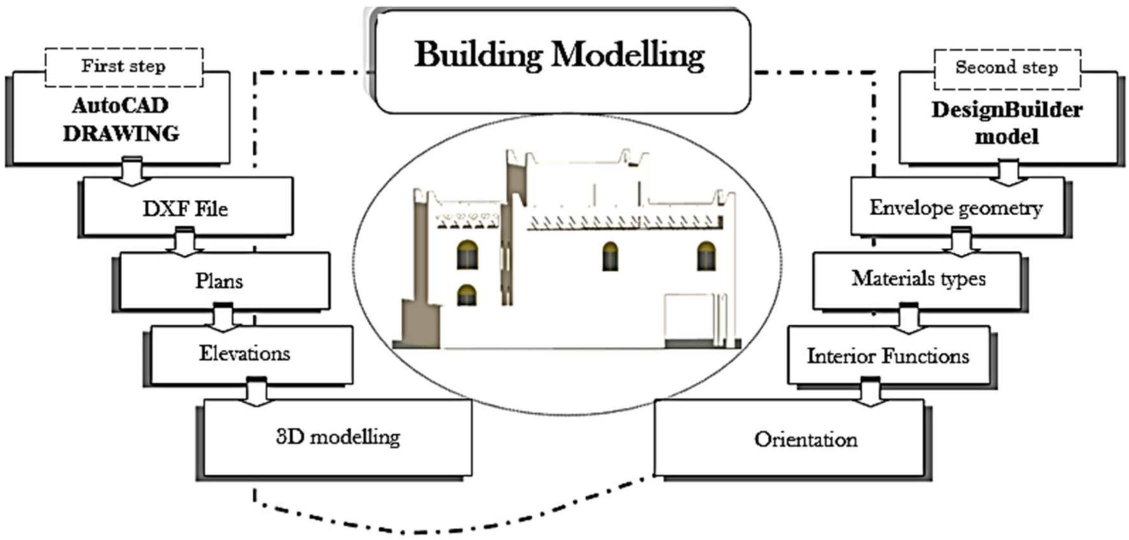
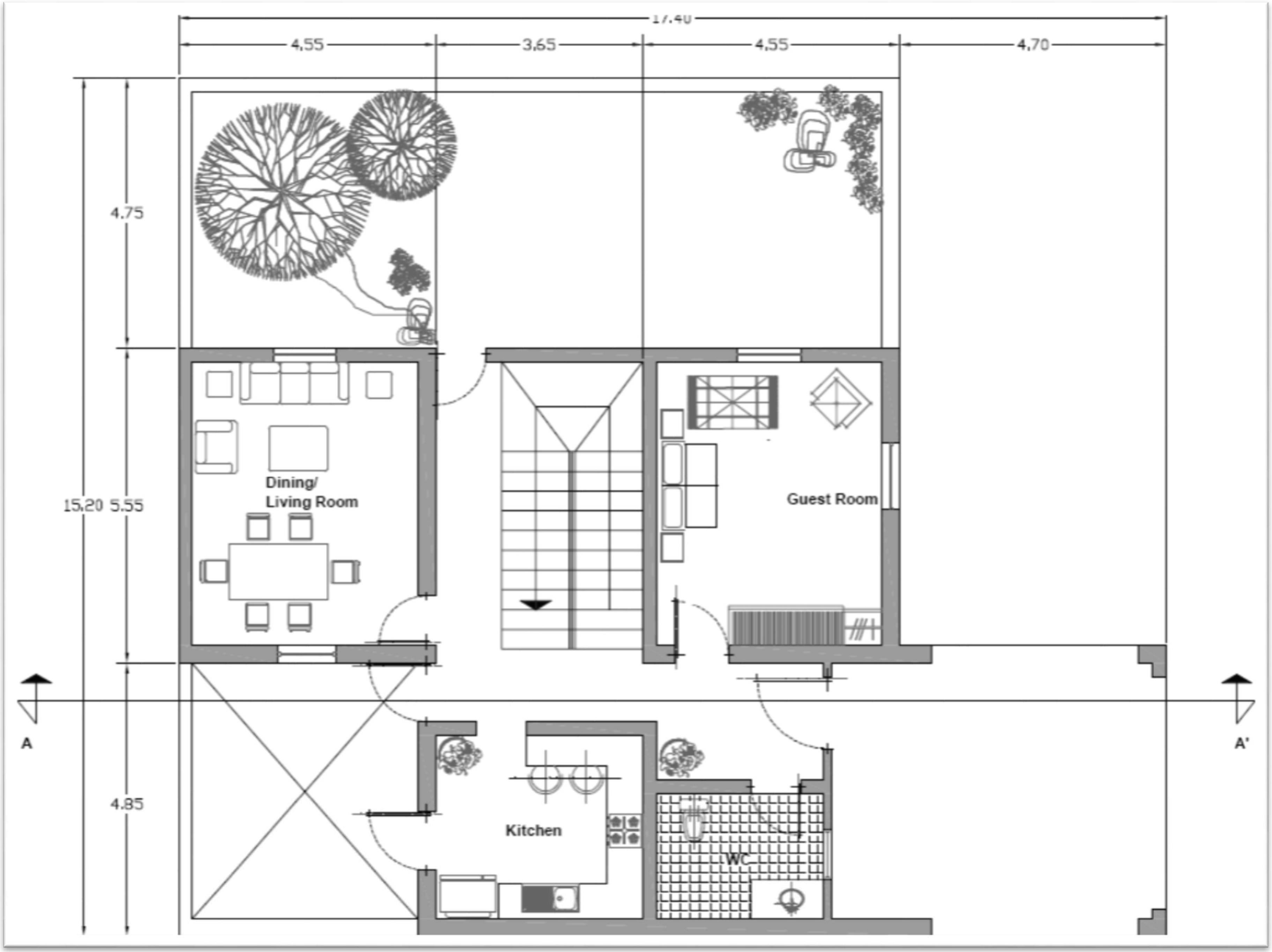


Figure 6.4: Building modelling in DesignBuilder



Scale 1:100

Figure 6.5: Ground floor

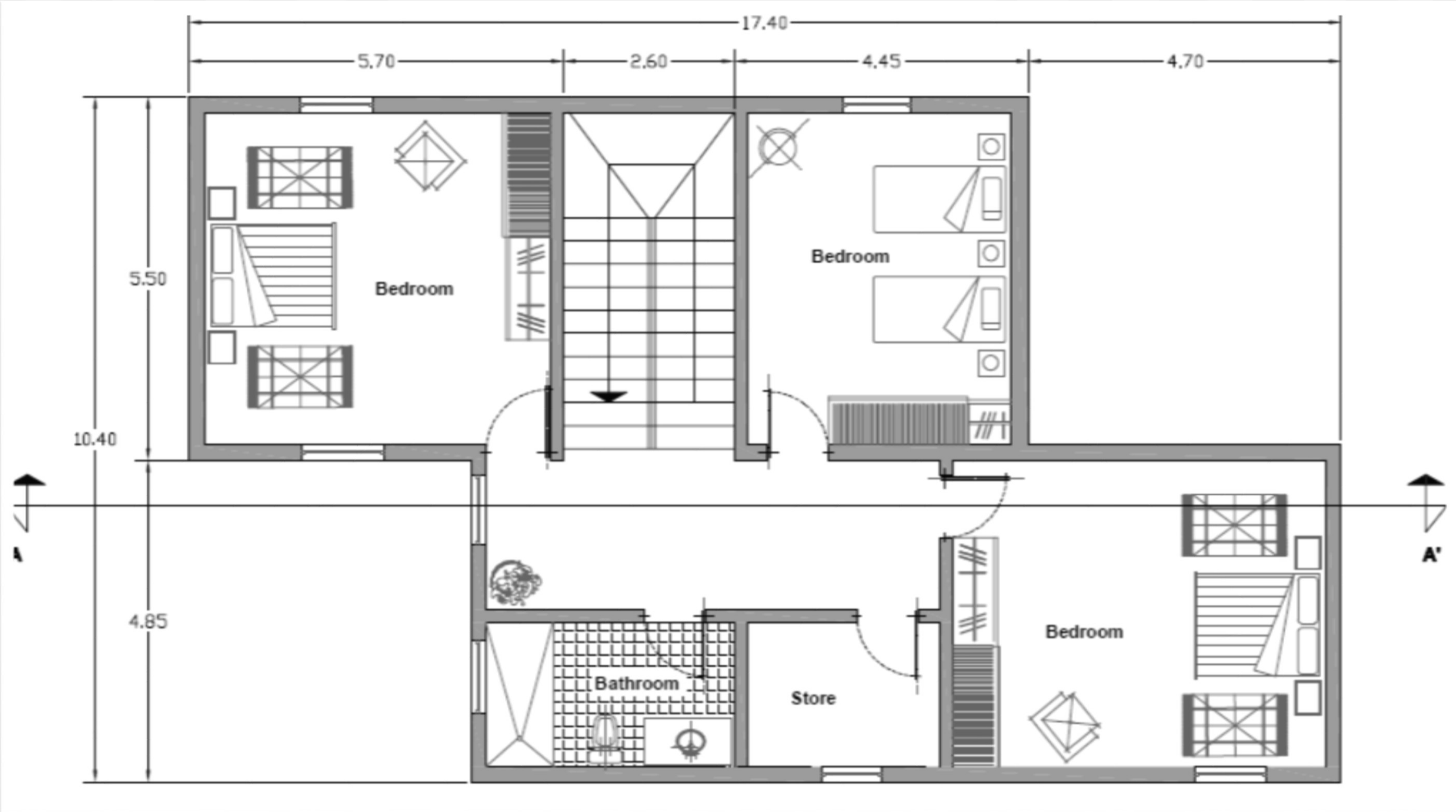


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Figure 6.6: First floor

Scale 1:100

Figure 6.7: Main façade

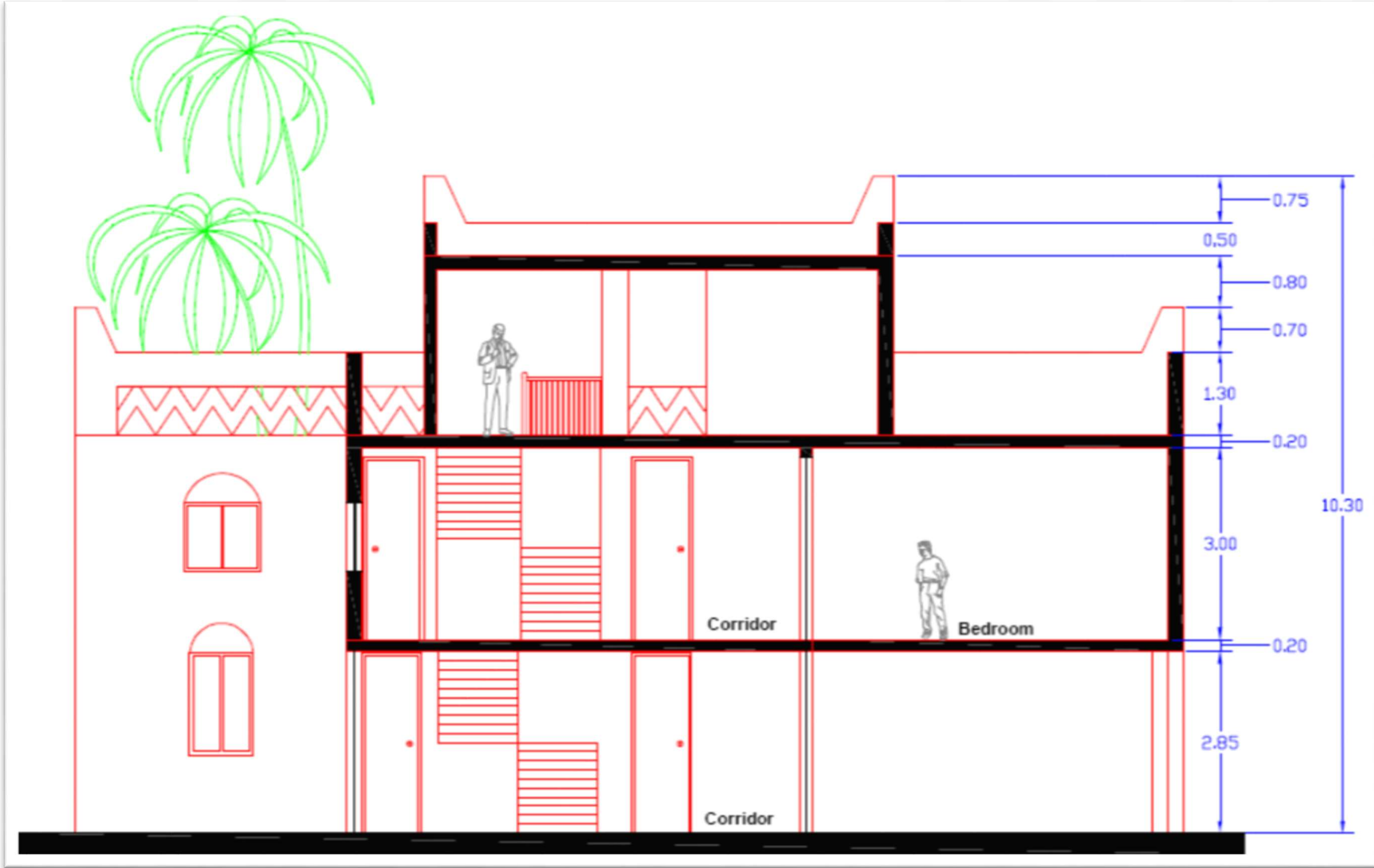

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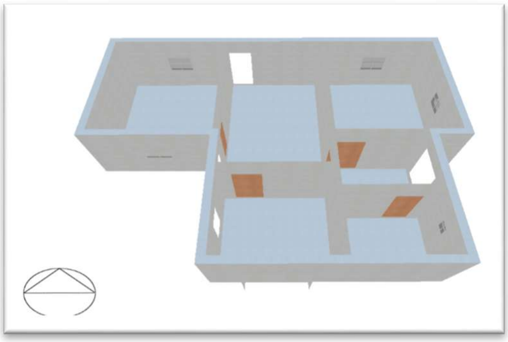
Figure 6.8: Section A-A



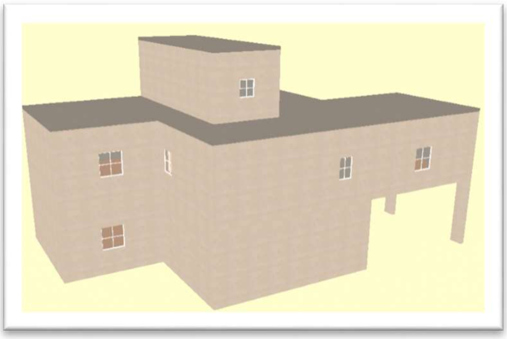


Figure 6.9 Exterior view of the base model terraced house in DesignBuilder programme. (A) Building up the envelope structure in the DesignBuilder; (B) Terraced house in the whole model.

The house consists of two storeys; the main level contains the living space, kitchen, saloon room, family room and WC; the first level contains three bedrooms, bathroom and storeroom. The total living floor areas of the house is 275 m². Table 6.3 outlines these common building materials used for the main building structures.

Table 6.3 Common building materials for the existing terraced houses in Ghadames

Construction	
Structure type	Heavy weight concrete structure
External walls	paint
	4 mm plaster
	250 mm concrete block
	4 mm plaster
	Paint
Roof	20mm tiles
	60mm sand and cement
	120 mm flat reinforced concrete slab
	4 mm plaster
	Paint
Internal floors	30mm tiles
	100mm sand and cement
Windows	Single un-insulated glazing
	Wooden frames
Exterior shading	No shading and overhangs
HVAC systems	No heating or cooling system

However, the thermal properties of the building materials were assigned to the base model which was specified from the DesignBuilder's materials libraries before running the simulation.

Significantly, the monitoring of indoor climate is ideal which leads to investigate how the precision of simulation algorithms of the virtual model coordinate with the weather data file to express the indoor climate of a real building. Therefore, the validation of simulation output results can assist to understand the effect of the actual weather surrounding the building on the calculated weather of the DesignBuilder simulation to predict real indoor temperatures. Furthermore, it helps to understand the differences between the actual thermal and physical properties of the building materials that input in DesignBuilder simulation. Ultimately, it helps to understand differences between the actual effect of occupant behaviour inside the building and that input in DesignBuilder simulation by the researcher.

6.7 Precedents Validation of DesignBuilder

Validation of computational simulation programmes is of significant importance for users to ensure quality of software. The American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE, 2006) approved the technical capabilities and applicability of DesignBuilder programme. The following studies by researchers show the validity and the accuracy of DesignBuilder performance comparing to the field measurement. The first case study by Sheta and Sharples (2010) took place in residential area, Cairo, which is characterized by being an extremely hot dry climate like the Ghadames weather, both places being located in the same desert region and the modern building materials are commonly used in both places. In this study, a validation exercise examined the capability and accuracy of DesignBuilder by comparing the simulation output with the field measurement data collected by HOBO data loggers. The measurements of indoor air temperature was taken in the last week of June (24-30 June), and the hottest day of the year was

24 June 2009. The results showed that the predictions of DesignBuilder, which were based on dynamic simulations on an hourly basis (WMO, weather file), demonstrated good agreement with the real weather data collected from field measurements by HOBO data loggers. Small variations were found within the range of ±3°C degree between indoor simulated temperatures and indoor measured temperatures in the summer, as well as the outdoor weather measurement and the simulation weather data showing a small difference. Therefore, it is a quite reasonable calibration for the simulation model (Figure 6.10, 6.11).

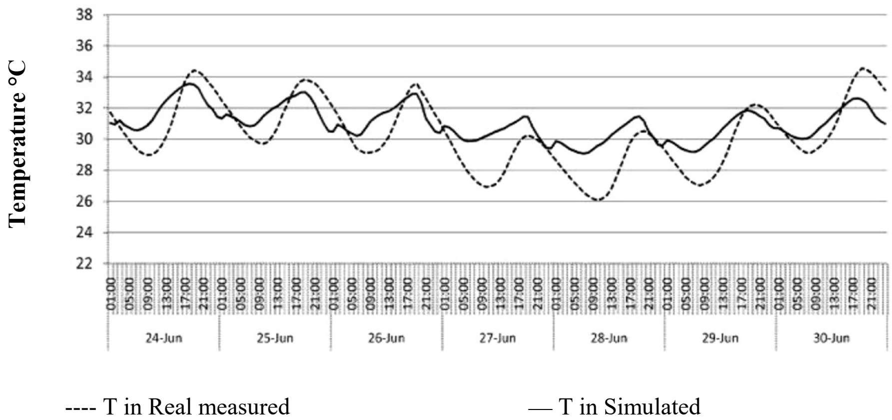


Figure 6.10: Simulation results against measured results for ground floor

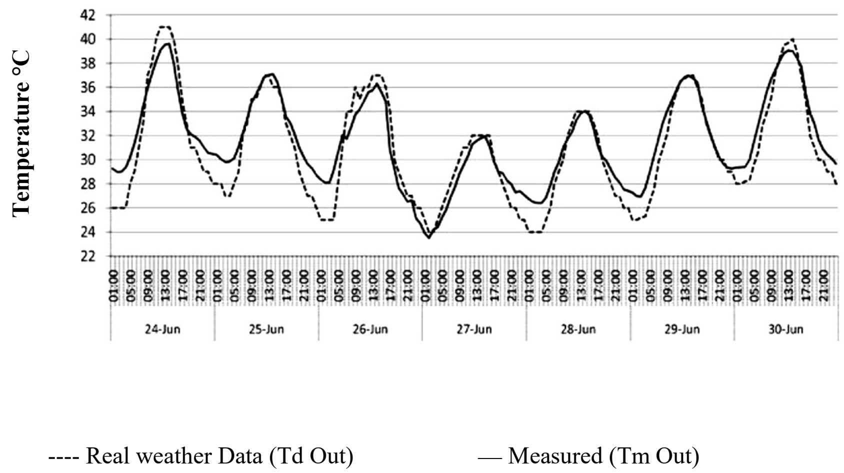


Figure 6.11: Comparison between outdoor measured temperatures and outdoor real weather data from the meteorological records obtained from weather file simulation.

The second case study by Rahman et al. (2010) considered mechanical ventilation system in hot humid climate at Queensland University

Campus, Australia. In this study, DesignBuilder software was used in the simulation to analyse different scenarios. The validation examined the capability and accuracy of DesignBuilder by comparing the simulation output with field-measured data collected by HOBO data loggers and smart meters. The simulated temperatures were found within 7% variation with the measured value of a typical summer day in 27/January/2007 (Figure 6.12) and the variation between predicted and measured humidity data were found within 11% in a typical summer day (Figure 6.13). This demonstrates that DesignBuilder predictions are in good agreement with the data collected by the HOBO data loggers and smart meters in ITD building. Hence, it can be assumed that the modelled ITD in DesignBuilder of virtual building is capable of producing approximately the actual operating conditions of the existing ITD building.

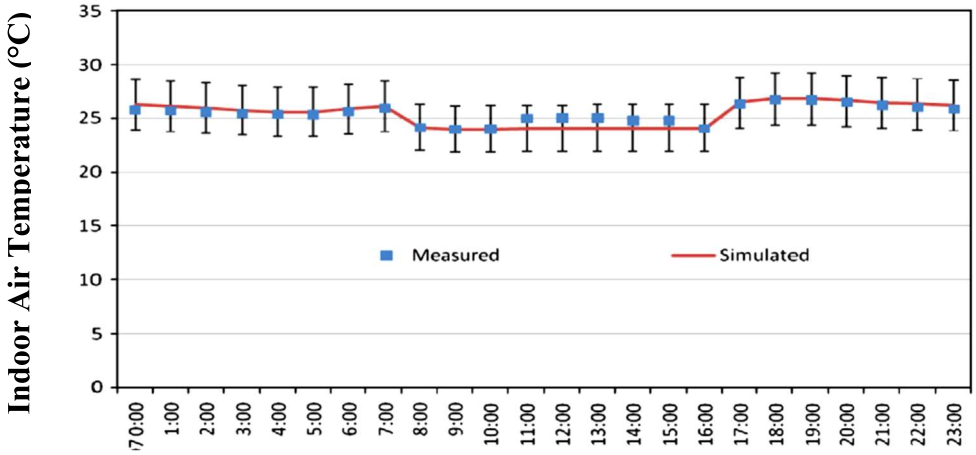


Figure 6.12: Measured vs. simulated indoor air temperature for a typical summer day. (27/January/2007).

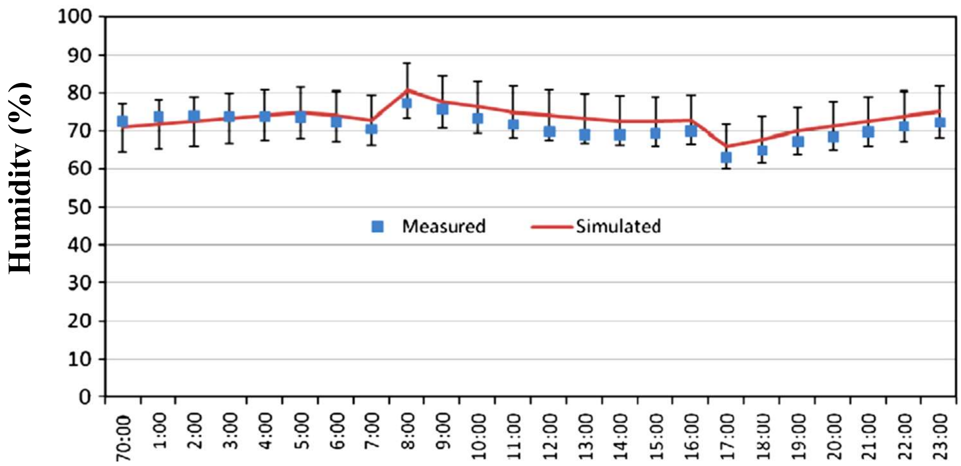


Figure 6.13: Measured vs. simulated indoor air humidity for a typical summer day. (27/January/2007).

The justification of DesignBuilder was undertaken to check the agreement of simulation output with the field measurements and to confirm the accuracy of simulation predictions. From the previous review, the internal and external surface temperatures and the indoor ambient conditions, such as the air temperature and relative humidity from the simulation, were validated with the field-measured data. The indoor mean radiant temperature was validated with the calculated mean radiant temperature based on field-measured data: the results show that the field-measured data and the DesignBuilder data are accepted.

6.8 Reliability and Validation of DesignBuilder Simulation to the Current Case Study

Building energy analysis simulation is used to predict thermal performance in the residential building; this includes temperatures and envelope gains. Therefore, the validation of DesignBuilder simulation version (4.2.0.54 – 2014) is necessary to calibrate the reliability of the results with the field-measured data to build a satisfactorily image about the integration of the modelling of building with the actual climate. Moreover, the validation assists in checking precision of the input data and the capability of the simulation tool to predict actual building performance with the input data, in addition to the applicability of the simulation tool to the building and the climate of the case study.

In this study, the actual weather data that was collected from outdoor monitoring by EasyWeather station, as described in Chapter 5, is employed in the simulation in order to compare the difference between the actual microclimate of indoor monitoring and the predicted one by simulation. In this stage, building model in DesignBuilder was constructed according to building materials of the existing building that applied as described previously. Then, the building was oriented towards north south according to the existing building that was considered in the case study where the monitoring of the indoor climate by HOBO data loggers were carried out. Furthermore, the actual schedule of the occupancy and the equipments was adjusted in the building simulation according to the data of post occupancy that was considered from the field survey in January and June 2014, such as family size, times of opening the doors windows, number of people of each room, equipments and occupancy time, to represent the real behaviour of the users. On top of that, the simulation schedules of natural ventilation, heating system and lighting were defined in DesignBuilder for weekdays of the model profile to represent the actual existing building performance.

As a final step, the DesignBuilder building simulation was run after time step was set to coincide with the weather data at 1 hour, considered in two seasons' winter and summer between 19/January/2014 to 23/January/2014 and 21/June/2014 to 26/June/2014 in the same dates of indoor climate monitoring by HOBO data loggers.

6.8.1 Winter Season Validation

The study focus on coldest day in the period of outdoor monitoring to show the details of indoor temperature pattern during 24 hours. The analysis is based on the air temperature and humidity factors of two individual rooms only due to the limitation of HOBO loggers, whereas, the living room located in the ground floor and the bedroom located in the first floor to consider family activity in day time and sleeping in night time.

A. Indoor Air Temperature

Figures 6.14 and 6.15 are showing DesignBuilder output of predicted levels of indoor air temperature against those measured by HOBO data loggers in the residential building of Ghadames in the coldest day from the period 19th January 2014 till 23th January 2014, representing room temperature variation in terms of air circulation patterns, window and door opening, loading density and environmental conditions of winter season. The existing climate data evidences on 22th January 2014 showed that outdoor temperature dropped down in the evening and reached 2.4°C as a cold night as described in Chapter 5.

In Figures 6.14 and 6.15, it can be seen that the actual and the average weather data that were predicted by DesignBuilder simulation produced various indoor air temperature ranges in the targeted rooms of each floor. An evaluation analysis was carried out to determine the agreement of the measured HOBO data loggers against the predicted simulation from the rooms which are located on the ground and first floors, facing south and north. The results showed quite a bit of variation in corresponding with actual monitoring data as shown in Figures 6.14 and 6.15, where a small performance gap can be noticed in coordination with the actual performance of weather data monitoring.

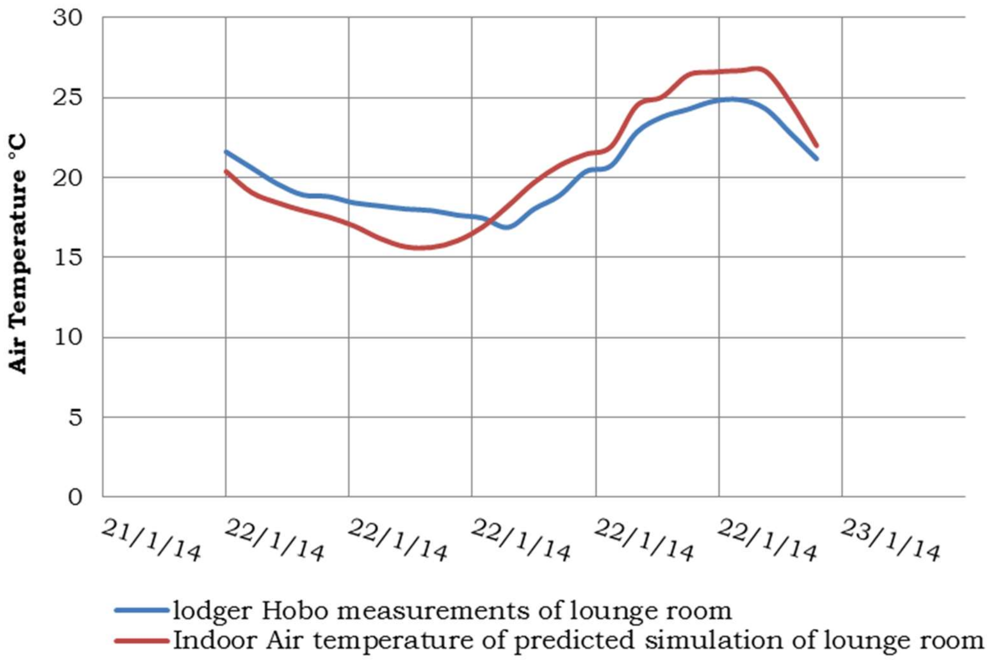


Figure 6.14: Temperature profiles of indoor monitored spaces vs output temperature of simulation during the winter in ground floor.

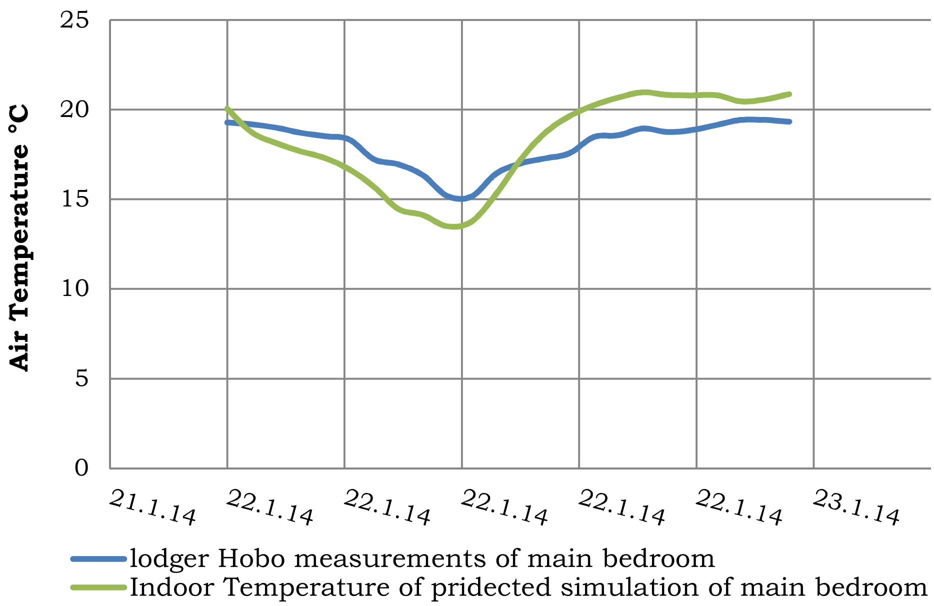


Figure 6.15: Temperature profiles of indoor monitored spaces vs output temperature of simulation during the winter in first floor.

In order to know how close the predicted indoor climate data from DesignBuilder simulation against monitored data is, a root mean squared error (RMSE) is a frequently used formula to measure the differences between values predicted by a simulation model and the values actually observed as explained in Chapter 5.

However, RMSE shows the differences of temperatures between the simulation predicted and the monitored on 22th January 2014 which was 1.63˚C in ground floor and 1.58˚C in first floor.

B. Indoor Relative Humidity Levels

The relative humidity levels that were predicted by DesignBuilder and measured by HOBO data loggers during the Winter season on 22th January 2014 as the coldest day represent the climate condition in the living room in ground floor and the bedroom in first floor. The graphs in Figures 6.16 and 6.17 compared the indoor monitoring data by logger against the predictions by the simulation tool which employed the actual weather data file.

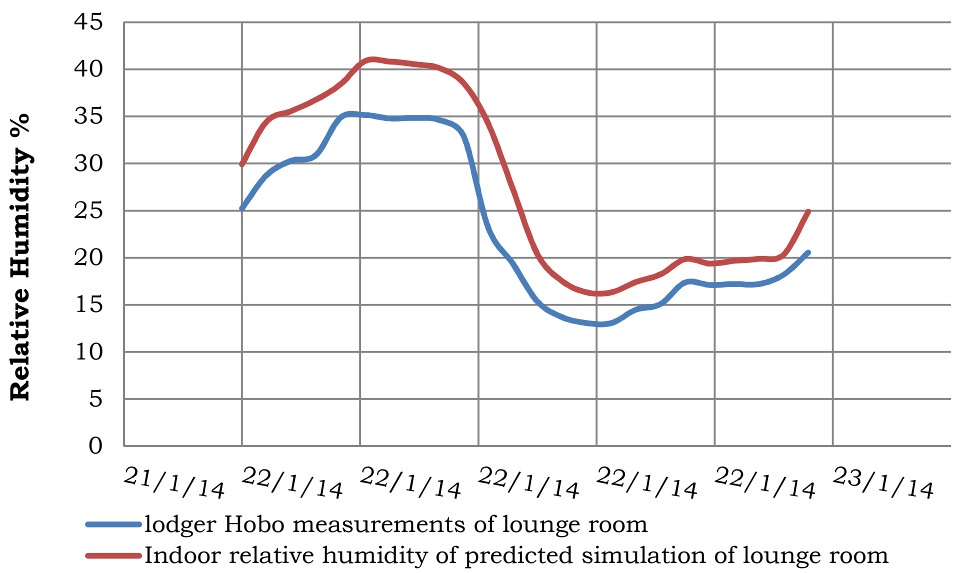


Figure 6.16: Humidity profiles of indoor monitored spaces vs output humidity of simulation during the winter in ground floor.

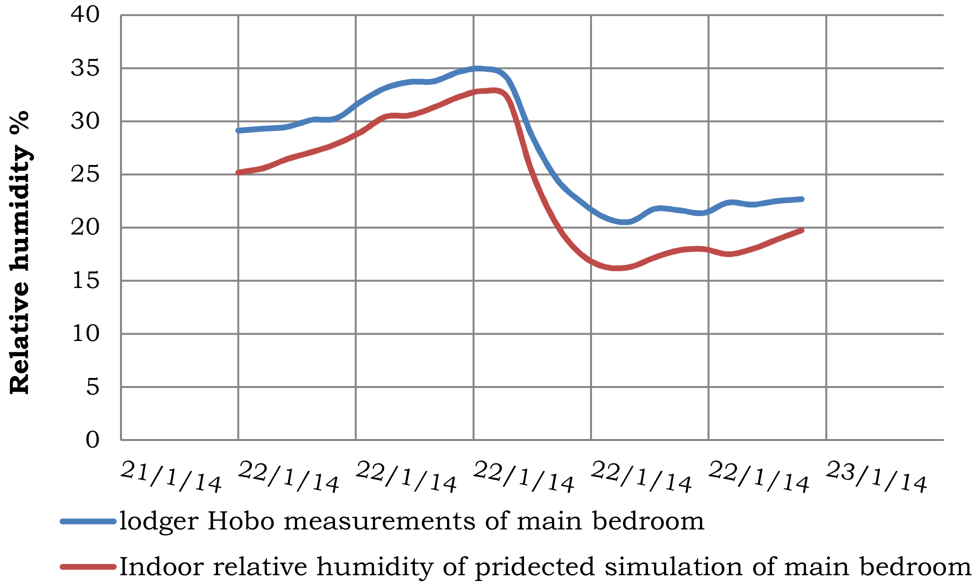


Figure 6.17: Humidity profiles of indoor monitored spaces vs output humidity of simulation during the winter in first floor.

Similar to the indoor air temperature, the predicted internal relative humidity levels are in a close pattern to the ones measured by HOBO data loggers, with some slight variations.

However, RMSE shows the differences of humidity levels between the simulation predicted and the monitored on 22th January 2014 which was overall 5% in ground floor and 3.5% in first floor.

On the whole, both indoor air temperature ranges and relative humidity levels followed the outdoor weather in the cold season where all openings are kept shut in the night. Furthermore, the results show that, using the actual weather data files in the simulation analysis, produces the nearest climate of actual building performance of indoor air temperature and the internal relative humidity levels. Definitely, on this basis, simulation appears to be very accurate with a small performance gap and aligned to indoor monitored data.

6.8.2 Summer Season Validation

The second focus in this study considers the hottest day in the period of outdoor monitoring to show the details of indoor temperature pattern during 24 hours. The investigation on two individual rooms only covered living room in ground floor and the bedroom in first floor are based on the air temperature and humidity factors due to the limitation of HOBO loggers, which appears similar to the previous experiment in the winter season.

A. Indoor Air Temperature

Figures 6.18 and 6.19 are showing DesignBuilder output of predicted levels of indoor air temperature against measured by HOBO data loggers in the residential building of Ghadames in the hottest day from the period 21th June 2014 till 26th June 2014, representing room temperature variation in terms of air circulation patterns, window and door opening, loading density and environmental conditions of winter season. The existing climate data evidences showed on 24th June 2014 that outdoor temperature reached the highest level in the evening when 47.2°C is recorded as the hottest day, as described in Chapter 5.

In Figures 6.18 and 6.19, an assessment analysis was carried out to determine the agreement of the measured HOBO data loggers against the predicted simulation from the rooms which are located on the ground and first floors, facing south and north. The results showed quite a bit of variation in corresponding with actual monitoring data as shown in Figures 6.18 and 6.19, where a small performance gap can be noticed in coordination with the actual performance of weather data monitoring.

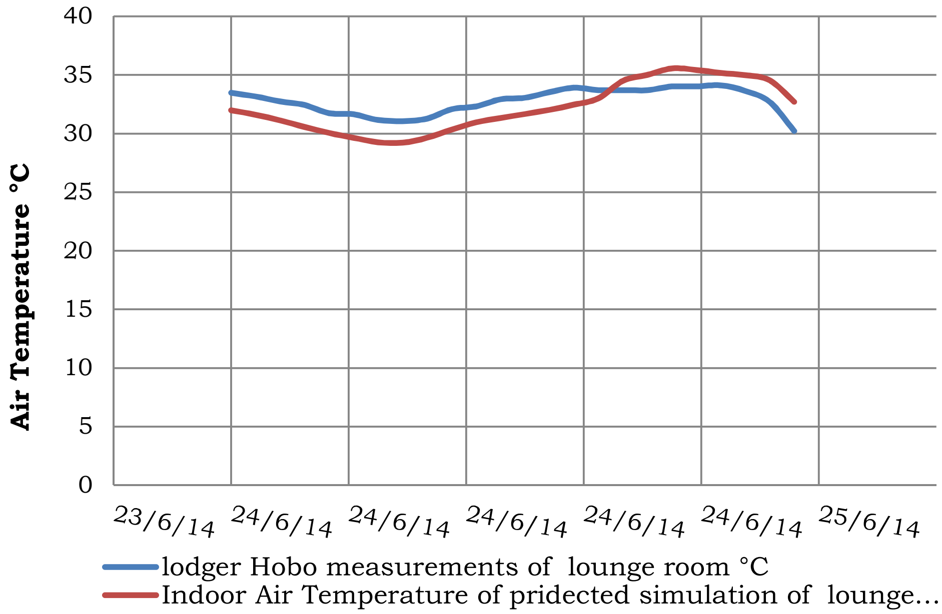


Figure 6.18: Temperature profiles of indoor monitored spaces vs output temperature of simulation during the summer in ground floor.

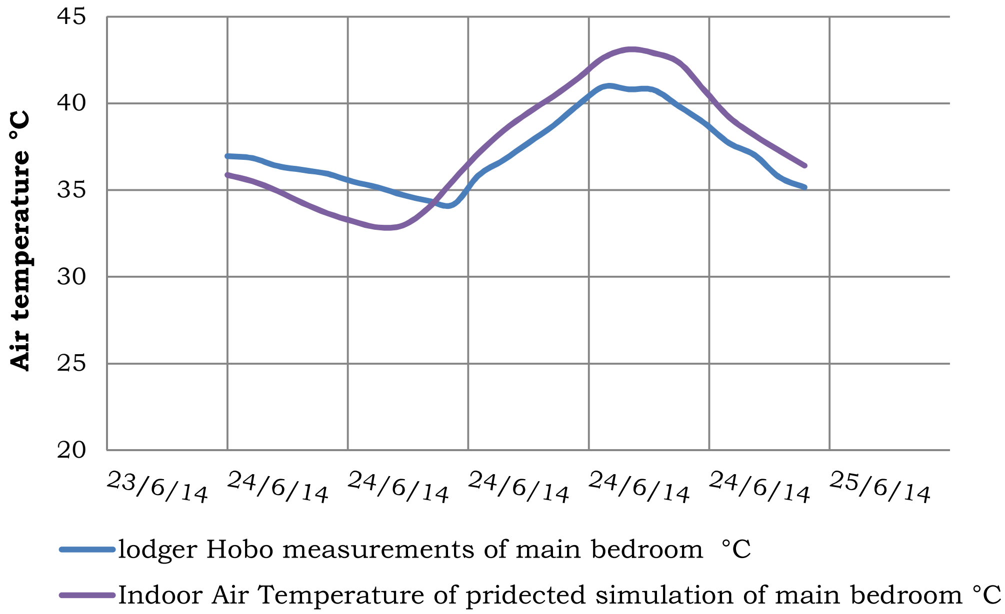


Figure 6.19: Temperature profiles of indoor monitored spaces vs output temperature of simulation during the summer in first floor.

However, RMSE shows the differences of temperatures between the simulation predicted and the monitored on 24th June 2014 which was overall 1.59°C in ground floor and 1.74°C in first floor.

B. Indoor Relative Humidity Levels

The relative humidity levels that were predicted by DesignBuilder and measured by HOBO data loggers during the winter season on 22th June 2014 as the coldest day are representing the climate conditions in the living room in ground floor and the bedroom in first floor. The graphs in Figures 6.20 and 6.21 compared the indoor monitoring data by logger against the predicted data by the simulation tool which used the actual weather data file.

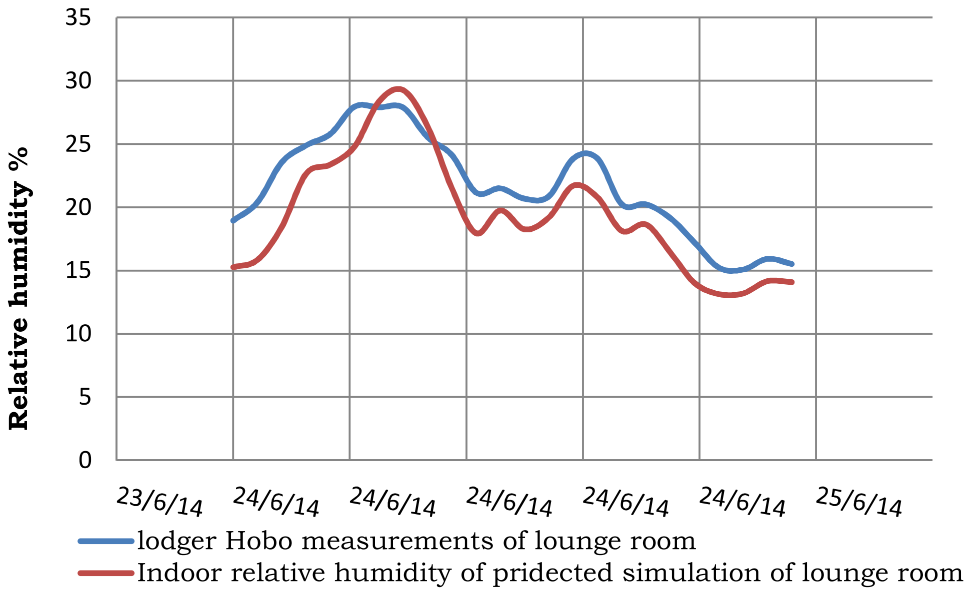


Figure 6.20: Humidity profiles of indoor monitored spaces vs output humidity of simulation during the summer in ground floor.

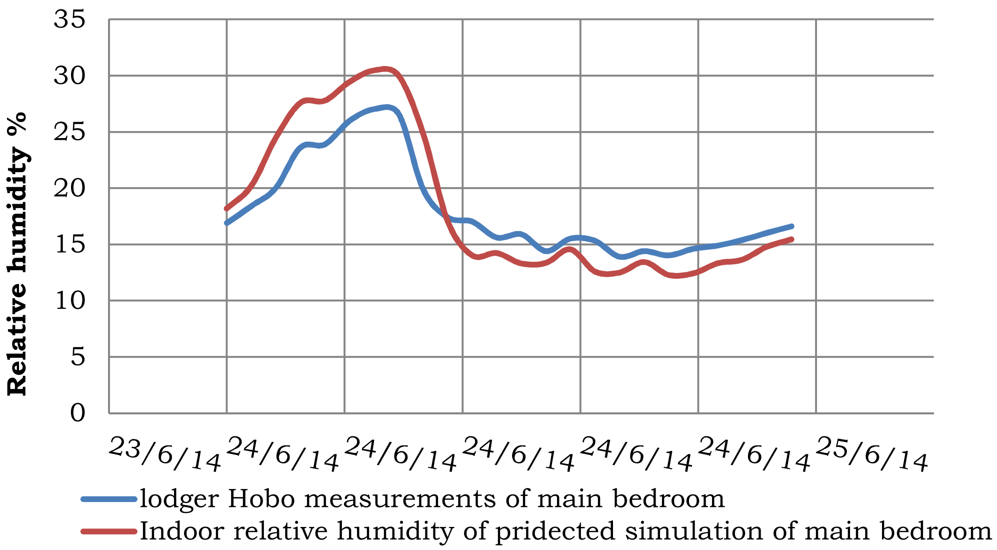


Figure 6.21: Humidity profiles of indoor monitored spaces vs output humidity of simulation during the summer in first floor.

Still, RMSE shows the differences of humidity levels between the predicted simulation and the monitored data on 24th June 2014 as being overall: 2.61% in ground floor and 2.59 % in first floor.

In general, both indoor air temperature ranges and relative humidity levels followed the outdoor weather in the hot season where all the openings are kept open during the night. Additionally, the results show that using the actual weather data files in the simulation analysis, produces real climate for existing building performance of indoor air temperature and the internal relative humidity levels. Positively, on this groundwork, DesignBuilder simulation showed a good performance with small gap and aligned to indoor monitored data.

6.9 Conclusion

Accordingly, the relationship between the measured data and the weather file data in DesignBuilder demonstrate that that here is a strong positive result in the accuracy of simulation algorithms based on the virtual model of building construction and the physical properties of building materials with respect to building orientation and natural ventilation. Altogether, this gives confidence and adequate matching with the real building data that gives high credibility to run DesignBuilder simulation in the analysis stage.

Definitely, the DesignBuilder simulation tool can be used to evaluate design options and to investigate design optimisation, as well as to facilitate the investigation of new ideas. The following chapter 7 examines the full scale investigation of modelling simulation test on the residential building under various natural conditions at the peak of winter and summer seasons.

Chapter VII

Simulation Analysis

7.1 Introduction

The suitability of passive envelope design in hot dry climate of Ghadames is a premise investigation in this chapter to test the beneficial aspects of passive and architectural factors to reduce solar radiation heat gain through the building envelope and to increase natural ventilation rate, especially when enhancing night ventilation in summer in order to improve the comfort levels inside the houses. Therefore this chapter describes the simulation test cases focusing on four aspects of passive cooling techniques:

- Natural ventilation condition by using night ventilation in summer.
- Thermal insulation by testing of different wall designs in winter and summer.
- Increased night ventilation rate using forced ventilation in summer
- Combinations of the effective design from the above techniques.

These analyses were performed by carrying out thermal simulation with the use of DesignBuilder as also stated in chapter 6. Moreover, the statistical technique has been applied as a tool for the investigation of relationship between those variables by using regression analysis.

7.2 Ventilation Plan in Simulation

According to Givoni (1991), windows in the building should be closed during daytime in summer to avoid bringing the warm outdoor air into the rooms to enhance night-time cooling effect. This means that night ventilation cannot be combined with daytime comfort ventilation as it will reduce the differences between indoor and outdoor temperatures, which at the same time decrease the effect of the mass heat sink.

In order to avoid high demand from cooling during the summer, (see Table 7.1), three proposed plan of ventilation modes were applied in simulations to enhance thermal comfort and to reduce overheating by natural means. However, in Ghadames, the residents are likely to alleviate the internal conditions by opening windows during night-time from around (19:00) until (07:00) of next day morning with respect to the weather conditions and the privacy.

Table 7.1: Proposed plan of ventilation scheme in thermal simulation

Proposed plan of ventilation	Scheme of (opening /closing) windows	Duration of ventilation (hours)
Night-time (nocturnal cooling)	20:00 ~ 06:00	10
Daytime (comfort ventilation)	6:00 ~ 20:00	14
Full-day ventilation (24 hours)	00:00 ~ 24:00	24

On the thermal simulation side, the natural ventilation analysis in DesignBuilder based on EnergyPlus AIRNET method that calculates airflow rates consists of two regimes of natural ventilation with control of window opening times as follows:

- Scheduled mode- the ventilation rates are predefined by the researcher using a maximum air change rate (ach) modified by operation schedules and opening sizes. ACH is an air-change rate relative to the volume of the space, the ventilation rate is referred to as the absolute amount of inflow air per unit time (a litre per second or l/s, cubic metre per hour or m^3/hr) (Atkinson et al. 2009).
- Calculated mode - the ventilation rates are calculated from the weather data file by using wind speed and buoyancy-driven pressure, and the researcher determined opening sizes and percentages of operation of the entire window area.

The model in simulation was naturally ventilated and windows opening times were considered according to the normal routine of the dwellers between 6:00 AM at 24/06/14 to 12:00 PM at 25/06/14. Hence, DesignBuilder calculates the air flow rate from the weather data file and also the scheduled natural ventilation is defined as (ACH) air changes per hour in zone volume under normal operating pressures through a percentage of total window area. Hence, the flow type defines the method used to set the maximum outside air natural ventilation rate in the zone. The air flow rate is calculated from the ach data using:

m^3/s = ach x ZoneVolume / 3600

Where 'ZoneVolume' is the actual air volume of the space.

7.3 Influence of Ventilation Strategies

In favourable climates and buildings types, natural ventilation can be used as an alternative to air-conditioning plants, saving 10%-30% of total energy consumption (Walker, 2014). However, ASHRAE Standard 62.2-2007 provides requirements for residential ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings. These requirements include minimum airflows for whole-house mechanical ventilation, as well as minimum airflows for local ventilation, maximum total exhaust airflow for combustion safety, garage and duct air-tightness, and maximum specific fan power. Overall, these requirements are designed to avoid the use of passive ventilation to meet a home's indoor air quality needs.

7.3.1 Assessing Ventilation Performance by Using Air Change Rate (ACH)

According to ASHRAE (2010), air Changes per Hour (ACH) is a scale to measure of how many times the air volume is added to or is removed from a defined space (normally a room or house) and then replaced with outdoor air. In the focus on the design recommendations for unconditioned buildings in hot dry climate, Nayak and Prajapati (2006) recommended that reduction in the air change rate reduces the yearly comfortable hours, hence for instance an air change rate of 9 ach is better than both 6 and 3 ach, because it gives an improvement of about 14.8%. Comparatively, an air change rate of 6 ach gives an improvement of 6.8%.

Concerning the ventilation, airflow through the building envelope is a factor influencing heat loss/gain and moisture transfer, therefore the scheduled methods examined different rates of air change per hour (No vent, 1.0, 3.0, 6.0 and 9 ach). As noted in the above text and as shown in Figures 7.1, 7.2, 7.3 and 7.4, the latter show the indoor operative temperature patterns in living room of ground floor and bedroom in first floor by using two strategies of natural ventilation (whole-day and night-time) (see Table 7.1). As a result, the simulation is showing that the configurations of temperature trends with air change rates follow the same pattern with small differences between them (0.5- 5.5K).

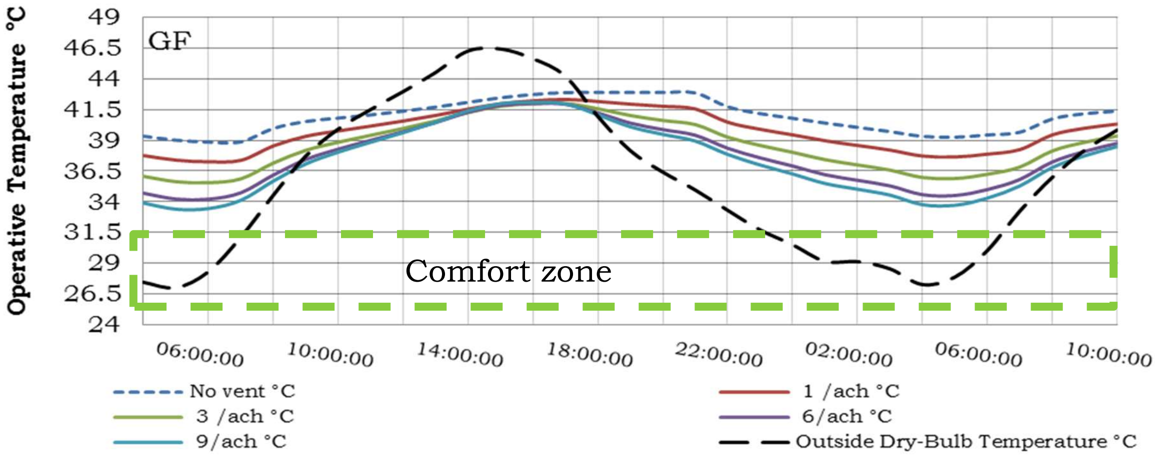


Figure 7.1: Scheduled of whole-day ventilation by using different rates of air change method for living room in ground floor in the hottest day, started from 6:00 AM at 24/06/14 to 12:00 PM at 25/06/14.

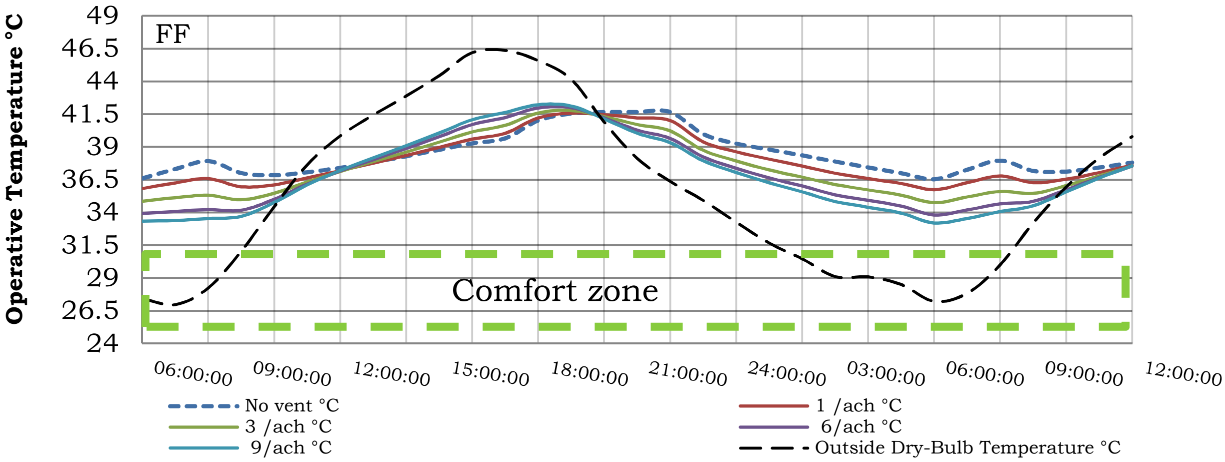


Figure 7.2: Scheduled of whole-day ventilation by using different rates of air change method for bedroom in first floor in the hottest day, started from 6:00 AM at 24/06/14 to 12:00 PM at 25/06/14.

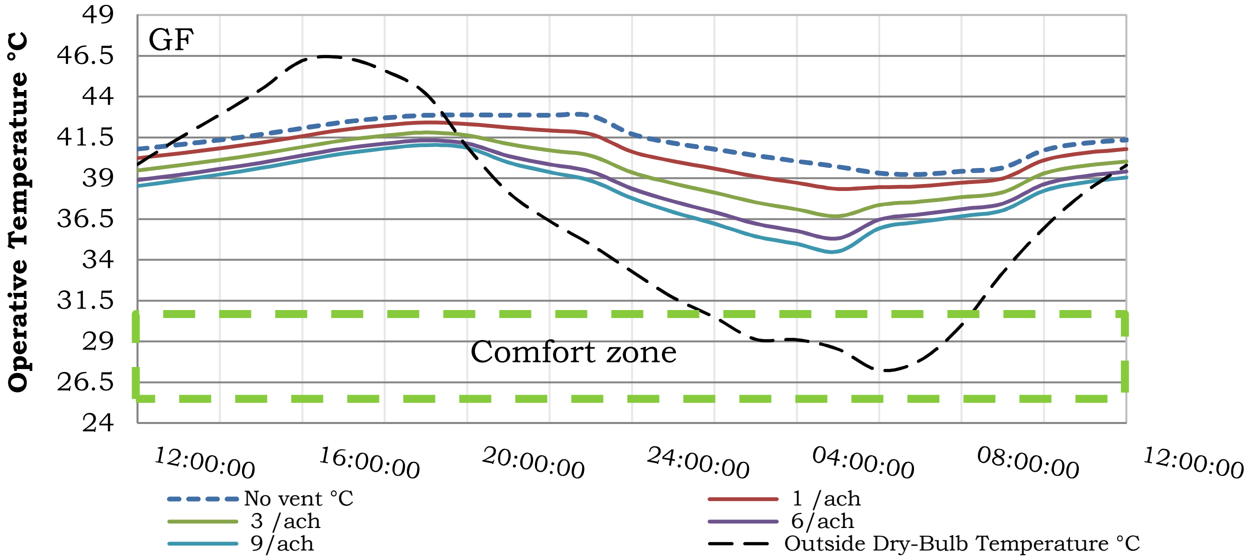


Figure 7.3: Scheduled of night-time ventilation by using different rates of air change method for living room in ground floor in the hottest day, started from 12:00 PM at 24/06/14 to 12:00 PM at 25/06/14.

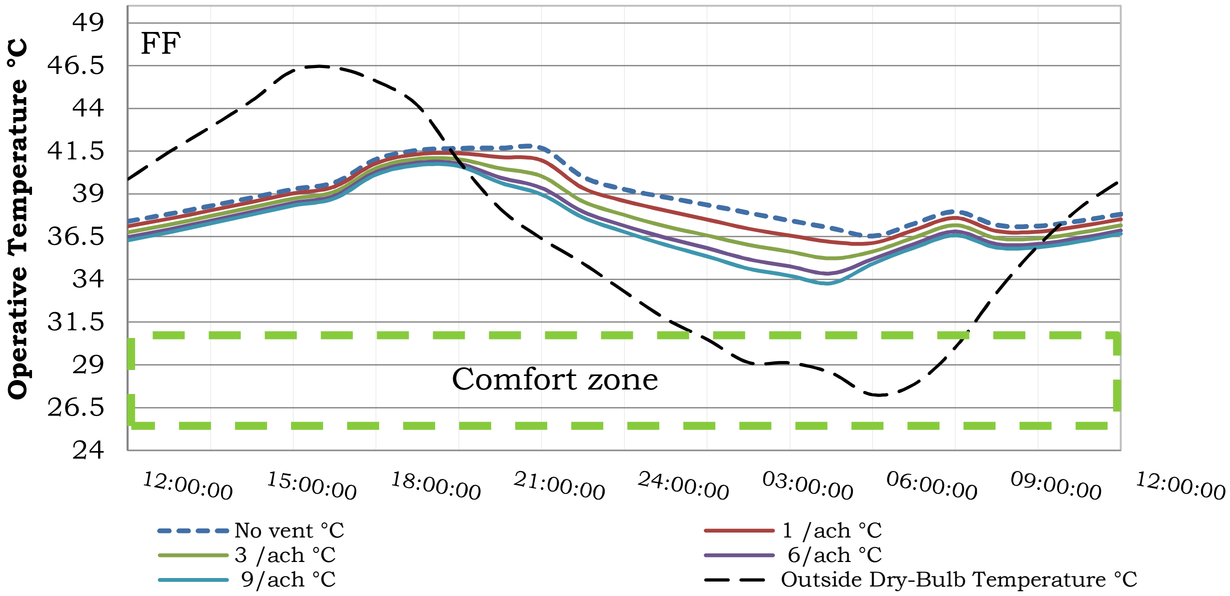


Figure 7.4: Scheduled of night-time ventilation by using different rates of air change method for the bedroom in the ground floor during the hottest day, started from 12:00 PM at 24/06/14 to 12:00 PM at 25/06/14.

On average, the results show that night cooling is superior to daytime ventilation in both strategies where the maximum indoor air temperature is about 4K cooler than the maximum outdoor air temperature in day-time with night cooling strategy. However, increasing the rate of ventilation to 9 ach is very significant and leads to decreasing in indoor air temperature to, thus providing a better comfort level in terms of enhancing the whole building envelope design. Yet, using different rates of air change method alone did not attain the indoor comfort temperature, which remains still high, above comfort zone.

7.3.2 Assessing Ventilation Performance by Using Ventilation Time Plan

In Figures 7.5 and 7.6, the indoor air temperature patterns of the living room in ground floor and bedroom in first floor represented the night-time, day time and whole day ventilation strategies as scheduled in Table 7.1. Regression analysis is used as a statistical technique, the goal is to determine how well a data series was generated and fitted to a function. Besides, the Chi Square is also used to determine whether there is a significant difference between the expected ventilation plan strategies and the outdoor temperature.

The Trendlines in Figure 7.7 [A] indicates how well data fit a statistical model for all ventilation patterns where on-peak of outdoor temperature started from 6:00 AM to 17:00 PM. Night-time ventilation slope line presented low slope with 0.53 in percentage of R^2 0.96 in ground floor. On the other side, first floor ventilation in Figure 7.8 [A] show that night-time ventilation slope line presented low slope with 1.06 in percentage of R^2 0.97. This means the temperature is rising gradually and slowly with the highest point being at 5:00 PM. Meanwhile on-peak of outdoor temperature reached over 46°C, a night-time application is more effective in day-time when indoor temperature can be kept stable in terms of closing windows and effectiveness of thermal mass. However, during off-peak temperature from 17:00 PM to 6:00 AM, night-time ventilation presented a negative slope line with -0.37 in percentage of R^2 0.88 in ground floor, similarly, in first floor it presented a slope line with -0.58 in percentage of R^2 0.91. The outcome of this application means that night-time ventilation is working when the outdoor temperature is dropping down when opening windows can be more effective.

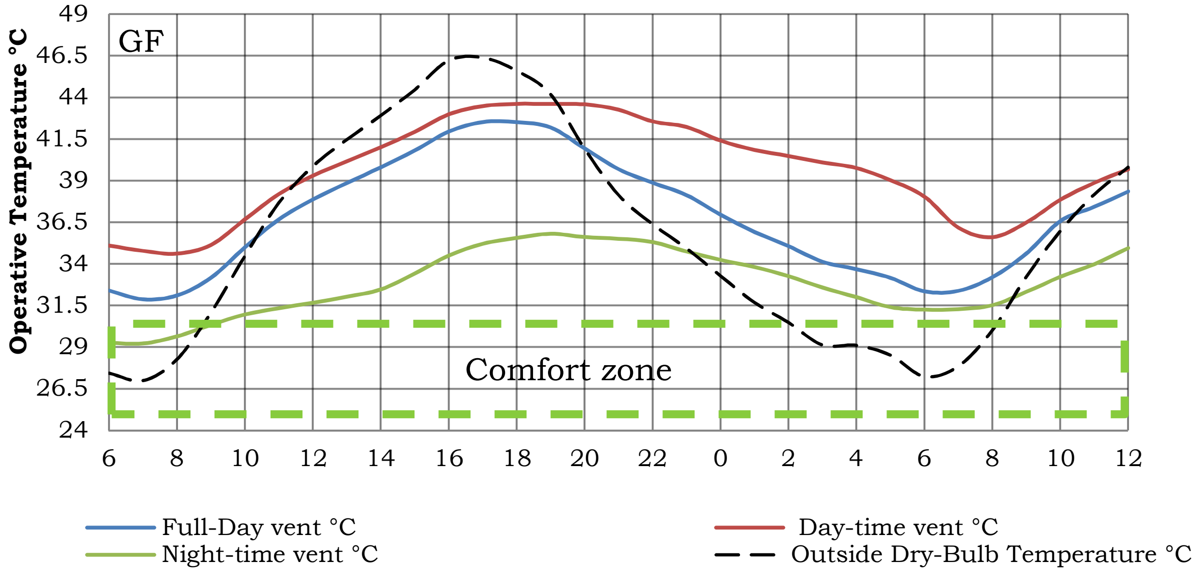


Figure 7.5: Variations method of scheduled natural ventilation by using calculated method time for living room in ground floor in the hottest day, started from 6:00 AM on 24/06/14 to 12:00 PM on 25/06/14.

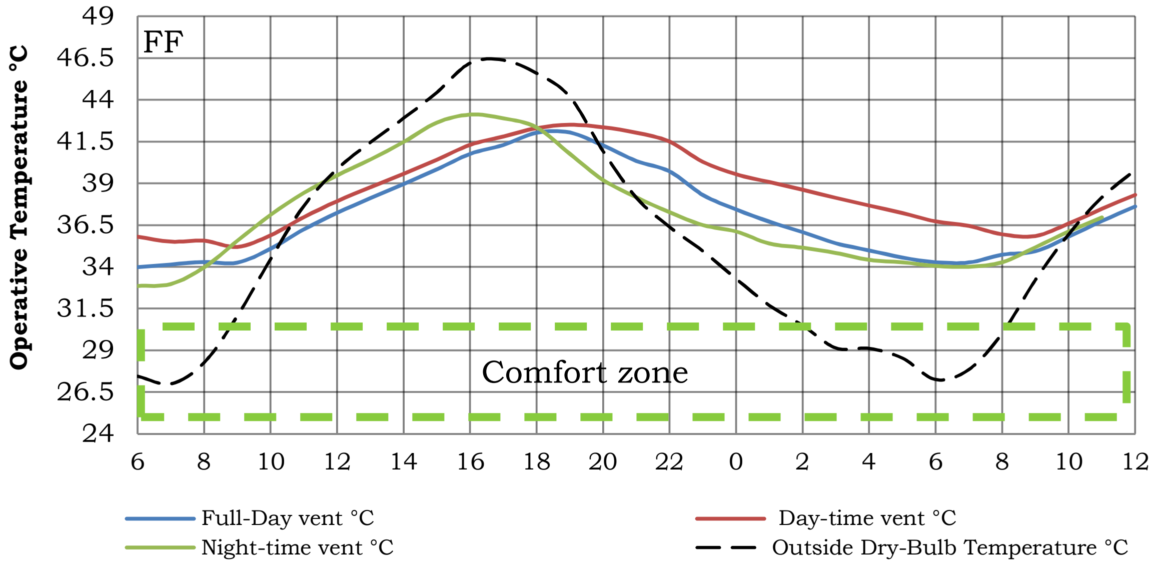


Figure 7.6: Variations method of scheduled natural ventilation by using calculated method time for bedroom in first floor in the hottest day, started from 6:00 AM on 24/06/14 to 12:00 PM on 25/06/14.

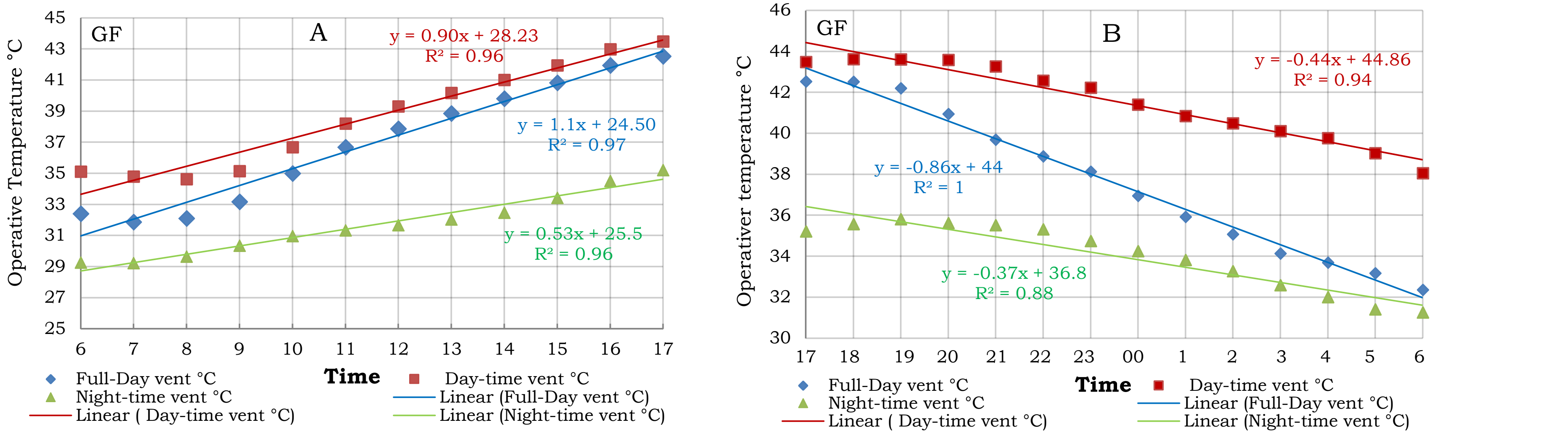


Figure 7.7: Trendline analysis for ventilation time plan in living room of ground floor for two period of time during 24 hours from 6:00 AM on 24/06/14 to 6:00 AM on 25/06/14. [A] On-Peak temperature from 6:00AM to 17 PM) – [B] Off-peak temperature from 17:00 PM to 6:00 AM)

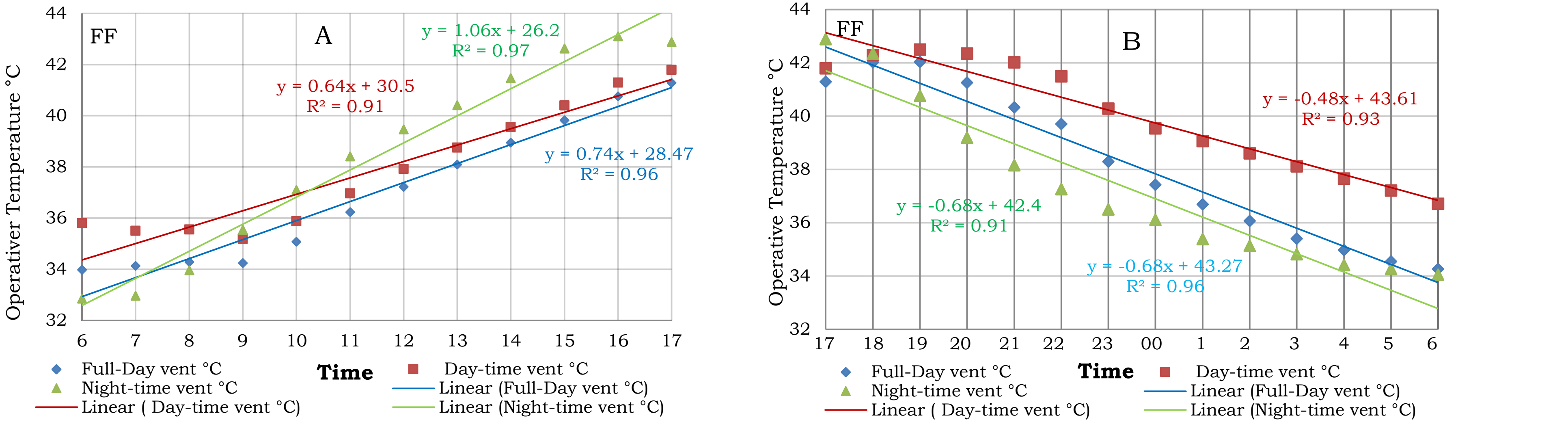


Figure 7.8: Trendline analysis for ventilation time plan in bedroom of first floor for two period of time during 24 hours from 6:00 AM on 24/06/14 to 6:00 AM on 25/06/14. [A] On-Peak temperature from 6:00AM to 17 PM) – [B] Off-peak temperature from 17:00 PM to 6:00 AM)

Day-time ventilation in Figures 7.7 and 7.8 presented the highest indoor temperature during on-peak temperature in percentage with R^2 = 0.96 and slope line of 0.90 in ground floor and R^2 = 0.91 with slope line of 0.64 in first floor. That means the temperature fluctuated with outdoor temperature, rising gradually and quickly.

This strategy is projecting the benefit of the character of cooling the thermal mass in night time. Moreover, there is an increase in the indoor temperature in day-time to above 40°C while the temperature increases outside to above 46°C. Alternatively closing the windows during night-time prevents the ventilation to maintain an indoor climate. However, during off-peak temperature from 17:00 PM to 6:00 AM, day-time ventilation presented the highest indoor temperature throughout off-peak temperature in percentage with R^2 = 0.94 and a slope line of -0.44 in ground floor and R^2 = 0.93 with slope line of -0.48 in first floor.

On the other hand, whole day ventilation presented a percentage of R^2 = 0.97 with high slope line of 1 in ground floor and R^2 = 0.96 with a high slope line of 0.74 in first floor. In this strategy, the indoor temperature fluctuated with outdoor temperature, rising gradually and quickly. In addition, it preformed with the level of outdoor temperature during the whole day, during the summer adding the factors of to the high daily variation of solar radiation, outdoor temperature and internal loads. This implies suspending the act of thermal mass to keep indoor temperatures cooler than outside by closing windows in day time and opening windows in night-time to reduce heat gains. However, during off-peak temperature from 17:00 PM to 6:00 AM, whole day ventilation presented a percentage of R^2 = 0.98 with high slope line of -0.86 in ground floor and R^2 = 0.96 with low slope line of -0.68 in the first floor. The outcome of this application means that whole day ventilation is a strategy act with outdoor temperature as the windows opening for 24 hours form on-peak of outdoor temperature that reached 46°C at 5:00 PM to off-peak of outdoor temperature that reached 27°C at 6:00 AM.

In the context of determining the relation between the whole performances of different ventilation time plan, Chi Square test is a method used for comparing variables between the observations from the simulation analysis against the reference of monitoring outdoor temperature. Statistically, it is a “goodness of fit” test which expresses whether there is a significant difference between what we observed and what was expected.

Basically, the chi-square values need to look at a Chi-square table to find the critical Chi square value for degrees of freedom, using the 0.95 probability level showing 13.848 Chi-Square Probabilities. In ground floor, ventilation plans have shown that night-time ventilation resulted in a significant difference between the day-time and the whole day ventilation where the sum of squares presented 23.3 that is above the Chi-Square Probabilities. This means the significant of night time ventilation can be seen in Figure 7.5 where outdoor temperature increased to 46˚C from 8:00 AM to 17:00 PM while indoor temperature decreased about 11K cooler than the maximum outdoor air temperature in day-time. However, when the outdoor temperature dropped to about 29˚C during night-time, the indoor temperature was higher to about 3K than the outdoor temperature.

On the other hand, night-time ventilation, on the first floor, resulted to insignificance since the sum of squares presented 12.0 which is below the Chi-Square Probabilities. This means the range of indoor temperature is closer to the outdoor temperature in day time while the difference is about 3K. Furthermore the indoor temperature is higher by about 5K during night-time than the outdoor temperature as shown in Figure 7.6.

Ventilation plans of day-time in the living room of the ground floor presented 34.7 of sum of Chi-Square, which is the highest between those three plans of ventilation and it exceeded the Chi-Square Probabilities. This means that ventilation plan of day-time has the worst performance during day-time as the indoor temperature started from 35°C at 6:00 AM while the outdoor temperature started from 26°C and reached 43°C at 18:00 PM when outdoor temperature reached 44°C. However, during night-time the outdoor temperature ranged from 38°C ~ 27°C while the indoor temperature ranged from 43°C ~ 35°C in terms of closing the windows which caused discomfort to indoor environment. Similarly, in the first floor the sum of Chi-Square is 28.2 which exceeded Chi-Square Probabilities and this ventilation plan performed identically as on the ground floor where the indoor temperature ranged between 36°C ~ 42°C in day-time while in night-time it ranged from 42°C ~ 36°C.

Lastly, the sum of Chi-Square showed insignificant results for the whole day ventilation plan causing uncomfortable environment that represented 9.7 on the ground floor as the indoor temperature is closer to the outdoor temperature, i.e. when the indoor temperature was about 42°C, the outdoor temperature reached 46°C. However, on the first floor the sum of Chi-Square resulted 16.7 as closer to the Chi-Square Probabilities which is an indication of insignificant result being recorded as shown in Figure 8.6 where indoor performance resulted in high temperature increasing over 40°C during day time as closer to outdoor temperature, whereas in night-time increasing above outdoor temperature as the indoor temperature is caused by heat that is released from thermal mass. However, with the ventilation time plan method, the indoor comfort temperatures have still not been achieved within comfort zone.

7.3.3 Assessing Ventilation Performance by Changing Window Opening Door Ratio

Recognizing the benefits of ventilation performance, Figures 7.9 and 7.10 are showing the profile of indoor operative temperature of the living room on ground floor and the bedroom on the first floor, as well as the calculated ventilation method that is used for the whole day ventilation strategy combining day-time and night-time. The opening ratios based on the choice of four scenarios that tested 25%, 50%, 75% and 100% of opening the whole window doors.

A profile of outdoor temperatures reveals a noticeable diurnal cycle with extensive maximum and minimum at 17:00 PM at 24/06/14 and 06:00 AM at 25/06/14. These variations are in an anticipated order as the peak of temperature in day-time over 40°C and the lowest temperature about 26°C during early morning were almost following the same pattern as noticed from weather monitoring.

Objectively, from monitoring weather data between 21/06/14 to 26/06/14, it can be observed that the significant temperature differences between all variations which is about 21K is due to big drops in outdoor temperatures between day-time and night-time. However, low and high wind speed from 0 km/h to 31.7 Km/h as recorded by the weather station in Ghadames with high outside temperature during the summer season doesn't show that much effect of reduction in heat gain, although, it is necessary to open the windows to allow air stream movement to refresh indoor space for health and wellbeing.

In Figures 7.9 and 7.10, the diurnal temperature swings of around 9K between day and night while the peak of temperature is 46°C at 17:00 PM and 27°C as the lowest at 6:00 AM. Therefore windows opening option is more effective in night-time where the thermal mass may play a role for moderating the indoor temperature swings by coupling to external air. One issue to be mentioned is that the effect of thermal mass to the overall thermal performance is not investigated at this step. However, it is obvious that the ventilation rates during the night time between 3:00 AM and 06:00 AM on 25th of June are relatively smaller than the day time where the potential for night ventilation can be decreased accordingly.

Logically, the aspect of night ventilation may be an optional way of reducing the internal operative temperature during the hot-season because of the role of thermal mass in moderating the temperature swings. In ground floor, Figure 7.9 is showing the profile of night-time ventilation when applying 25% opening area for ventilation was about 1.9 ~ 3K below the reference building of no ventilation during the night-time and early morning, whereas about 1.5K below the reference building in the peak hour.

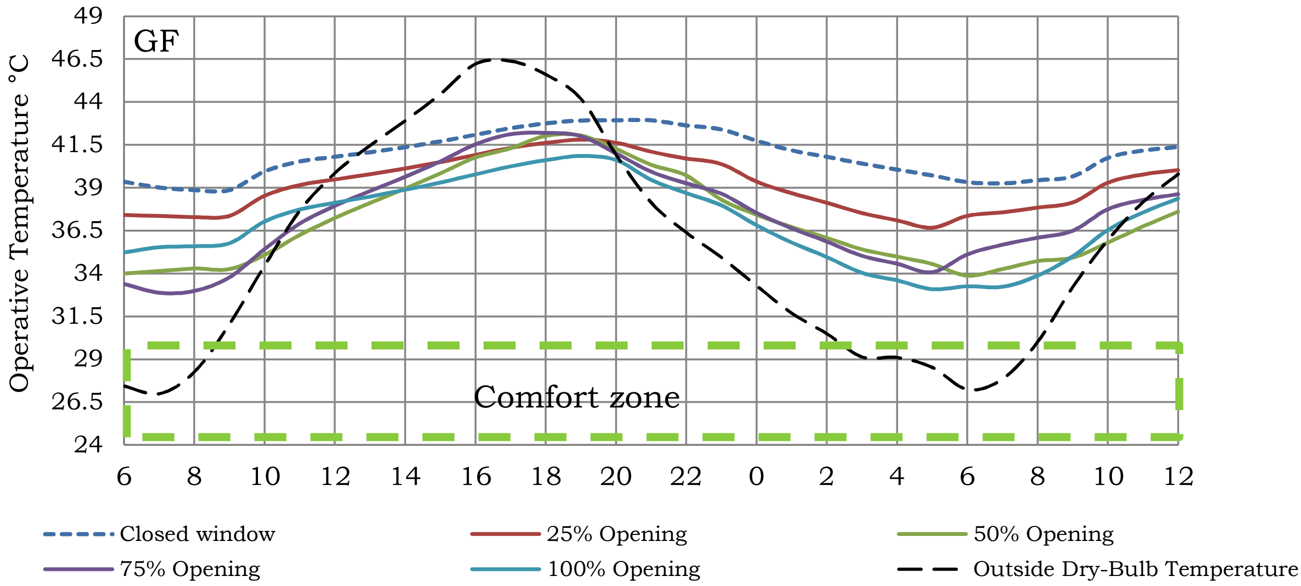


Figure 7.9: Different opening ratio by using calculated method with whole-day ventilation strategy for living room in ground floor in the hottest day, started from 6:00 AM at 24/06/14 to 12:00 PM at 25/06/14.

In first floor, Figure 7.10 is showing the profile of night-time ventilation when applying 25% opening area for ventilation was about 1~1.5K below the reference building of no ventilation during the night-time and early morning, whereas about 0.5K below the reference building in the peak hour. On the other hand, applying 50% and 75% of opening window door for ventilation in ground floor provided the same character between 18:00 PM to 4:00 AM which is about 0.55~5.5K below the reference building of no ventilation. Meanwhile, in first floor as shown in Figure 7.10, when applying 50% and 75% of opening window door for ventilation from 6:00 AM to 21:00 PM, this is presenting a state of agreement about 0.5K below the reference building of no ventilation during the day-time to both options. Similarly, in night-time between 20:00 PM to 5:00 AM there is a state of agreement about 0.35 ~ 2.75K below the reference building of no ventilation during the night–time.

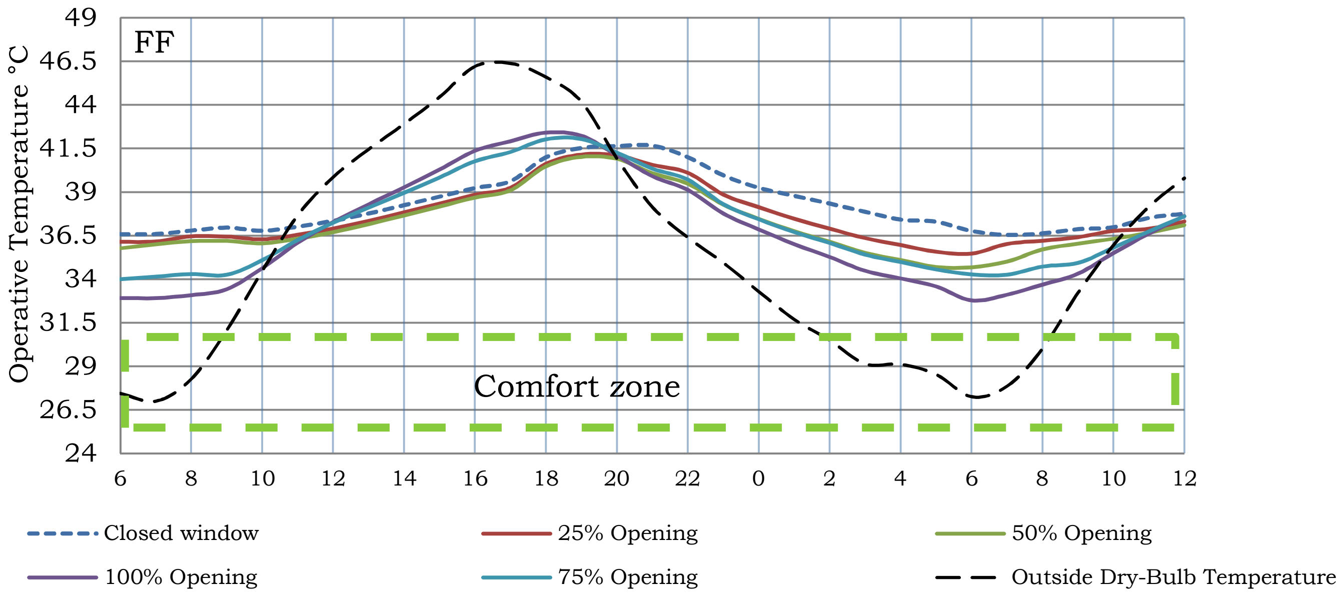


Figure 7.10: Different opening ratio by using calculated method with whole-day ventilation strategy for bedroom in first floor in the hottest day, started from 6:00 AM at 24/06/14 to 12:00 PM at 25/06/14.

On the overall performance, 100% opening area for ventilation has two different characteristics, in the peak of day-time and in the peak hour about 2K below the reference building while on the ground floor about 4.8 ~ 4K below the reference building of no ventilation in night-time and early morning between 20:00 PM to 6:00 AM. However, on the first floor, as the thermal performance is different from the ground floor due to thermal mass character and the roof being exposed to sun rays, the indoor temperature is higher than the reference building of no ventilation about 2K in day-time while at night-time approximately 0.3 ~ 4K below the reference building of no ventilation between 20:00 PM ~ 6:00 AM.

As previously mentioned, the analysis demonstrated that 100% of opening area is best among openings' options to enhance indoor thermal performance of night-time during the hot summer where outdoor temperature is cooler than that of day-time. However, it may be more difficult to achieve the desired adaptive thermal comfort if the ventilation velocity rates are less than 0.5 m/s which are not adequate for personal cooling at comfortable air temperatures (Heerwagen, 1996).

7.4 Thermal Performance Analysis

The thermal performance of a building depends on how a building has been designed in the way of how a building behaves and performs as governed by its envelope design (walls, roofs & windows). It is therefore important to understand material behaviour under the influence of thermal loads to meet the comfort of occupants, as well as, to identify the optimum “passive design” and construction materials’ specifications and details for the new envelope design. The ability of a wall, floor, roof, window or door to impede heat loss from a dwelling is described in terms of its thermal transmittance (U-value), which is expressed as the transfer of heat in watts per square metre of area per degree difference in temperature (Doran and Bernard, 2008). In simple words, the simulation analysis is applied to the entire building as an integrated system to capture interactive effects of building components on thermal performance on the following aspects.

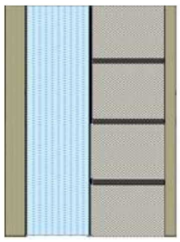
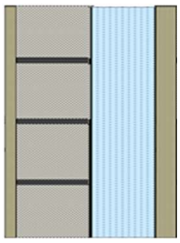
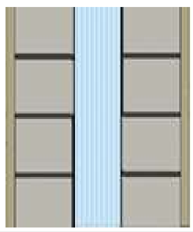
7.4.1 Influence of Insulation in Thermal Mass on Indoor Air Temperature

In terms of insulation and application, polyurethane foam has an R-value of approximately 6.0-7.0 per inch. This R-value is significantly higher than glass fibre, wool, and cellulose insulations. It is adequate for residential, commercial, and industrial buildings, as well as, adds strength to the building structure (Do, et al. 2009).

The levels of thermal insulation polyurethane foam were tested (100mm, 150mm, 200mm, 250mm & 300mm) to investigate the effect of thermal transmittance (U-value) of the external walls on internal temperature and the existing residential building (Base-case) has been simulated as a reference case without any thermal insulation.

Thermal mass and insulation are a combination of the two materials to optimise fabric energy efficiency where the position of the insulation relative to the thermal mass is of particular importance. The first step is to analyse the place of insulation positioning on the walls to determine the best performance that can make improvement to attain indoor comfort temperatures as shown in Table 7.2:

Table 7.2: Thermal insulation position in external wall

Wall Materials	Thickness (mm)	Wall Section
1. Exterior wall rendering (Out) 2. Polyurethane foam (Thermal insulation) 3. Cement block 4. Plaster	15 100 200 5	In  Out
1. Plaster (Out) 2. Cement block 3. Polyurethane foam (Thermal insulation) 4. Plaster board	5 200 100 15	In  Out
1. Plaster (Out) 2. Cement block 3. Polyurethane foam (Thermal insulation) 4. Cement block 5. Plaster	5 200 100 150 5	In  Out

The effect of mass and insulation location related to mass layer affects both the time lag of the heat, flux through a wall and the ability of reducing interior temperature fluctuation (Byrne and Ritschard, 1985).

Figures 7.11 and 7.12 investigated thermal mass effect on indoor operative temperature in winter season between 21/01/14 to 23/01/14 by adding insulation in three places: the outside surfaces, inside surfaces and between walls of the structure. In Figures 7.11, applying a 100mm layer of thermal insulation with (U= 0.21 W/m² K) for external walls maintains indoor temperature and keeps it steady on the ground floor where the averages of temperature fluctuate between about 22.5°C to 29°C, which is approximately in the range of 6.5K between day and night. At the same time, comparisons between applying insulation outside wall surface and inside wall surface are provided: they indicate that the performance of insulation outside the wall showed a better action which keeps operative temperatures in the range between about 11.5K to 7.5K higher than the performance of applying insulation inside the wall surface in ground floor.

On the other hand, the operative temperature in reference building of ground floor fluctuates in the range of 8.5K between day and night.

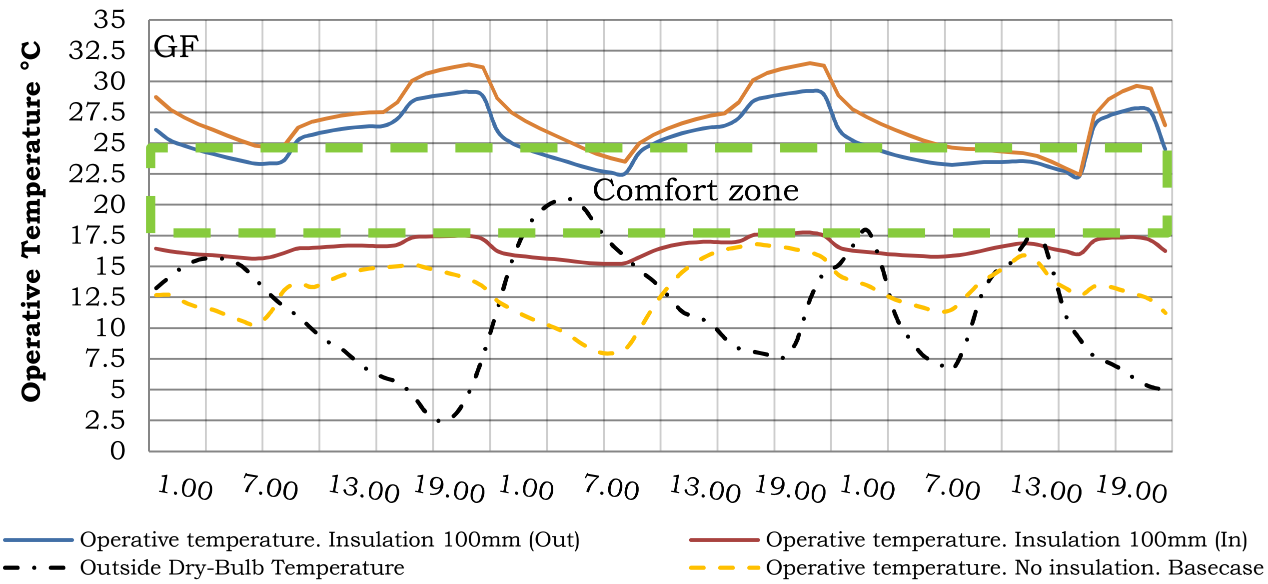


Figure 7.11 shows effects of out wall insulation and internal insulation on internal operative temperature against the reference building which has no thermal insulation in living room of ground floor in the coldest days, started from 1:00 AM at 21/01/14 to 12:00 PM at 23/01/14.

Meanwhile, the variation of applying insulation between walls is depicted in Figure 7.11. As can be seen, the operative temperature is fluctuating approximately between 31-22°C and thus the variation range is 2K higher than that of the insulated outside the wall scenario.

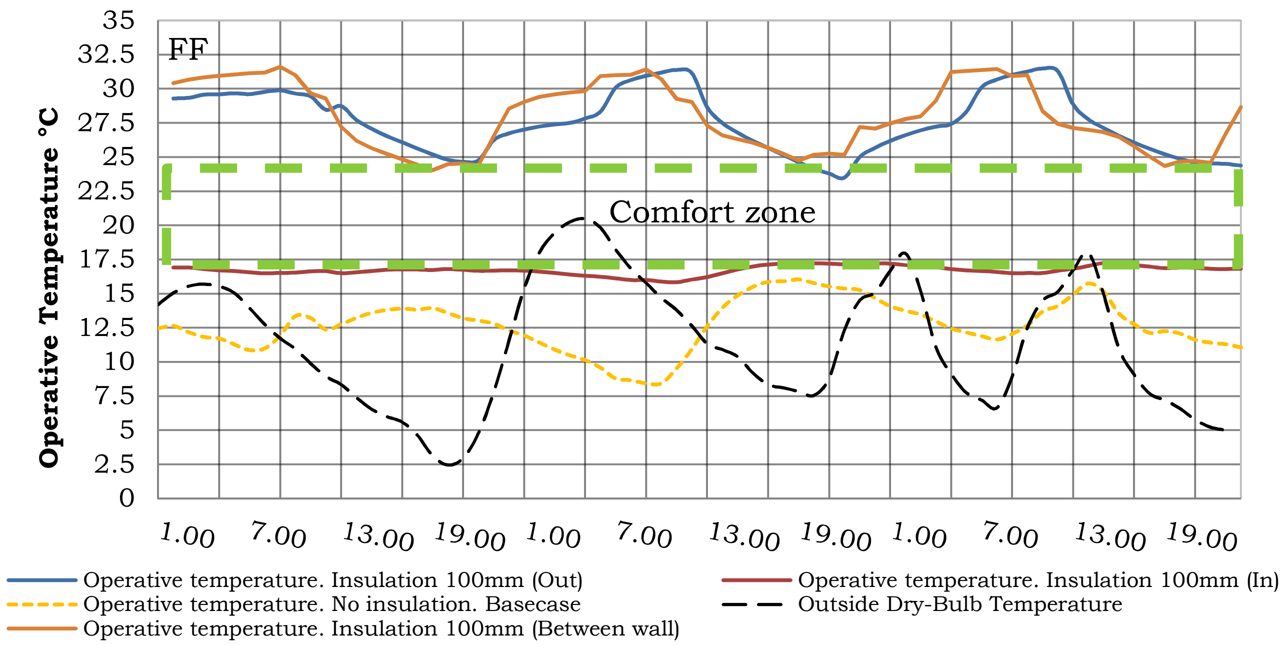


Figure 7.12 shows effects of out wall insulation and internal insulation on internal operative temperature against the reference building which has no thermal insulation in a bedroom of first floor in the coldest days, started from 1:00 AM at 21/01/14 to 12:00 PM at 23/01/14.

On the first floor, as can be seen in Figure 7.12, there is a similar character of performance as the one on the ground floor where operative temperature in reference building fluctuates approximately in a maximum range of 8K between day and night. Meanwhile, insulation with (U= 0.21 W/m2 K) for external walls maintains operative temperature and fluctuates over 23°C, and keeps it steady in an average of 6K between day and night. The simulated operative temperature from applying insulation between walls is depicted in Figure 7.12. As can be seen, the operative temperature is fluctuating approximately between 24-31°C. However, applying insulation inside the wall surface is showing the worst performance between other insulation options where the operative temperature is fluctuating in steady-state position about 2K variations between day and night in the range of temperature between 15.8~17°C.

In the same way, Figures 7.13 and 7.14 investigated thermal mass effect on indoor operative temperatures in the summer season between 24/06/14 to 25/06/14 by insulating the external wall surface, insulating the internal wall surfaces, and also insulating the cavity wall as shown in Table 7.2.

On the ground floor, as can be seen in Figures 7.13, applying insulation between walls shows that the operative temperature from simulation results dropped down about 4K between 6:00 AM ~ 13:00 PM in the range of temperature approximately among 36°C-32°C. However, the operative temperature increased between 13:00 PM ~ 20:00 PM where outdoor temperature started to increase from 41°C then to decrease when the outdoor temperature started dropping down to about 39°C. In the evening and night-time when out-temperature is dropping down from 46°C at 17:00 PM to 27°C at 6:00 AM, the indoor operative temperature also started to drop down about 7K. Similarly, on first floor, Figure 7.14 is implying that applying insulation between walls provided the same pattern as that of the ground floor where the operative temperature dropped down about 2K between 6:00 AM ~ 14:00 PM in range of temperature approximately among 36-34°C, then increased from about 34°C to around 40°C at 20:00 PM then again dropped down in evening and night-time to 32°C at 6:00 AM which is about 8K.

Overall, the Figure 7.13 is showing the poor performance of applying insulation inside wall surfaces of the structure on the ground floor where indoor operative temperature increased at 9:00 AM from 37°C~42°C then dropped down in evening and night-time similar to the other insulation scenarios. Likewise, the Figure 7.14 is showing the poor performance of applying insulation inside wall surfaces on the first floor between 6:00 AM to 19:00 PM about 6K ~ 7K higher than applying insulation between walls from 9:00 AM to 20:00 PM. On the other hand, applying insulation on the outside wall shows that the performance fluctuated in the same order of applying insulation between walls with some variations in the temperature between 6:00 AM to 20:00 PM, then dropped down in evening and night-time in the same character of other insulation options/scenarios.

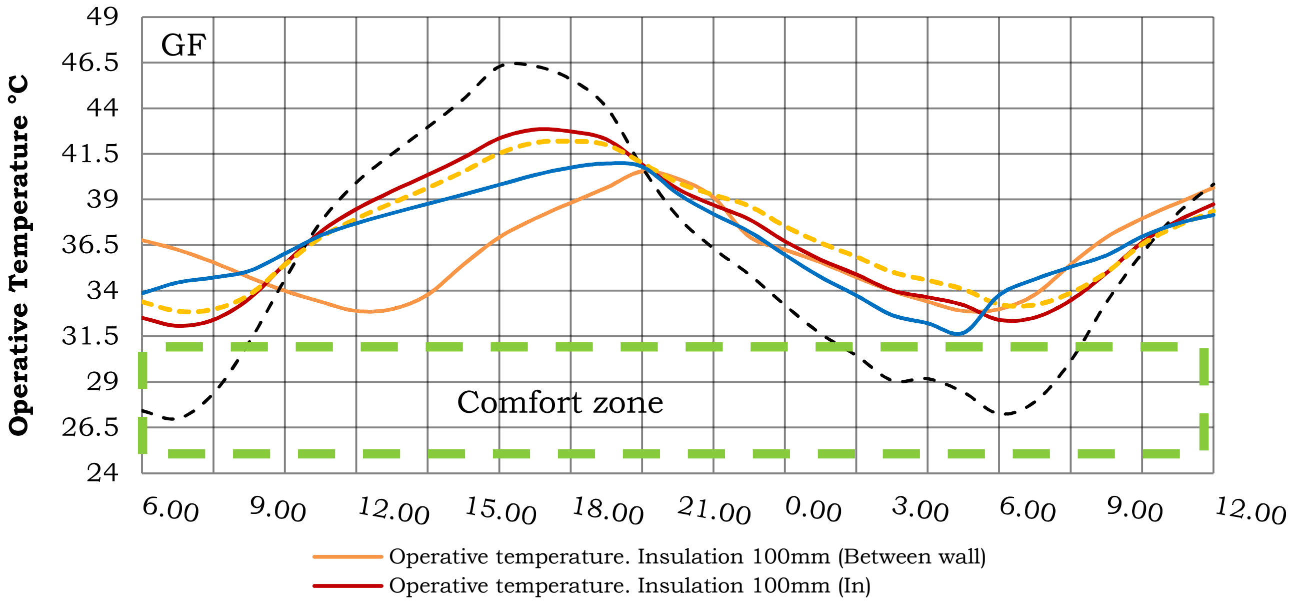


Figure 7.13 shows effects of out wall insulation and internal insulation on internal operative temperature against the reference building which has no thermal insulation in living room of ground floor in the hottest days, started from 6:00 AM at 24/06/14 to 12:00 PM at 25/06/14

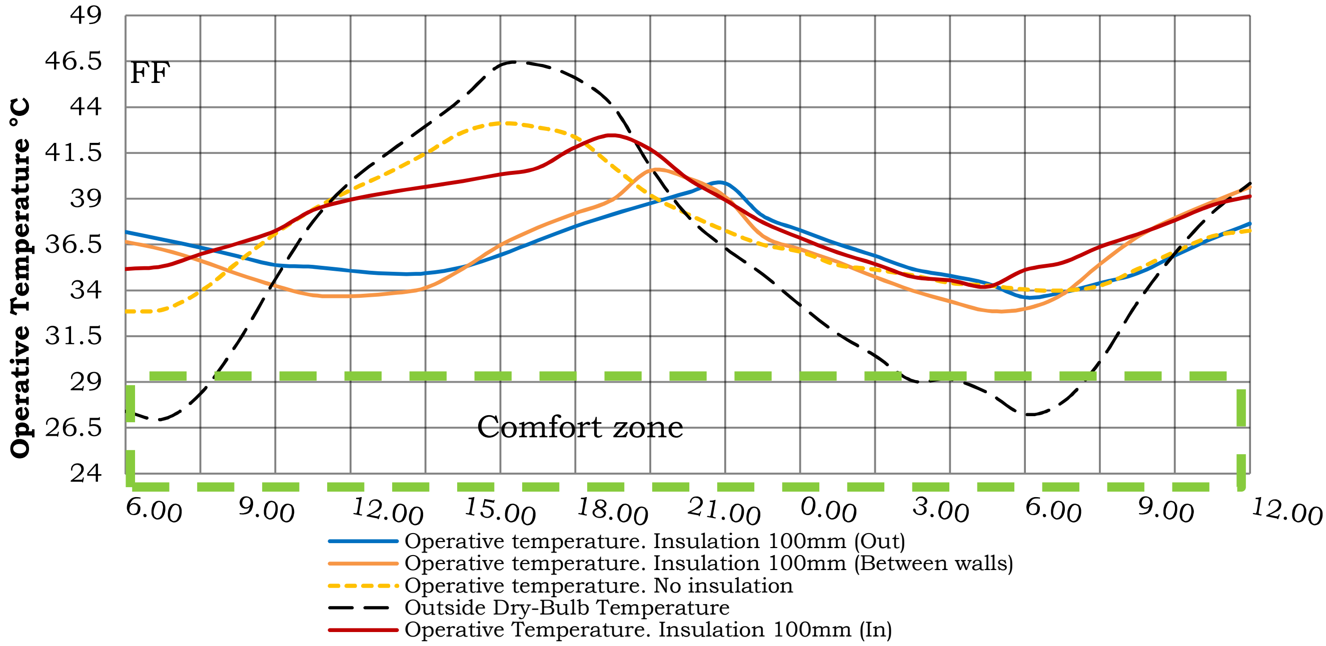


Figure 7.14 shows effects of out wall insulation and internal insulation on internal operative temperature against the reference building which has no thermal insulation in the bedroom of first floor in the hottest days, started from 6:00 AM at 24/06/14 to 12:00 PM at 25/06/14.

In order to finalize the output data, the thermal simulation analysis has used a wide range of forecasting temperature with about 71 hours in winter and about 31 hours in summer. As a result, the differences are compressed to recognize the best option regarding insulation solutions which, making these differences more difficult to judge large values. Therefore, using the common logarithmic scale "base of ten" as a nonlinear scale is useful to reduce a large range of quantities and this is based on orders of magnitude where the equation y = log b (x) means that y is the power or exponent so that b is raised to an order to get x (Robbins, 2012).

In winter, the Figure 7.15 demonstrated the averages of operative temperature according to calculated standard deviation which lead to R-value, when looking at the graphs in Figure 7.15, the results of one type of wall to the other: it appeared that the option of design wall thickness with (inner insulation) had almost no effect on the thermal behaviour. The Trendlines of applying inner insulation inside wall surface showing standard deviation where R2 are 0.39 on ground floor and 0.28 on first floor that almost a horizontal straight line in both floors, which means insulating the materials on a building's interior cannot provide thermal mass and had little or no influence on thermal behaviour.

On the other side, the result for walls designed with outer insulation has proven to be sensitive to indoor thermal behaviour, the tendencies observed were much high than what was in wall thickness with inner insulation. The R^2 coefficients of the Trendlines presented 0.41 in ground floor and 0.71 in first floor as shown in Figure 7.16. This means outer insulation (Expanded Polystyrene) is one of the most effective solutions that can have benefits as a design option outside external walls to maintain interior spaces from the surrounding. However, applying insulation between walls provided the lowest R^2 0.31 on the ground floor, meaning that this option has a significant effect on the operative temperature and has common interaction points where the indoor temperature shared the same character with outer insulation design. On the first floor, the R^2 is 0.69 and the Trendline intersection with Trendline outer insulation shared the same character.

In summer, similarly, when applying wall thickness with inner insulation, the Trendline deviated to high temperature when the coefficient of determination R2 is over 0.90 in ground floor and over 0.80 on the first floor that means the Trendline is too steeper and that it is not sensible to apply inner insulation as a valid option.

Looking at outer insulation, the graph about the ground floor showed that R2 is 0.85, which means that the outer insulation has little influence on the indoor climate as the Trendline deviated to high temperature. However, applying insulation between walls led to a very low R2 value about 0.18 which had more sensible influence on the minimal indoor operative temperature. On the first floor, the option of outer insulation has a significant effect on operative temperature and has common interaction points where the indoor temperature shared the same character with outer insulation design. For the first floor, the R2 is 0.69 and the Trendline intersection together with the Trendline of insulation between walls shared the same character where R2 is 0.11.

As is evident from the Figures 7.15 and 7.16, in terms of difference between the insulation types, it clearly appears that the insulation between walls has an influence on the average air temperature. Therefore, it can be concluded that the relationship between averages of air temperature with thermal mass depends on the insulation thickness on one the hand, and the location of insulation with thermal mass on the other hand, which still remains effective.

In this study, in order to choose the best option of insulation place that is reliable for thermal mass, one-tail t-test was used to compare the means of each insulation option between outside temperature and different insulation treatments given. In statistical terms, the purpose of analysis is to determine what type of insulation was generally increasing or decreasing operative temperature with time by using two hypotheses to test whether one mean was less than the other: $\mu_{\text{(outside temperature)}} < \mu_{0\ \text{(indoor temperature)}}$ or greater than the other: $\mu_{\text{(outside temperature)}} > \mu_{0\ \text{(indoor temperature)}}$. Firstly in the winter, the null hypothesis was H_0: outside temperature = indoor temperature (after insulation) or alternative hypothesis was H_1: outside temperature < indoor temperature (after insulation) with α =0.05. Secondly in summer, the null hypothesis is H_0: outside temperature = indoor temperature (after insulation) or alternative hypothesis is H_1: outside temperature > indoor temperature (after insulation) with α =0.05.

The comparisons are made in order to determine which treatments were the best options in keeping the temperature lower or higher with regard to the summer and winter seasons respectively. On the top of that, the analysis shows that there are significantly different average temperature between the operative temperature and all other treatments given. Among the treatments, thermal insulation between walls has the highest mean values of 1.4293 and in fact with temperature fluctuation of about 26.8°C and a high value of stdev 0.0383 throughout the day compared to the mean of operative temperature o: 171 r insulation 1.4040 in average of operative temperature 25.3°C with stdev 0.0349. In contrast, the inner insulation indicates a lower mean of 1.2166 in average of operative temperature 16.4°C with stdev 0.0183, which is below the adaptive comfort temperature of 21.5°C. On the average, the thermal insulation between walls is about 1.5K warmer than the outer insulation. This difference varied at the standard deviation level when the inner insulation is rejected for poor performance against other insulation places.

Similarly, for the first floor, the insulation in bedroom external wall shows that thermal insulation between walls has a mean of 1.4445 and an average of operative temperature of 27.8°C with stdev value of 0.0387, values that are slightly higher compared to the mean of the outer insulation of 1.4383 in the average of the operative temperature of 27.4°C with stdev 0.0357. Conversely, the inner insulation indicated a lower mean 1.223 in average of operative temperature 16.7°C with stdev 0.00882, which is below adaptive comfort temperature 21.5°C. On the average, the thermal insulation between walls is about 0.4K warmer than the outer insulation. This difference varied at standard deviation while inner insulation is rejected after having produced a poor performance against other insulation places.

In the same way, in summer, on ground floor, the insulation in the living room wall shows that thermal insulation between walls has a mean of 1.5562 in average of the operative temperature of 35.9°C with a stdev value of 0.0288, which are slightly lower compared to the mean of the outer insulation of 1.5629 in average of operative temperature of 36.5°C with a stdev of 0.0316. Nevertheless, inner insulation indicates a high mean of 1.5655 and an average in the operative temperature of 36.7°C with a stdev 0.0411. Overall, all thermal insulation places have evidenced a high indoor temperature than the adaptive comfort temperature of 28°C with little variation between each other of about 0.6 ~ 0.7K.

Correspondingly, on the first floor, the bedroom insulation shows that thermal insulation between walls has a mean of 1.5584 in an average of operative temperature of 36.1°C with a stdev value 0.0187, which are slightly higher compared to the mean of outer insulation of 1.5564 in an average of operative temperature of 36°C with a stdev of 0.0267. Nonetheless, the inner insulation indicates a high mean of 1.5767 in an average of operative temperature of 37.7°C with a stdev of 0.0268, which is higher than the adaptive comfort temperature of 28°C. Altogether, the thermal insulation places have proven a high indoor temperature than the adaptive comfort temperature of 28°C with a slight difference between each other of about 0.1 ~ 1.7K and of about 9, higher than the adaptive comfort temperature in summer.

Ultimately, in both seasons of winter and summer, the thermal insulation of inner insulation has proven a poor thermal performance.

On the other hand, thermal insulation between walls can maintain indoor temperature above the adaptive comfort level in winter.

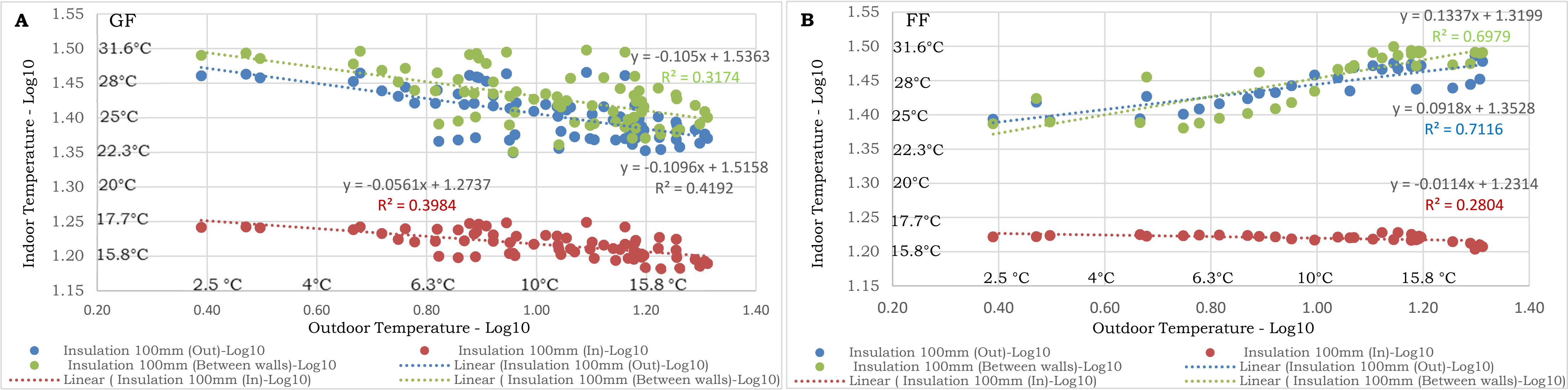


Figure 7.15: Trendlines analysis effect of insulation's location on indoor operative temperature in winter from 21/01/14 to 23/01/14. [A] living room in ground floor – [B] Bedroom in first floor

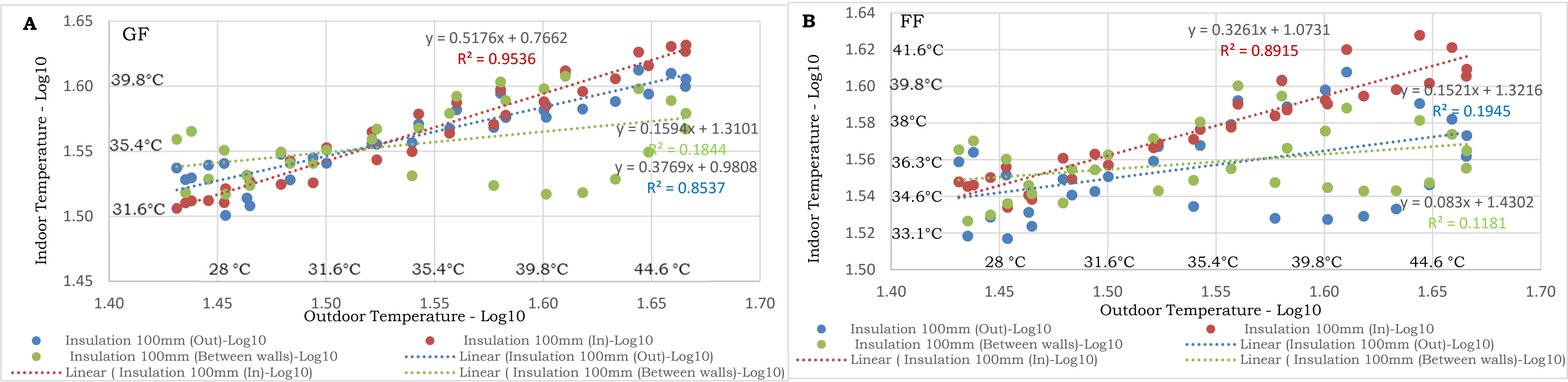


Figure 7.16: Trendlines analysis effect of insulation's location on indoor operative temperature in summer from 24/06/14 to 25/06/14. [A] living room in ground floor – [B] Bedroom in first floor

However, in summer, the thermal insulation between walls cannot maintain an indoor temperature without changing the insulation thickness to achieve optimum thermal mass which can maintain indoor adaptive comfort temperature. The next step is to vary the insulation thickness in terms of improving thermal behaviour of indoor climate by using a cavity wall insulation.

7.4.2 Influence of Thermal Mass and Insulation Thickness on Indoor Air Temperature

A thermal insulator decelerates the transfer of heat between different areas at different temperatures and limits heat loss through the building fabric in winter and inward heat flow in summer (Mohammad and Shea, 2013). In relation to thermal mass performance, the results from dynamic simulation provide a different appraisal of the optimum solution throughout variations of thermal insulation thickness between walls (as shown in Table 7.3) that are employed to investigate the effect of thermal transmittance (U-value) of opaque constructions (walls) on internal temperature.

Table 7.3: Thermal transmittance for different insulation thickness with thermal mass

Insulation Thickness (mm)	Total thermal mass of Double wall thickness (mm)	U-value ($W/m^2 K$)
No insulation	250	1.08
100	350	0.19
150	400	0.14
200	450	0.11
250	500	0.09
300	550	0.08

In winter, Figures 7.17 and 7.18 plotted graphs show the effects of external walls with U-values compared against the reference building between 21/01/14 to 23/01/14 by adding insulation thickness as shown in Table 7.3. Figure 8.17 indicated that applying a 300mm layer insulation with thermal mass thickness (U= 0.08 W/m^2 K) maintains indoor temperature and keeps it steady on the ground floor where average of temperature fluctuates between about 25°C to 32°C, which, approximately is in the range of 7K between day and night.

In same time, the operative temperature of first floor in Figure 7.18 indicated that applying 300mm layer insulation with thermal mass thickness preserves indoor temperature and keeps it steady while average of temperature fluctuates between about 25°C to 32°C, which, approximately is in the range of 7K between day and night. However, in both floors, comparing between applying different thickness of insulation showing small variation of changing indoor temperature between different insulation thickness 150, 200, 250 & 300mm which about ±0.5K. Conversely, the variation of changing indoor temperature between 100mm and 300mm of insulation thickness is about 2K.

Overall, in winter, the performance of applying 300mm showed the operative temperature is fluctuating approximately between 25-32°C in range of 7K and higher 15~17K than reference building that fluctuates at lower range between 16 ~ 8°C between day and night . On hot summer days, the graphs in Figures 7.19 and 7.20 illustrated the effects of adding insulation thickness on external walls with U-values compared against the reference building between 24/06/14 to 25/06/14 as shown in Table 7.3.

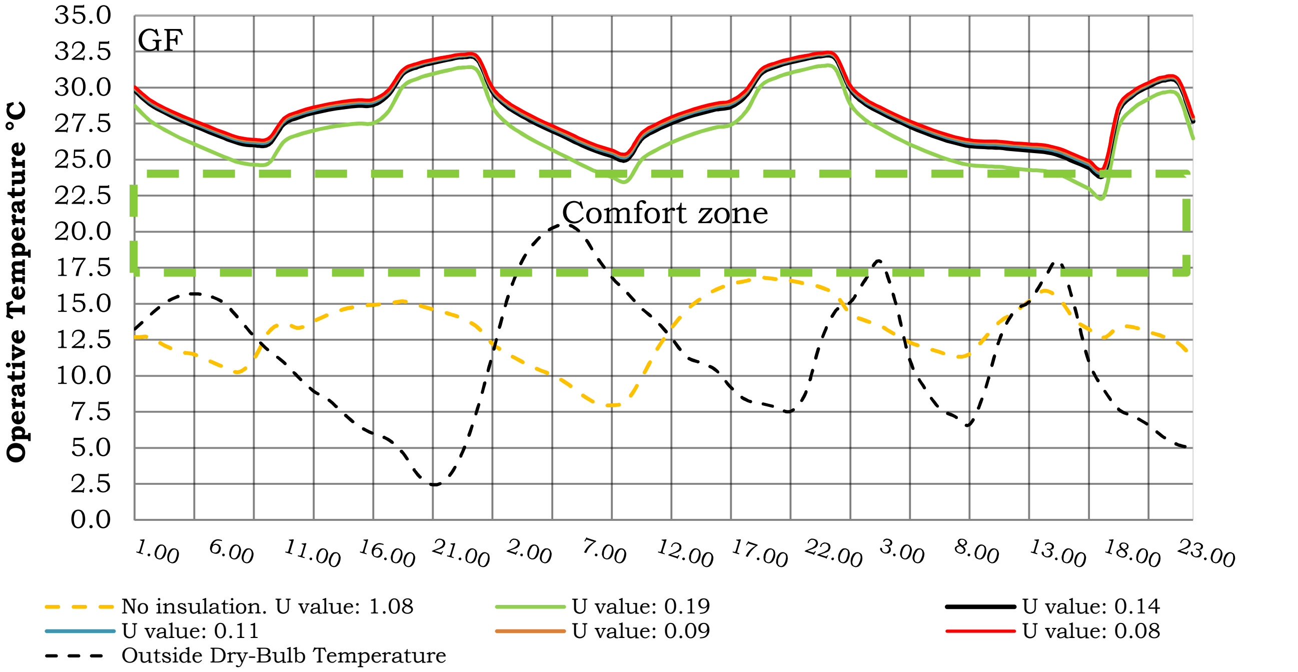


Figure 7.17 shows effect of U-values of wall insulation on operative temperature in living room of ground floor in the cold days, started from 1:00 AM at 21/01/14 to 12:00 PM at 23/01/14.

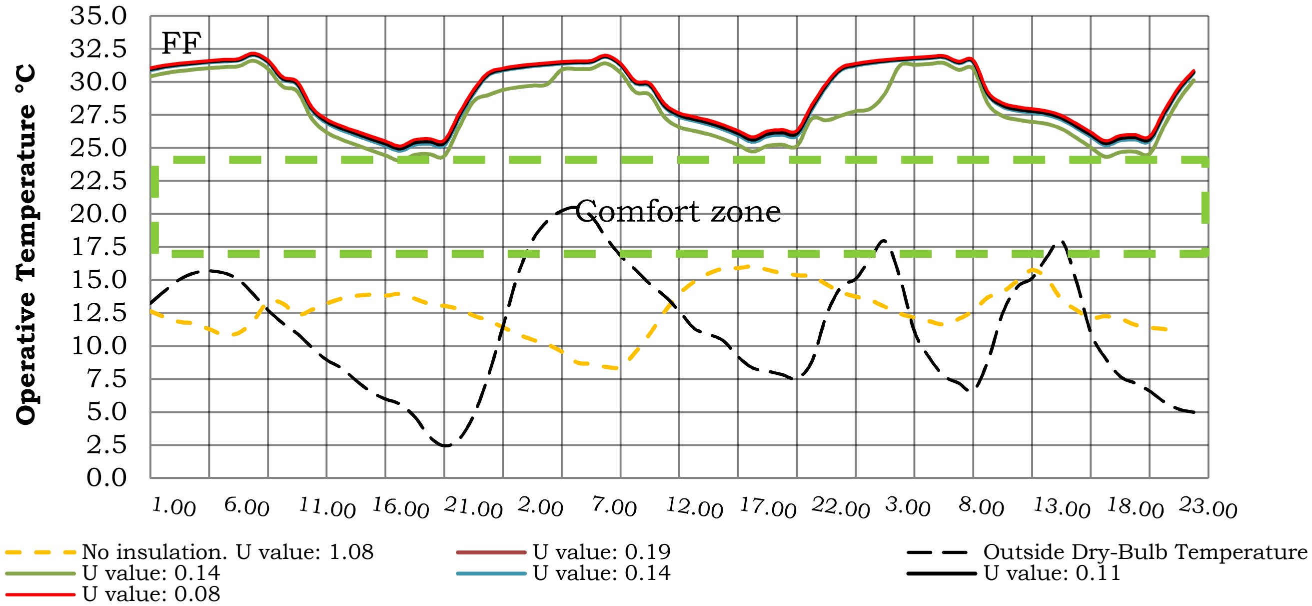


Figure 7.18 shows effect of U-values of wall insulation on operative temperature in bedroom of first floor in the cold days, started from 1:00 AM at 21/01/14 to 12:00 PM at 23/01/14.

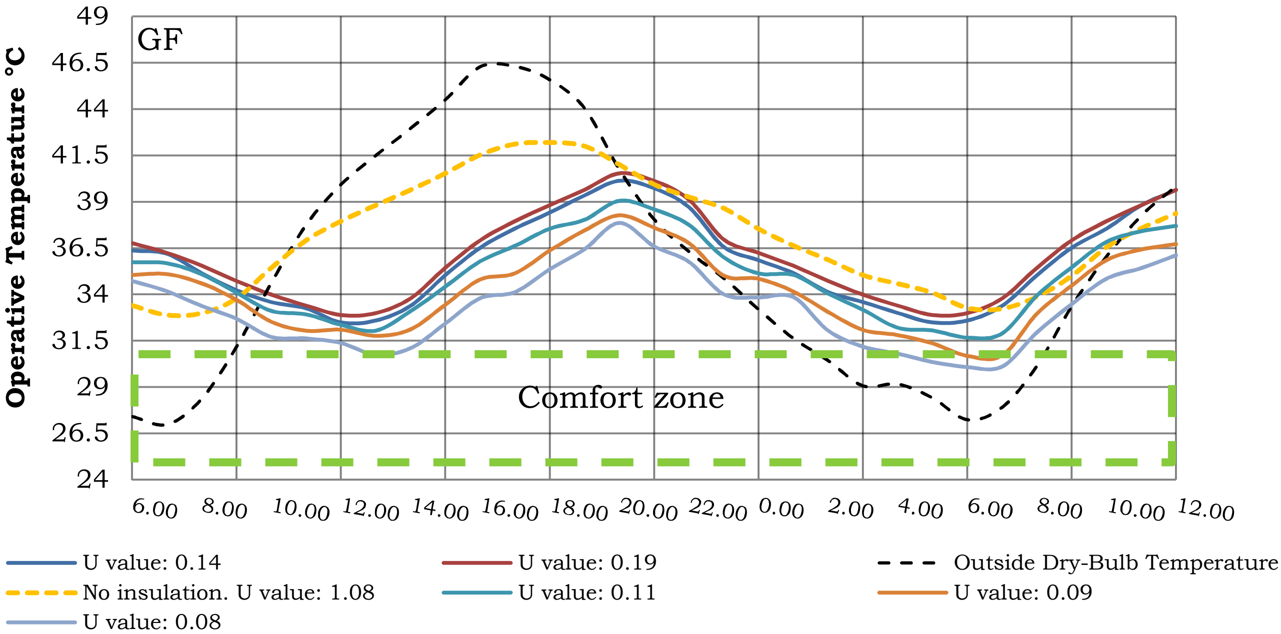
In ground floor, Figure 7.19 indicated that applying a 300mm layer insulation with thermal mass thickness (U= 0.08 W/m2 K) preserves the indoor temperature and keeps it steady in the ground floor where the average temperature fluctuates between about 30°C to 37°C, which, approximately is in a range of 7K between day and night. At the same time, the operative temperature of first floor in Figure 8.20 indicated that applying a 300mm layer insulation with thermal mass thickness preserves the indoor temperature and keeps it steady while the average temperature fluctuates between about 31°C to 39°C, which approximately, is in range of 8K between day and night.

However, in both floors, comparisons between applying different thickness of insulation show a slight variation in indoor temperature changing according to different insulation thickness of 150, 200, 250 & 300mm which is about ±0.5K. Conversely, the variation of fluctuating indoor temperature between 100mm and 300mm of insulation thickness is about 4K on the ground floor and 2K on the first floor.

Generally, in summer, the performance of applying 300mm shows the operative temperature fluctuating approximately in the range of 7K on the ground floor and 8K on the first floor and lowering about 8K than the reference building in day time and by 3K in night time in both floors.

Statistically, t-test analysis shows that there are significantly different average temperatures between the operative temperature and all the wall insulation thickness given. In the winter season, on the ground floor, between different thicknesses, U value 0.08 of double wall thickness 550mm with 300mm of thermal insulation have the highest mean values of 1.4537 and in fact with a temperature fluctuation of 32°C and a stdev of 0.0321 throughout the day.

U value of 0.19 and of 350mm in a double wall thickness with 100mm insulation have the lowest mean of 1.4293 with satisfactory thermal performance while other insulation thickness respectively of 150mm in double wall thickness of 400mm (U values: 0.14 with mean 1.4481), 200mm in double wall thickness of 450mm (U values: 0.11 with mean 1.4508) and of 250mm in a double wall thickness of 500mm (0.09 with mean 1.4525) have a slightly different range of small fluctuations, the beneficial impact of an increasing wall thickness on the thermal performance. This indicates that increasing wall thickness improves the thermal resistance and results in a lower U-value.



7.19 shows effect of U-values of wall insulation on operative temperature in living room of ground floor in the hottest days, started from 6:00 AM at 24/06/14 to 12:00 PM at 25/06/14.

Similarly, for the first floor, the same conclusion can be drawn from Figure 7.18 showing that U-values 0.08 of double wall thickness 550mm with 300 mm insulation thickness result in the highest mean of 1.4617 with a stdev of 0.0360; whereas U value of 0.19 of 350mm of double wall thickness with 100mm insulation have the lowest mean of 1.4445 with a reasonable thermal performance. Regarding other insulation thickness individually, 150mm in double wall thickness of 400mm (U values: 0.14 with mean of 1.4580), 200mm in double wall thickness 450mm (U values: 0.11 with mean 1.4598) and 250mm in double wall thickness of 500mm (0.09 with mean 1.4610) had slightly range of small different of fluctuating, U-values can vary significantly on the thermal performance when increasing wall thickness.

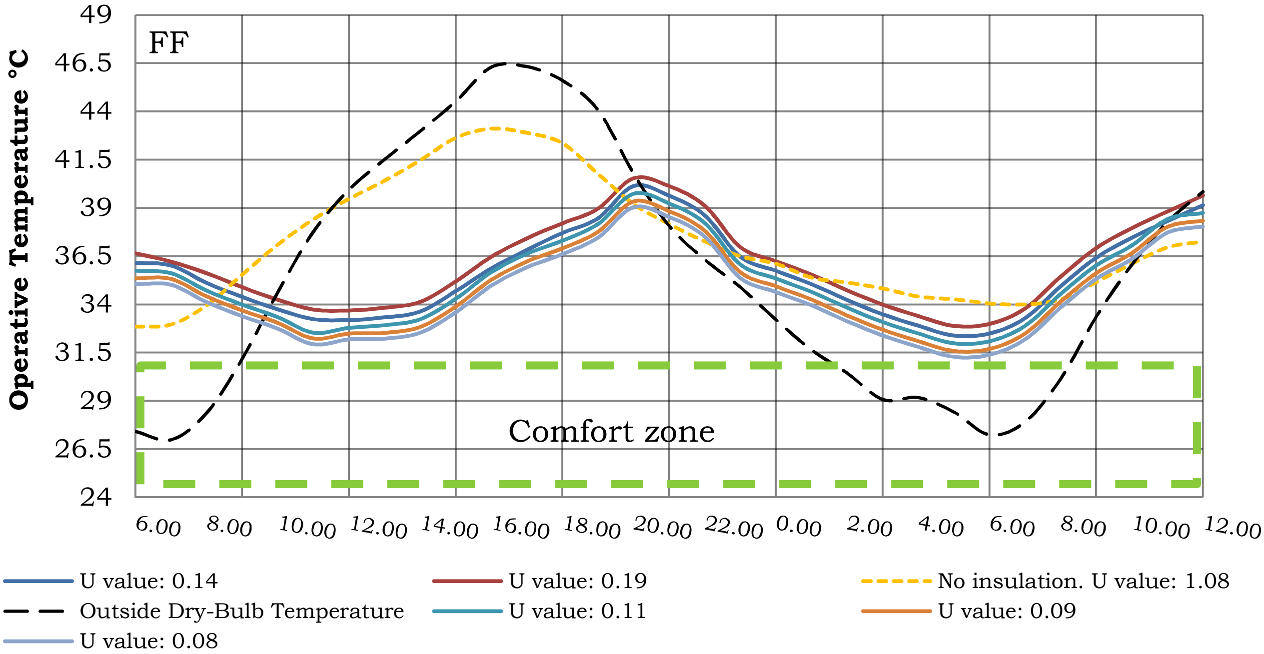


Figure 7.20 shows effect of U-values of wall insulation on operative temperature in bedroom of first floor in the hottest days, started from 6:00 AM at 24/06/14 to 12:00 PM at 25/06/14.

Correspondingly, in summer, on the ground floor, the different means of wall thicknesses, 100mm in a double wall thickness of 350mm (U values: 0.19 with a mean of 1.5562), 150mm in a double wall thickness of 400mm (U values: 0.14 with mean 1.5518), 200mm in a double wall thickness of 450mm (U values: 0.11 with mean 1.5430), 250mm in double wall thickness of 500mm (0.09 with mean 1.5327) and 300mm of thermal insulation in a double wall thickness of 550mm (0.08 with a mean 1.5214). As discussed above, the performance of 300mm of thermal insulation in a double wall thickness 550mm (0.08 with mean 1.5214) have a good performance among other insulations that can maintain indoor temperatures lower. However, 100mm insulation in a double wall thickness of 350mm (U values: 0.19 with a mean of 1.5562) resulted in high indoor temperatures overall the performance of different insulation thickness.

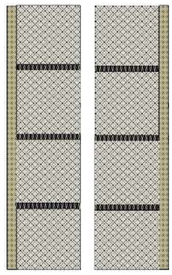
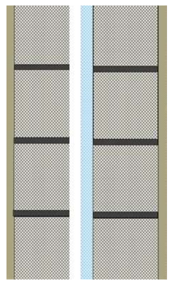
Likewise in the first instance, the different means of wall thicknesses, 100mm in a double wall thickness 350mm (U values: 0.19 with a mean of 1.5564), 150mm in double wall thickness 400mm (U values: 0.14 with a mean of 1.5504), 200mm in a double wall thickness of 450mm (U values: 0.11 with a mean of 1.5457), 250mm in a double wall thickness of 500mm (0.09 with a mean of 1.5410) and 300mm of thermal insulation in a double wall thickness of 550mm (0.08 with a mean of 1.5372). Presenting the performance of 300mm of thermal insulation in a double wall thickness of 550mm (0.08 with a mean of 1.5372) have a good performance among other insulation that can maintain indoor temperature to a lower temperature. However, 100mm insulation in a double wall thickness of 350mm (U values: 0.19 with a mean of 1.5564) have a high indoor temperature overall within the performance of different insulation thickness.

Altogether, a high U-value increases the indoor temperature, whereas the low U-value reduces the rate of conduction heat gains through external walls, showing that the lowest temperature enhancing the thermal performance for both floors.

7.4.3 Influence of Air-gap between Thermal Mass on Indoor Air Temperature

The simulation of cavity walls with air gap analysis using two types of air gap thickness between walls 50 and 100 mm, the employ of air gap and the between inner air of blocks as detailed in Table 7.4 to overview how cavity walls can be thermally efficient in decreasing the indoor air temperature.

Table 7.4: Thermal transmittance of cavity wall with air gap

Wall materials	Thickness (mm)	Thermal transmittance (U value) W/m2K	Wall Section
1. Plaster (Out) 2. Cement block 3. Air gap 4. Cement block 5. Plaster	5 100 50 /100 250 5	0.71	In  Out
1. Plaster1. Plaster (Out) 2. Cement block 3. Air gap 4. Polyurethane (Thermal insulation) 5. Cement block 6. Plaster	5 100 100 100 250 5	0. 18	In  Out

In cold days of winter, plotted graphs in Figures 7.21 and 7.22 show the effects of air gap in external walls as shown in table 8.5 compared against the reference building between 21/01/14 to 23/01/14. On the ground and on the first floor, Figures 7.21, 7.22 indicate that applying air gap and air gap with insulation between walls are not enough when the average of operative temperature is fluctuating below adaptive thermal comfort of 21.5°C, about -4.5K ~ -6.5K on the ground floor and of about -4.5K ~ 3.5K on the first floor.

On the other side, Figures 7.23 & 7.24 shows the profiles of applying air gap with insulation during 24/06/14 to 25/06/14 in summer period, when the indoor temperature of ground floor is in a range of adaptive thermal comfort of 28°C and slightly increasing between from 12PM to 8PM in about 2K and decreasing in night time while outdoor temperature is dropping down. On the other hand, applying air gap only between walls keeps the indoor operative temperature over an adaptive comfort in a range of about 1K ~ 3K.

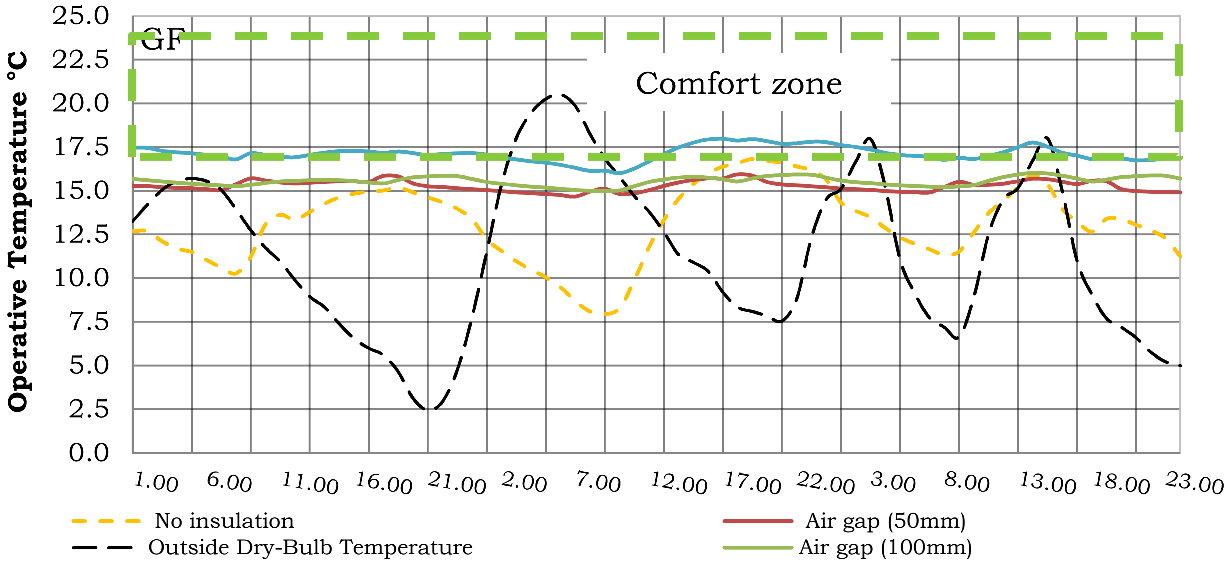


Figure 7.21 shows effect of air gap in cavity walls on operative temperature in living room of ground floor in the cold days, started from 1:00 AM at 21/01/14 to 12:00 PM at 23/01/14.

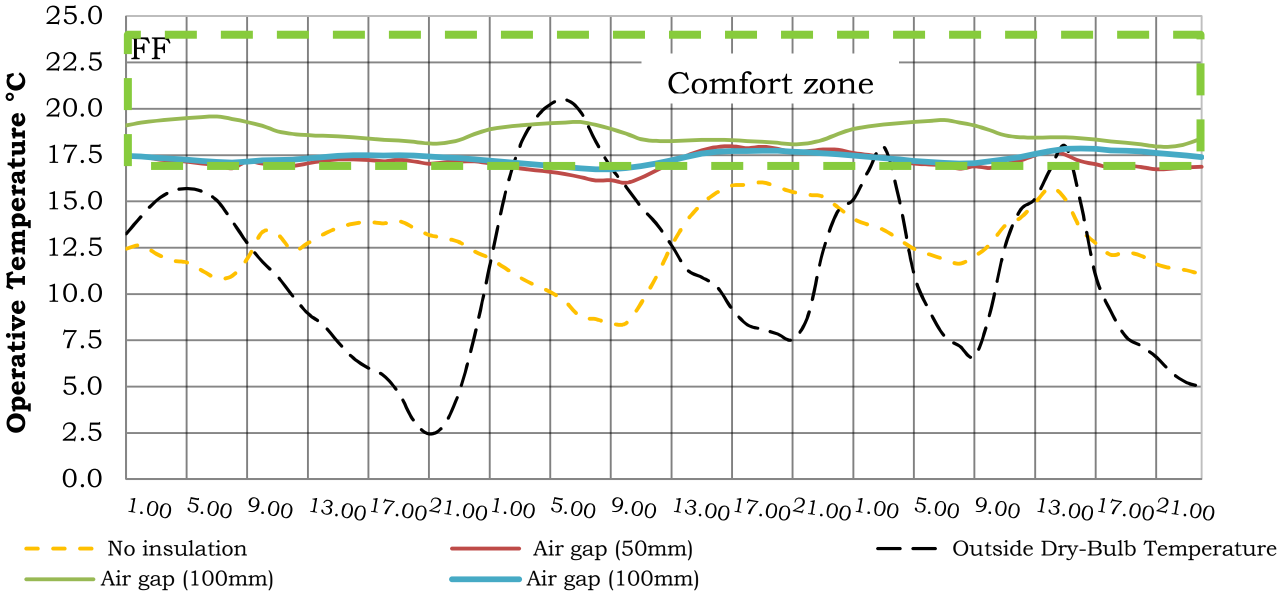


Figure 7.22 shows effect of air gap in cavity walls on operative temperature in bedroom of first floor in the cold days, started from 1:00 AM at 21/01/14 to 12:00 PM at 23/01/14.

Similarly, on the first floor, the average of operative temperature when applying air gap with insulation is higher than the adaptive thermal comfort about 5.5K ~7.5K while the variation of applying air gap is only higher by about 6.5K ~ 8.5K.

Overall then, designing air gaps into the walls provides some enhancement to the thermal behaviour of a building. However there are insufficient performances in winter for both floors and this is caused , on the first floor, in summer, by the influence of the ambient conditions such as incidence solar irradiation, local wind speed and direction and air temperature.

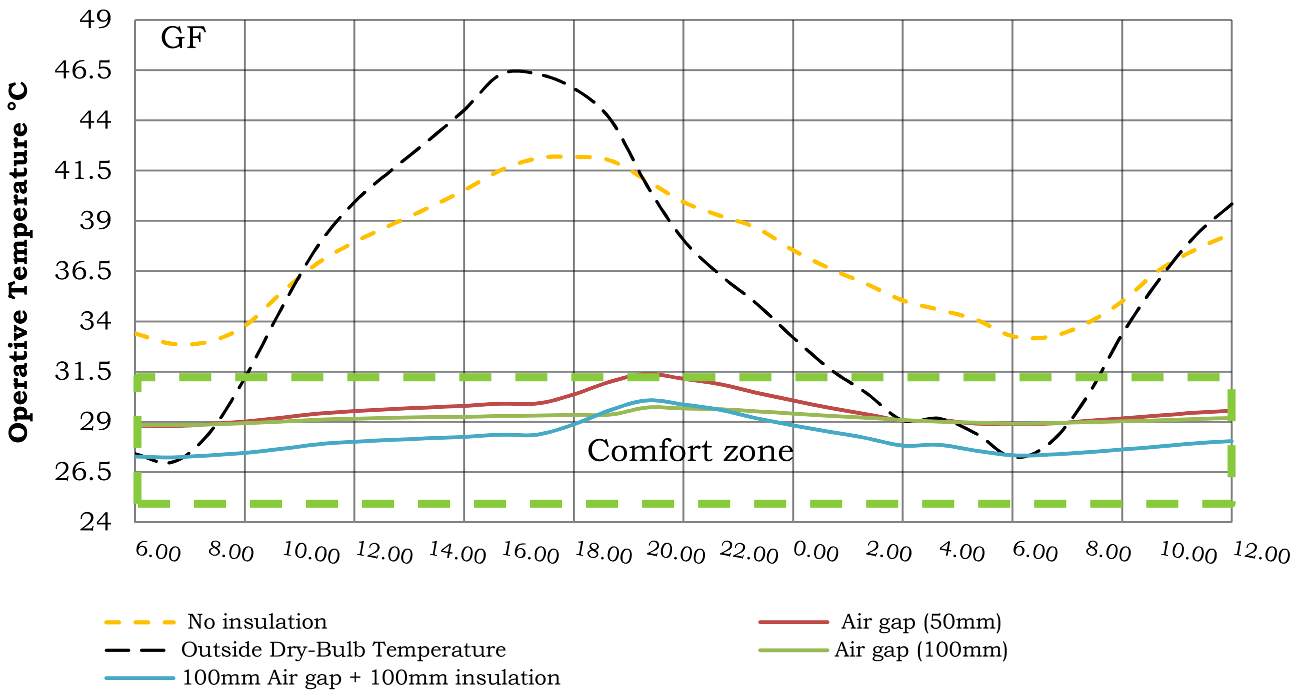


Figure 7.23 shows effect of air gap in cavity walls on operative temperature in living room of ground floor in the hottest days, started from 6:00 AM at 24/06/14 to 12:00 PM at 25/06/14.

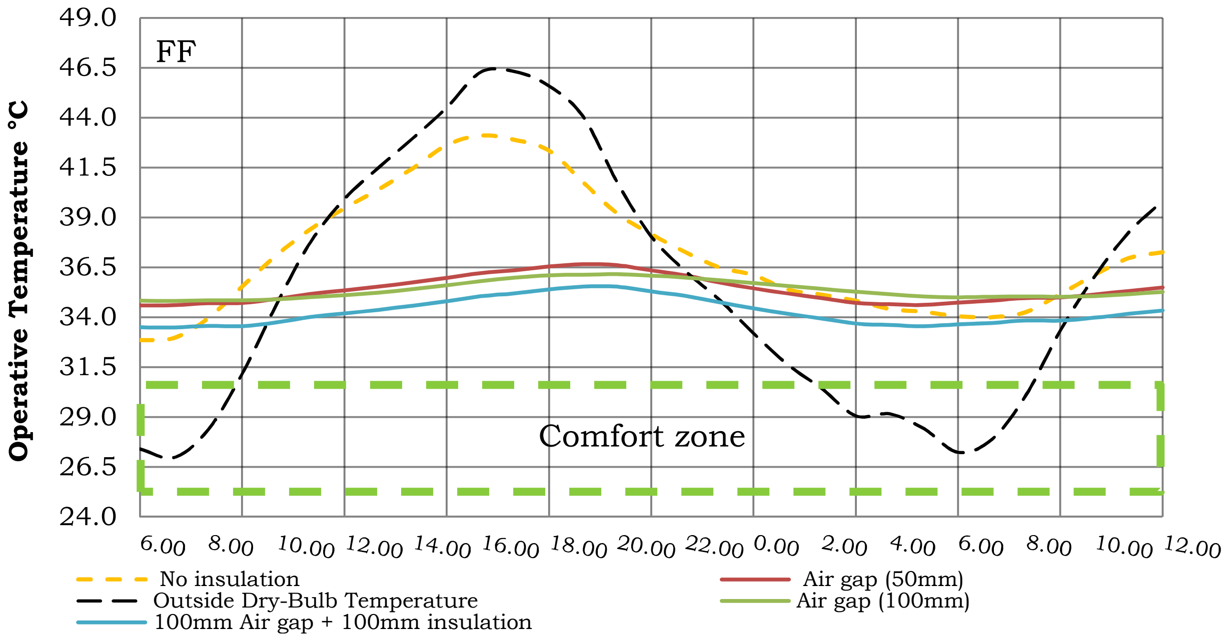


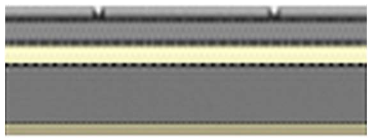
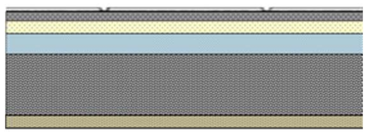
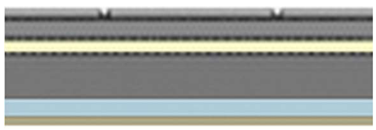
Figure 7.24 shows effect of air gap in cavity walls on operative temperature in bedroom of first floor in the hottest days, started from 6:00 AM at 24/06/14 to 12:00 PM at 25/06/14.

7.4.4 Influence of Roof Mass Design on Peak Indoor Air Temperature

A typical building roof in Ghadames is a horizontal skin exposed to impacts of solar radiation, as it receives sunlight for practically the whole of the day. Significantly, it affects the indoor air temperature as a heat gain through roof elevation, ceiling surface temperature and radiant heat load on the occupants in adjacent interiors throughout the summer season. Optimizing roof materials can play a vital role in lowering down the heat build-up and can provide significant energy savings in cooled buildings or improve indoor thermal conditions (Madhumathi et al., 2014) & (Zinzi and Agnoli, 2012).

The thermal simulation of roof analysis considers two different locations of insulation that are placed on and under the concrete roof slab as detailed in Table 7.5. The thermal Transmittance value ('U' value) was calculated on all the roofs and is presented in Table 7.5 to overview how the roof can be thermally-efficient to decrease indoor air temperature.

Table 7.5: Thermal transmittance of roof insulation

Roof materials	Thickness (mm)	Thermal transmittance (U value) W/m²K	Roof Section
1. Tiles (Out) 2.Cement mortar 3. Sand 4. Concrete slab 5. Plaster	20 20 30 120 5	2.27	Out  In
1. Tiles (Out) 2.Cement mortar 3. Sand 4. Polyurethane (Thermal insulation) 5.Concrete slab 6. Plaster	20 20 30 50 120 5	0.53	Out  In
1. Tiles (Out) 2.Cement mortar 3. Sand 4. Concrete slab 5. Polyurethane (Thermal insulation) 6. Gypsum board	20 20 30 120 50 10	0.52	Out  In

Figures 7.25 and 7.26 plotted the averages of operative temperature according to calculated standard deviation which led to R-value. Looking at the graphs in Figures 7.25 and 7.26, the results reveal that by applying inner insulation under the roof slab surface show some moderate effects in maintaining an operative temperature while a potential increase in the resultant temperature of a maximum of about 0.5K ~ 8K is being achieved in winter, above the reference building with no insulation and less than the adaptive comfort temperature between

2.5K ~ 5K sum me. On the other side, at summer time, similar results when applying inner insulation under the roof slab surface are obtained with a very slight reduction of about 4K when the peak of indoor temperature is 46°C at 17PM in the reference building with no insulation. At night-time, the reduction of indoor operative by applying inner insulation under the roof slab surface is less effective as the indoor temperature of reference building drops down while the result of applying insulation under the roof increases the resultant temperature between 2k ~ 3.5K.

Positively, the design option of applying insulation on the concrete roof slab show variation in indoor temperature in both seasons. In winter, the results displayed from in Figure 7.25 show how highly effective in maintaining the operative temperature that increases in the resultant temperature of a maximum of about 1K above applying the insulation under the roof slab. Overall, the performance of applying insulation on the concrete roof slab shows that a maximum of about 3K ~ 11K is achieved in winter, above the reference building with no insulation and less than the adaptive comfort temperature between about 1K ~ 3.5K.

Regarding hot summertime temperatures, applying insulation on the concrete roof slab is obtained with very slightly higher potential reduction of indoor temperature, less than the reference building in day-time between about 2K ~ 6K and dropping down at night-time in the same character of reference building.

As a result, the Trendline of regression analysis reveals a linear relationship between indoor and outdoor temperature in terms of applying roof slab insulation. This illustrates a significant difference between those two roofs: applying insulation on the concrete roof slab results in effecting the thermal behaviour, whereas in winter, the Trendline is slightly steeper deviated to a high temperature with R2 of 0.24. On the other side, in summer the Trendline is deviated steeper on average of high temperature with R2 of 0.77. While applying inner insulation, under the roof slab surface shows slightly less effective in maintaining the operative temperature in winter, the Trendline is slightly steeper deviated to slightly high in temperature between 16°C ~ 19°C with R2 of 0.21. By contrast, in summer, the Trendline is deviated slightly steeper on average of temperature above 36°C when R2 is 0.38. The following steps in varying different insulation thickness in terms of improving thermal behaviour of indoor climate can be used for the insulation on the roof slab.

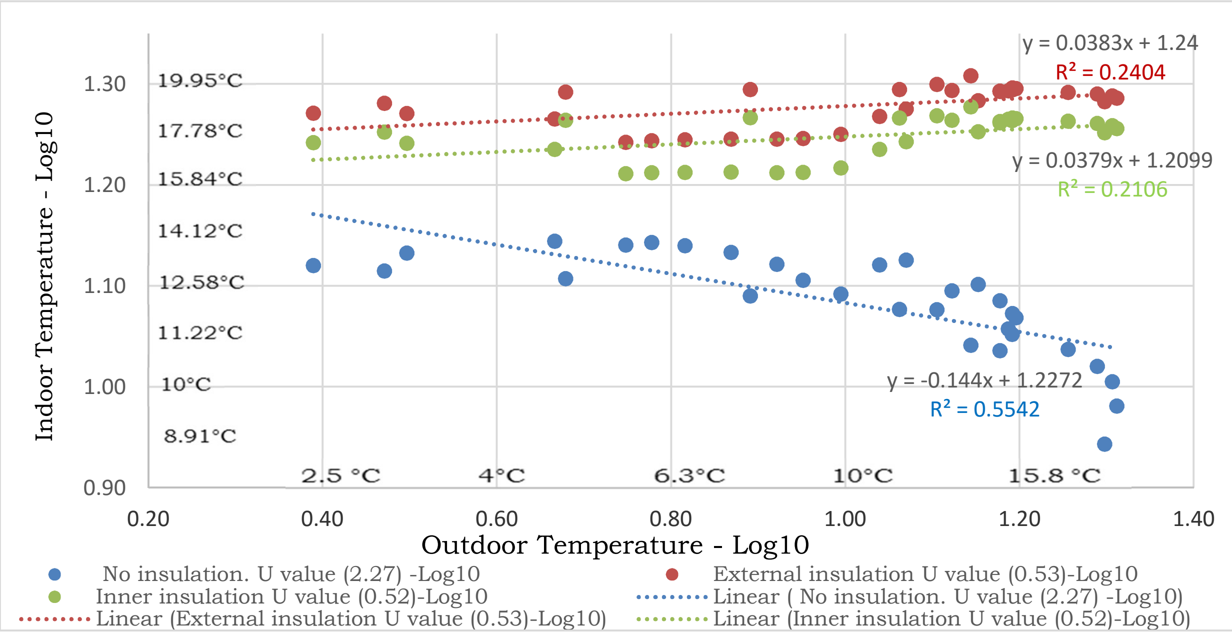


Figure 7.25: Trendlines analysis effect of roof insulation's location on indoor operative temperature in bedroom of first floor (winter from 21/01/14 to 23/01/14)

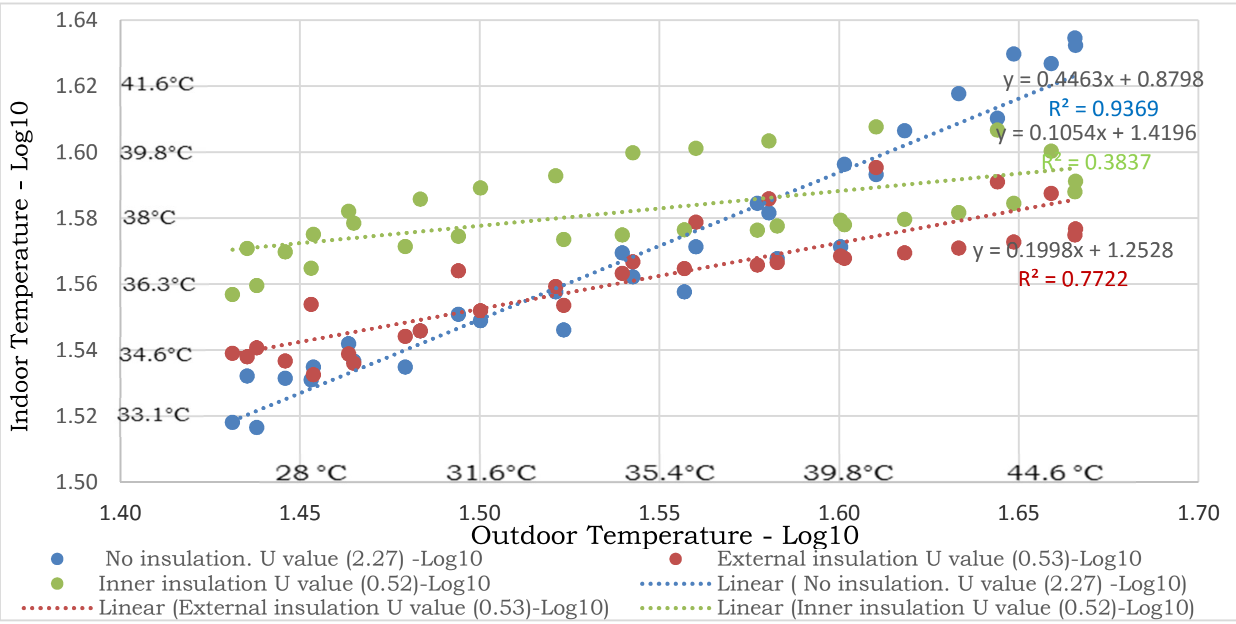


Figure 7.26: Trendlines analysis effect of roof insulation's location on indoor operative temperature in bedroom of first floor (summer from 24/06/14 to 25/06/14).

7.4.5 Influence of Different Insulation Thickness on Roof Slab on Indoor Air Temperature

In order to evaluate the capability of different configurations of roof insulation thickness, Table 7.6 shows four U-values of thermal transmittance that are used in roof slab design with different insulation thickness.

In winter, Figure 7.27 shows that the roof insulation on the first floor with U-value 0.25 of 320mm thickness of thermal insulation has a mean of 1.2796 in average of an operative temperature of 19°C with a stdev value of 0.0309, which are slightly higher when compared to a mean of an outdoor temperature of 1.020 and other thickness means with various standard deviations.

At all events, the variation of indoor temperature between each thermal mass thickness is about ±0.5K and the improvement of the indoor operative temperature is about 2K ~ 11.5K, higher than the existing thermal behaviour with a U-value of 2.27 W/m^2 K.

In the same way, in summer, Figure 7.28 shows that roof insulation on the first floor with a U-value of 0.25 of 320mm thickness of thermal insulation has a mean of 1.5424 in average of operative temperature about 35°C with a stdev value of 0.0222. This is slightly lower compared to the mean of the outdoor temperature of 1.5443 and other thickness, also varied at standard deviation.

Table 7.6: Thermal transmittance for different insulation thickness with roof slab mass

Roof insulation thickness (mm)	Total thermal mass of roof thickness (mm)	U-value (W/m^2 K)
No insulation	195	2.27
50	245	0.53
75	270	0.38
100	295	0.30
125	320	0.25

In any case, the variation of indoor temperature between each thermal mass thickness is about ±0.5K and the improvement of indoor operative temperature is about 0.5K ~ 7.5K, lower than the overall existing of thermal behaviour with a U-value of 2.27 W/m2.

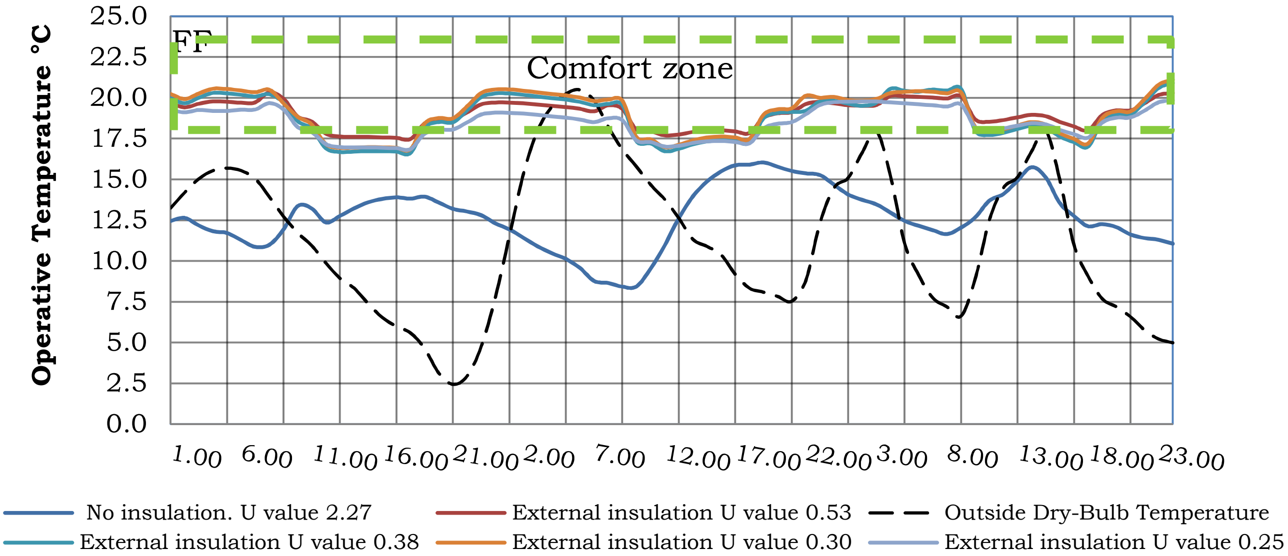


Figure 7.27: Effect of different roof insulation thickness on indoor operative temperature in bedroom of first floor (winter from 21/01/14 to 23/01/14).

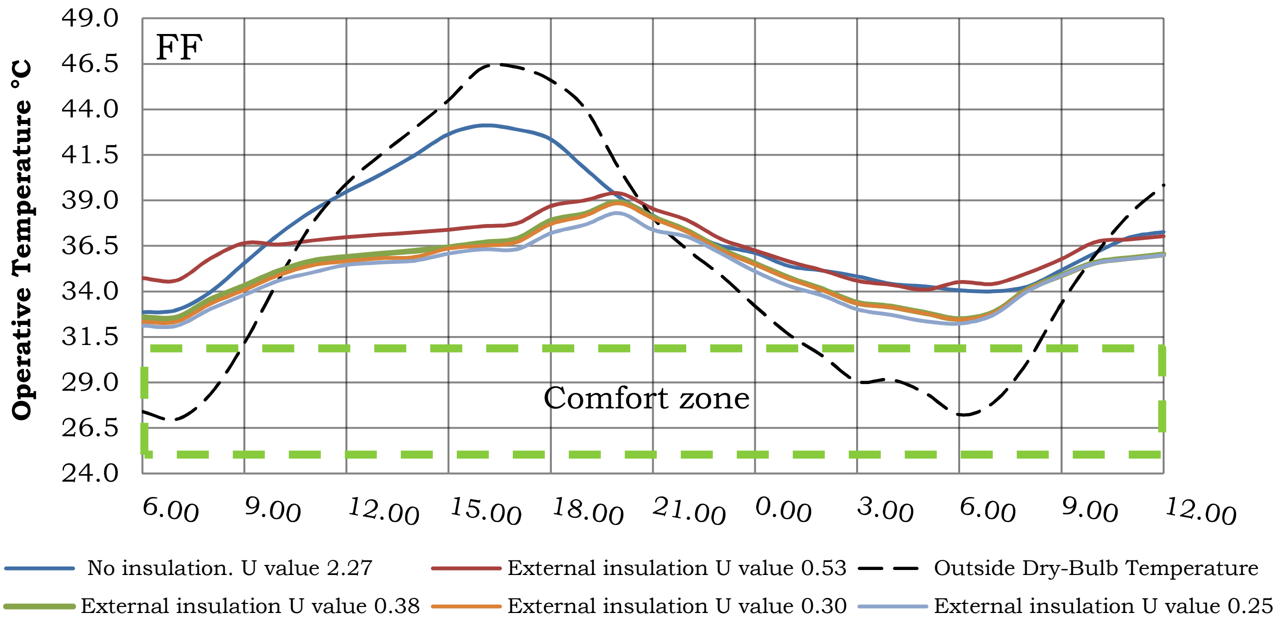


Figure 7.28: Effect of different roof insulation thickness on indoor operative temperature in bedroom of first floor (summer from 24/06/14 to 25/06/14).

Clearly, thermal insulation in both seasons proves the result of roof slab designed with a U-value of 0.25 of 320mm thickness to be more effective to indoor thermal behaviour and much better than what was in roof thickness with no insulation with a U-value of 2.27 W/m2K.

7.4.6 Influence of Combinations between Proposed Walls and Roof Design on Indoor Air Temperature

In order to illustrate the interpretation of the above results, the simulation running the combinations between proposed walls and roof design to show the thermal behaviour of proposed envelope shell was carried out. Looking at the proposed operative temperature in Figure 7.29, there are several observations between winter and summer where the thermal behaviours of the indoor building are different. Regression results in winter as presented in Figure 7.29 which show that proposed operative temperature on the ground floor performed an average of 20.7°C and on the first floor preformed an average of 22.7°C through a moderate relationship between indoor and outdoor temperature with a R^2 of 0.1971 on the ground floor and a R2 of 0.2528 on the first floor. In other words, the average of indoor operative temperature observes high levels of significance across the coldest days of winter when outdoor temperature performed an average of 11.4°C and the existing operative temperature on the ground floor performed an average of 13.1°C and 12.7°C on the first floor. At a proposed operative temperature level, this would appear as an applicable design to combinations of between walls in a U-value of 0.08 W/m2K and roof in a U-value of 0.25 W/m2K. Together these are more resilient to increases in internal heat on average 7.5K than the existing ones on the ground floor and an average of 10K in the first floor. In general, proposed operative temperature in average is higher, about 9K than outdoor temperature and also 11K on the first floor whereas it was about 1.7K, different from the outdoor temperature of the ground floor and 1.3K on the first floor.

Reviewing the proposed operative temperature in summer, Figure 7.30 presented regression results where the average of proposed operative temperature is 29°C on the ground floor and on the first floor performed an average of 30.7°C through a very strong relationship between the indoor and the outdoor temperature with a R2 of 0.8478 on the ground floor and a strong relationship with a R2 of 0.5401 on the first floor.

On another description, the average of indoor proposed operative temperature detects a significance across the hottest days of summer when the outdoor temperature performes an average of 35.6°C and an existing operative temperature on the ground floor performed an average of 37.1°C and 37.2°C on the first floor. It can be observed, of course, at a proposed operative temperature when a combination is made between a U-value of 0.08 W/m2K of walls design and a U-value of 0.25 W/m2K of roof design. Altogether, there is a decrease in the indoor proposed operative temperature in an average of 8K than the existing one on the ground floor and in an average of 6.5K on the first floor. As a whole, proposed operative temperature in average is lower by about 6.5K less than the outdoor temperature of the ground floor and also 11K on the first floor while it is about 1.5K different from the outdoor temperature of the ground floor and 1.6K of the first floor.

To comment on them generally, on winter the downtrend line slope of existing operative temperature show the consequence of low outdoor temperature fluctuating down indoor temperature below adaptive thermal comfort 21.5°C in both floors. Whilst the Trendline of the proposed operative temperature has a lesser steep trend when the pattern of temperature data points spread around the Trendline in temperatures ranging between 19°C ~ 23°C on the ground floor as the operative temperature becomes closer to the adaptive thermal comfort. On the first floor, the Trendline of proposed operative temperature has an uptrend line in the pattern of temperature data points spread around the

Trendline in temperatures ranging between 20°C ~ 27°C on the first floor as the operative temperatures get closer to the adaptive thermal comfort.

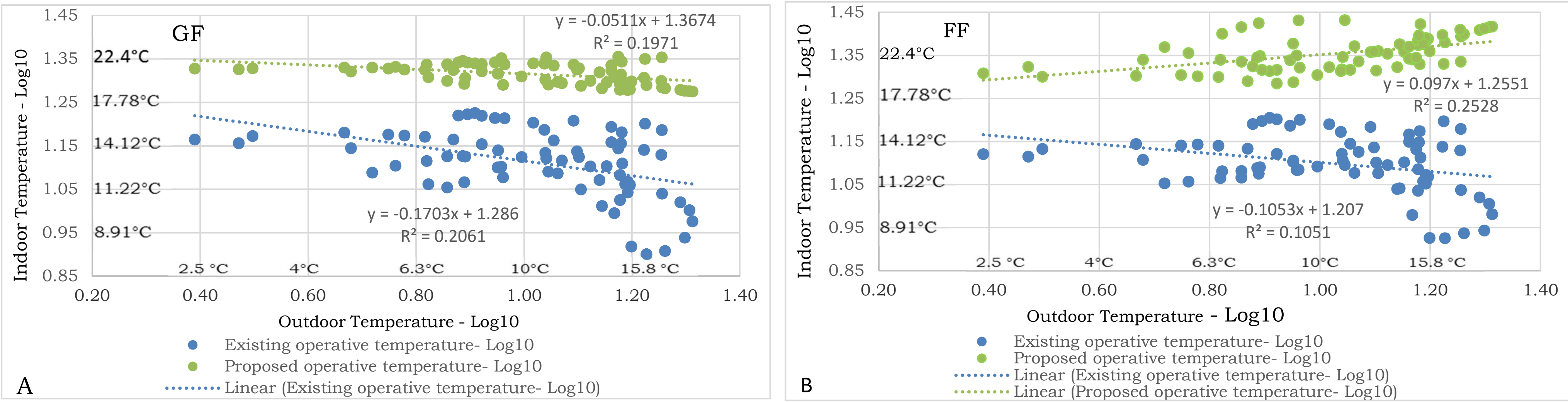


Figure 7.29: Trendlines analysis the effect of combinations between proposed walls and roof design on indoor operative temperature in winter from 21/01/14 to 23/01/14. [A] living room in ground floor – [B] Bedroom in first floor

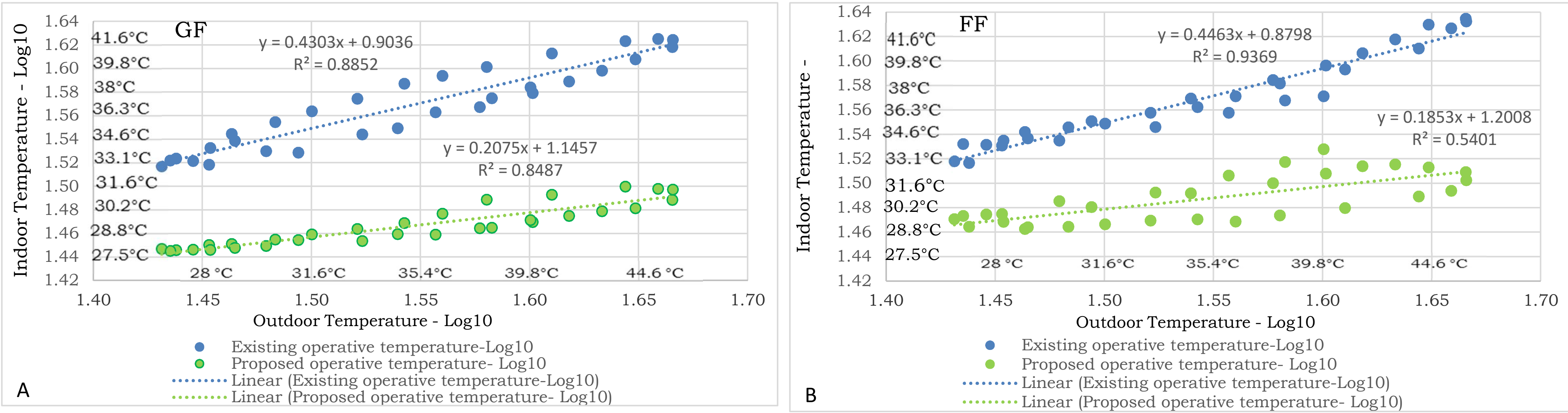


Figure 7.30: Trendlines analysis the effect of combinations between proposed walls and roof design on indoor operative temperature in summer from 24/06/14 to 25/06/14. [A] living room in ground floor – [B] Bedroom in first floor

In a similar fashion, at summertime, a slight uptrend slope line shows the improvements of indoor thermal performance when the temperature data points spread around the Trendline in temperatures ranging between 28°C ~ 31°C on the ground floor as the operative temperatures get closer to the adaptive thermal comfort of 28°C. On the first floor, the Trendline of the proposed operative temperature has a slight uptrend slope line in pattern of temperature data points spreading around the Trendline in temperatures ranging between 29°C ~ 33°C as the operative temperature gets closer to the adaptive thermal comfort of 28°C.

On balance, the proposed combination of walls in a U-value of 0.08 W/m2K and a roof in a U-value of 0.25 W/m2K can maintain indoor temperature of both floors during the harsh climates of winter or summer.

7.5 Final Discussion

In the light of the above results, the results of simulation suggest opening area @ 100% of windows area and airflow rate @ 9 ac/h enhance night-time ventilation between 20:00PM ~ 06:00AM in summer. Despite this fact, there are variations in diurnal daily outdoor temperature which can have a small effect in the summer season, but is still desirable during night-time. In winter, the weather operates generally between warm day and cold night so suspending the ventilation by closing windows, increases the internal operative temperature. In terms of achieve the adaptive comfort, the potential of selected building fabric combination has generated the maximum enhancement of adaptive thermal comfort in winter and summer among proposed walls and roofs. The selection of thermal insulation of 300mm of polyurethane foam (a U-value of 0.08 W/m2K) between walls and 125mm of extruded polystyrene insulation board (a U-value of 0.25 W/m2K) on the roof improves the indoor operative temperature and shows a slightly high temperature for the winter as well as reduce high fluctuation in temperatures in summer, minimizing discomfort to a narrow range. In general terms, it is possible to design and operate buildings to be comfortable in the free-running mode when the prevailing mean outdoor temperature lies between ±10°C to over 40°C. This will undoubtedly change the result and make the thermal response of building envelope much better.

7.6 Conclusion

In reflecting on the above undertaken analysis, it should be clear from this discussion that, in designing naturally ventilated buildings, it is crucial to consider the reaction of the building envelope with the climate, particularly for buildings in the hot weather of Libya.

In particular, increasing insulation is very effective. A highly insulated envelope with low solar absorption and high emissivity surfaces experiences relatively lower heat gain. All the cases which acted as optimum in the different scenarios are considered for the final hybrid design. Accordingly, the following points were observed:

1. The heat flow through building materials characterised by their resistance “R-value”, thermal capacity, absorption, and U-value of envelope structures, these have important roles in building simulation which helps in understanding the physical character of building envelope design.

2. The heat gains from the roof contribute to a higher portion of building configuration. A massive roof composed of material such as reinforced cement and concrete tends to delay the transmission of heat into the interior. Therefore, concrete slab 120mm + Insulation 125mm with U-value 0.25 W/m^{2}K of roof design can reduce heat

gain and contribute, with the walls, to a high portion of saving comfort zone.

3. Walls are a major part of the building envelope and receive a large amount of direct radiation. Thus, the U-value of 0.08 W/m2K of double walls concrete block thickness of 550mm with insulation of 300mm of polyurethane foam can control heat gain and slow down the heat flow through the exposed walls.

The following chapter highlighted the guidelines to enhance passive cooling design and indoor adaptive comfort of residential buildings in hot dry climate. It also discussed the limitations of this study and findings as well as included the recommendations for future work development.

Chapter IX

Conclusion and Recommendations

8.1 Research Overview

Earlier studies of thermal comfort in Ghadames have shown that huge dependence on and use of air-conditioning cannot guarantee to maintain comfort boundary as the houses suffer from summer overheating problems. It is therefore necessary to alleviate this issue as a hot and dry climate of Ghadames in Libya that is characterized by a mean monthly maximum temperature above 30°C in summer and surrounded by sandy desert with little vegetation, which makes it imperative to control solar radiation and movement of hot winds.

In this perspective, the present research focuses on the study of the suitability of residential houses in Libya's hot climatic region and identifies those architectural factors most relevant for reducing heat gain enhancing thermal comfort. This study therefore attempts to answer the following three questions: firstly, are redesigns of building envelope climatically, technically and efficiently suitable for hot arid region? Secondly, can the adaptive thermal comfort be effectively used for natural ventilation in this climate? And thirdly, how profoundly can U-value of building materials impact the thermal performance of building envelope?

In this regard, the study aims to understand the passive design strategies of domestic vernacular buildings in hot dry climate and to apply design techniques, which will utilize the favourable conditions and at the same time to minimize the unfavourable elements of the local climate on a modern building. The key design considerations for thermal comfort and energy efficiency here is the building envelope. This "shell" is an integral part of the energy system. In terms of passive architectural design, it is the component with the most profound effect on a building's indoor environment. Consequently, in this climate, successful use of passive strategies and solutions for houses can provide thermal comfort by reducing solar gains in summer and increasing thermal capacity in winter.

8.2 Conclusion

The aim of this thesis was to assess and recommend an application of passive cooling techniques in existing houses in urban area of Ghadames and also to develop an optimum model that can aid thermal design decisions to passively improve the buildings' thermal behaviour. The present review clarifies the support of the aim that was achieved in five objectives and were shaped in order to complete the task of this research study.

1. In essence of objective two *"evaluate internal climate and to find solutions that can provide qualitative, physical, and psychological benefits to housing users (adaptive comfortable houses in a hot dry climate)"*, a literature review presented in Chapter Two focused on the conceptual framework. In this review, a descriptive and scientific study looked at the method of passive cooling applications and natural ventilation connected to the thermal comfort of the dwellers, possible ways to succeed this comfort by removing the internal heat, controlling and reducing the external heat gains. In more details, the thermal comfort, the adaptive thermal comfort and the parameters that have some effects on these are discussed in order to improve the indoor thermal comfort without the use of mechanical systems to dissipate heat.
2. In favour of objective one *"explain the problems are important aspects of passive design strategies and thermal performance in the residential buildings",* Chapter Three opens an overview on thermal performance of residential buildings in Ghadames. This review provides a general glimpse to understand the techniques of studying thermal human comfort in hot dry climate of Ghadames. It offers an opportunity to review the

previous investigation about thermal comfort in the field and provides some significant information about the thermal building performance through different field studies that were stated by various researchers in detail. Following from Chapter Three, a wider picture of an important aspect of the vernacular desert architecture in general and of Ghadames in particular were illustrated in Chapter Four. Implicitly, it is showing the opportunity of applying the simplicity of passive techniques through a building which can be adapted to suit the building user's needs and the environmental considerations of the local building's surroundings in achieving comfort.

3. On support of objective three *"examine real weather data format for the simulation process in terms of investigating the effect of outdoor climate on building design and indoor comfort"*, in Chapter Five the field study portrayed three major important steps to analyse the current situation and to undertake DesignBuilder energy simulations by real outdoor weather data and to validate the output results of indoor simulation with real data from the indoor climate. The first step was collecting the information that was gathered through environmental monitoring of the weather, which were carried out during the winter and summer 2014 by local weather stations that was fixed by the author in line with different climatic contexts between winter and summer to support the research investigation. The weather monitoring focused on measuring the four thermal parameters that have impacted on the thermal comfort and thermal performance: these parameters being air temperature, relative humidity, wind speed and direction were formulated in EnergyPlus weather files (EPW) to set the basis of the building simulation and

validation of building simulation model. The following step was set up by a portable sensors HOBO data logger to monitor the indoor conditions of an existing house in winter and summer 2014 by measuring air temperature and humidity levels. Generally, the field monitoring of weather conditions indicated a big fluctuation between indoor environments that had big impact of increasing temperature in summer in line with outdoor temperature as well as decreasing temperature in winter along with outdoor temperature. In order to get more understanding about the residents ' responses to indoor environments, the step three in Chapter Five presented a holistic perspective of indoor environments through the questionnaire method to investigate and evaluate both the thermal sensation and the subjects' preferences. In depth, samples were studied in 60 houses in order to take account of the full difficulty of current conditions that subjects experience with those families in each house investigated in this study. The questionnaire was conducted in summer 2014 focusing on overall satisfaction of occupants' perceived experiences about indoor climate in winter and summer. As well as the questionnaire, individual measurements were provided and what appropriate solutions could be used for continuous complaints from the residents about the indoor climate. Collecting data such as age, gender, house construction, ventilation system, opening windows, occupancy time and clothing was considered. Overall, the outcome from the questionnaire indicated that the thermal preference votes in winter in terms of no electrical heating use at the ground floor was experienced by 65% of the occupants who felt slightly cool while only 35% felt cool during the winter season. However, at the first floor 73% of occupants were feeling cool while 27% were feeling slightly cool. In summer, the indication of indoor temperature fluctuating between 31.6°C ~ 36°C when the outdoor temperature was very hot, in terms of using natural ventilation. Occupants' thermal preference votes revealed that 38% of occupants were feeling slightly warm and 48.5% were feeling warm while 13.5% were feeling hot at the ground level. While at the first floor it is observed that indoor temperature in first floor ranged between 36.3°C ~ 40.6°C, especially during night time when the thermal mass releases the storage heat out. Occupants' thermal preference votes in terms of using natural ventilation revealed that 41.7% of occupants were feeling warm while 58.3% were feeling hot. In conclusion, the neutral levels of temperature are not achievable in the indoor climate as the building envelope is not integrated with the outdoor climate, and therefore becomes uncomfortable.

4. With regard to the objective four *"develop computer simulation models for the analysis of thermal performance of naturally ventilated buildings and to investigate the interactions between passive design and performance parameters"*, Chapter Six showed the assessment of building energy simulations packages considered to choose optimum tool that can be used in the analysis stage. The valuation method considered all evidence related to designing the models, building materials database, the type of algorithm that integrated it with the energy simulation analysis tools. Moreover, an attention was also given to the validation of energy simulation performance which is needed to approve the output results and overall performance. Arguably, DesignBuilder approved to investigate the influence of the outer envelope of a typical family house prototype in the new urban area of Ghadames by analysing

the indoor thermal conditions, external heat gain and natural ventilation performances at night time.

5. On the side of objectives five, the last objective is to *" expand knowledge and studies in this area by utilising building simulation for improving indoor thermal performance",* in this stage, Chapter Seven demonstrated the importance of natural ventilation and thermal mass which is outlined in this thesis to examine the potential for enhancing thermal performance in residential buildings, where passive design strategies are applied to investigate thermal performance of a prototype house in a new Ghadames area by using field studies coupled with thermal simulation analysis. DesignBuilder simulation program, which is used when considering local weather data to investigate different scenarios that affect the composition of the roof, the walls and the natural ventilation to enhance indoor thermal comfort. As a result, the simulations encompassed an alternative design option with different hypothesis of design scenarios which are applied, with the first phase having to do with the analysis of the influence of varying different natural ventilation strategies so as to avoid the use of mechanical ventilation. This scenario is simulated to reduce cooling in peak summer where different design options were applied.

   A. The first design option exposes "*natural ventilation performance by using air change rate (ach)"*. The thermal simulation results indicated that night cooling is superior to daytime ventilation in both strategies where the maximum indoor air temperature is about 4K cooler than the maximum outdoor air temperature in day-time with night cooling strategy. However, increasing the rate of ventilation to 9 ach is very significant and can lead to decrease indoor air temperature so as to provide a better comfort level in terms of enhancing the whole building envelope design.

B. The second design option exposes "*the performance of using natural ventilation time plan*". The whole day ventilation in an insignificant plan causes an uncomfortable environment as the indoor temperature is closer to the outdoor temperature where the indoor temperature is about 42°C while outdoor reached 46°C. However, at the first floor the indoor performance resulted in high temperature increasing over 40°C during day time as closer to outdoor temperature, whereas, at night time it increases above the outdoor temperature as the indoor temperature is affected by heat that is released from the thermal mass.

C. The third design option exposes "*the performance by changing window opening ratio Overall the performance*". The ratio of 100% opening area for ventilation has two different characteristics, in the peak of day-time about 2K below the reference building in the peak hour while in ground floor about 4.8 ~ 4K below the reference building of no ventilation in night-time and early morning between 20:00 PM to 6:00 AM. However, at the first floor, as the thermal performance is higher than the ground floor, due to the thermal mass character and the roof being exposed to the sun rays , the indoor temperature is higher than the reference building of no ventilation being about 2K in day-time while in night time approximately 0.3 ~ 4K below the reference building of no ventilation between 20:00 PM ~ 6:00 AM.

The second phase carried out to analyse the thermal performance to the entire building as an integrated system to capture interactive effects of building components on thermal performance on the following aspects.

A. The first design option exposes "*Influence of insulation in thermal mass on indoor air temperature"*. In winter, applying thermal insulation with a U= 0.21 W/m^{2}K for external walls preserves indoor temperature and keeps it steady at the ground floor where the average of temperature fluctuates between 22.5°C to 29°C, which is approximately in the range of 6.5K between day and night. However, applying insulation outside wall surface showed better action: it keeps operative temperatures between about 11.5K ~ 7.5K. On the first floor, applying insulation with a U= 0.21 W/m^2 K for external walls maintains operative temperature fluctuating over 23°C, and keeps it steady in an average of 6K between day and night. Applying the insulation between the walls keeps the operative temperature fluctuating, approximately between 24~31°C. In summer, at the ground floor, applying insulation of a U= 0.21 W/m^{2}K between the walls shows that the operative temperature of the simulation results dropping down about 4K between 6:00AM ~ 13:00PM in the range of temperature approximately among 36°C~32°C. However, the operative temperature increases between 13:00 PM ~ 20:00 PM when the outdoor temperature starts increasing from 41°C then decreasing down when the outdoor temperature started to drop down to about 39°C. In evening and night time where outdoor temperature is dropping down from 46°C at 17:00 PM to 27°C at 6:00 AM, the indoor operative temperature also starts to drop down about 7K. At the first floor, the operative temperature drops down about 2K between 6:00 AM ~ 14:00 PM in temperature ranging approximately between 36-34°C. Then it increases from about 34°C to around 40°C at 20:00 PM then again drops down in evening and night time to 32°C at 6:00 AM which is about 8K. However, applying the insulation inside the wall surface shows the worst performance on the thermal behaviour between other insulation options in both floors.

B. The second design option exposes the *"Influence of thermal mass and insulation thickness on indoor air temperature"*. In winter, the effects of insulation with thermal mass thickness (U= 0.08 W/m^2K) maintains indoor temperature and keeps it steady on the ground floor where the average of temperature fluctuates between about 25°C to 32°C, which is, approximately, in the range of 7K between day and night. At the same time, the operative temperature which is indicated on the first floor keeps it steady while the average temperature fluctuates between about 25°C to 32°C, which is, approximately, in the range of 7K between day and night. On hot summer days, on ground floor, insulation with thermal mass thickness of U= 0.08 W/m^2K preserves the indoor temperature and keeps it steady at the ground floor where the average of temperature fluctuates between about 30°C to 37°C, which is, approximately, in range of 7K between day and night. At the same time, on the first floor, the operative temperature is steady while the average temperature fluctuates between about 31°C to 39°C, which is, approximately, in the range of 8K between day and night. However, in winter, in both floors, applying different thickness of insulation shows a small variation in the change of indoor temperature between different insulation thickness 150, 200, 250 & 300mm which is about ±0.5K. Conversely, the variation of changing indoor temperature between 100mm and 300mm of insulation thickness is about 2K. In summer, in both floors, applying different thickness of insulation shows a slight variation in the indoor temperature change between different insulation thickness of 150, 200, 250 and 300mm which is about ±0.5K. Conversely, the variation of fluctuating in indoor temperature between 100mm and 300mm of insulation thickness is about 4K on the ground floor and 2K on the first floor.

C. The third design option exposes the *"Influence of air-gap between thermal mass on indoor air temperature*". In winter, on the ground and first floor, applying air gap and air gap with insulation between walls are not enough when the average of operative temperature is fluctuating below the adaptive thermal comfort of 21.5°C about -4.5K ~ -6.5K at the ground floor and is about -4.5K ~ 3.5K on the first floor. In summer, at the ground floor, when the indoor temperature of ground floor has a range of adaptive thermal comfort of 28°C and slightly increasing between from 12PM to 8PM in about 2K and decreasing at night time while the outdoor temperature is dropping down. On the other hand, applying air gap only between walls keeps indoor operative temperature over adaptive comfort in the range of about 1K ~ 3K. At the first floor, the average of operative temperature when applying the air gap with insulation is higher than the adaptive thermal comfort which is about 5.5K ~7.5K while the variation of applying air gap is higher, only about 6.5K ~ 8.5K.

Generally, designing air gaps into the walls provides some enhancement to the thermal behaviour of a building. However there are insufficient performances in winter for both floors and at the first floor, in summer, it is caused by the influence of the ambient conditions (incident solar irradiation, local wind speed and direction, air temperature).

D. The fourth design option exposes the *"Influence of Roof Mass design on Peak Indoor Air Temperature"*. In winter the results reveal that by applying inner insulation under the roof slab surface shows a moderate effect in maintaining the operative temperature while a potential increase in the resultant temperature of a maximum of about 0.5K ~ 8K. Whereas during summer time the reduction is about 4K when the peak of indoor temperature is 46°C at 17PM in reference building with no insulation. At night-time, the reduction of indoor operative temperature is less effective as the indoor temperature of the reference building dropped down while the result of applying insulation under the roof has increased, resulting in temperatures between 2k ~ 3.5K.

E. The fifth design option exposes the *"Influence of different insulation thickness on roof slab on indoor air temperature"*. Positively, the design option of applying insulation on the concrete roof slab with a U-value of 0.25 showing a variation in indoor temperatures in both seasons. In winter, overall, the performance of applying insulation on the concrete roof slab is showing a maximum of about 3K ~ 11K in winter above the reference building with no insulation and less than the adaptive comfort temperature between about 1K ~ 3.5K. In hot summertime temperatures, applying insulation on the concrete roof slab is obtained with very slightly higher potential reduction of indoor temperature less than reference building in day-time between about 2K ~ 6K and dropped down in night-time in the same character of reference building. Clearly, thermal insulation in both seasons prove the result of roof slab being designed with a U-value of 0.25 of 320mm thickness to be effective to indoor thermal behaviour and much better than what was in roof thickness with no insulation with U-value 2.27 W/m^{2}K.

F. The last design option was analysed taking into account the whole building envelope design, applying the combinations between proposed walls, roof design and natural ventilation plan to improve overall building envelope performance. In order to finalize the solution, the simulation running the combinations between proposed walls in a U-value of 0.08 W/m^{2}K and roof in a U-value of 0.25 W/m^{2}K designed to show the thermal behaviour of proposed envelope shell. Looking at the proposed operative temperature, there are several observations between winter and summer where the thermal behaviour of the indoor building are different. In winter, the ground floor performed an average of 20.7°C and in first floor performed an average of 22.7°C through a moderate relationship between indoor and outdoor temperatures. In summer, the average of proposed operative temperature is 29°C on the ground floor, while on the first floor it performed an average of 30.7°C through a very strong relationship between indoor and outdoor temperatures. It can be seen, of course, at a proposed operative temperature in the combination between a U-value of 0.08 W/m^2 K of walls design and a U-value of 0.25 W/m^2 K of roof design. Altogether, decrease indoor proposed operative temperature of an average of 8K is more than the existing one in the ground floor and an average of 6.5K on the first floor. As a whole, the proposed operative temperature on average is lower, about 6.5K, than the outdoor temperature of the ground floor and also 11K on the first floor while it presents about 1.5K difference from the outdoor temperature at the ground floor and 1.6K on the first floor.

Finally in this chapter, after examining the process of enhancing thermal performance by design of the envelope structure as a passive technique in the hot-dry climate of the Libyan Desert, the results from this study guided the design of a set of parameters based on the simulation analysis. The recommendations proposed in this research contribute to the knowledge of passive design strategies suitable for housing design in hot and dry climates. The guidelines suggested are controlling the indoor comfort temperature and deriving benefits from designed thermal insulation, thermal mass, and natural ventilation. Overall, the findings derived from the results that were gathered from field studies are also coupled with computer simulation work, which are used to optimize a series of design guidelines aimed at the improvement of the thermal performance of residential buildings as summarized below.

8.3 Design Guidelines

The results of this thesis contribute to some understanding of the thermal behaviour of residential housing of Ghadames and provide guidelines to develop a rough idea of what the final building composition should look like. As well as the appropriate solutions to be attained, which assist architects and engineers to consider passive design strategies in the early stages of a design to characterize the envelope design and to increase comfort, particularly during the hot season. The comprehensive concepts introduced herein in favour of understanding a sufficient qualitative treatment are highlighted below.

A. Nocturnal Ventilation Strategy

The high heat gain from the envelope shell to the indoor environment means high cooling effect of night ventilation, as the relative difference between indoor and outdoor temperature. In summer, night ventilation is the more significant plan in diminishing higher peak temperatures when the area of exposed thermal mass increases. Therefore, it is possible to cool the building by night time ventilation from 08:00PM until 06:00AM, where ventilated air enhances convective heat losses from mass elements and dissipates the released heat to the lower temperature outdoor. However, in Ghadames City as a desert climate with hot ambient temperature in summer days and intense sunlight, the simulation results of proposed design approved that opening percentage of the windows should not be less than 100% to provide better thermal response in the building, as high indoor temperature decrease is achieved, particularly when the outdoor temperature swing is greater.

B. Building Materials and Thermal Properties

Obviously, thermal properties and selection of materials are important steps for assessing thermal performance in the residential building in terms of control heat gain in hot climate. Therefore, materials that are very good at resisting the flow of heat (high R-value and low U-value) can be more effective as insulation materials and are more desirable during the hot season. The output of computer simulations demonstrated the impact of each variable on the overall performance of building environment as follow:

1. Walls

Mainly, designing thermal mass of the walls is a result in easing of overheating of internal wall temperature, while during the night the stored heat will result in higher wall temperatures, leading to a warmer living space. Hence, enhancing night time ventilation and de-activating the higher thermal conductivity of the concrete roof has a positive effect on occupancy comfort. Ten different wall construction types, with different sizes of thermal mass, insulation and air gap were analysed with changed U-Values and simulated.

However, the diurnal temperature difference in summer is wide , so the usage of the mass wall construction with a U-value of 0.08 W/m^2K can decrease the heat gain during warm weather because of its thermal storage capacity. When the outside temperature reaches the extreme value of above “30°C”, in this case, heat will conduct from the warm side into the material and gradually move through it to the colder side. Therefore, a big thermal mass of the walls, (considering the insulation ,"mass effect" and "effective R-value"), which is highly insulated, will provide fine internal condition as the reduction of overheating hours can be achieved in integration with roof design to avoid solar heat gain. In cold nights of winter, whilst night ventilation is off, the wall mass is augmenting by moderate temperature variations thus increasing thermal comfort, while in summer, there was always around 2K of difference between ground floor and first floor. With that in mind, size, position of the glazing and openings have another occurrence on heat gains and are more important in parallel with thermal mass.

2. Roof

Mostly, concrete floor slabs can contribute to the heat capacity of a building where in winter and summer high absorptions of heat or cold from roof and walls travels from outside to inside, but heat or cold flows can be reduced by using materials which have a high resistance to heat flow (R-value = resistance). Consequently, the rooms in the top floor have direct influence of the heat or cold gain and therefore the roof design should be considered carefully by employing extruded polystyrene insulation 125mm with thermal conductivity of 0.035 W/m^2K and a R-value of 3.571. Overall, it is desirable to employ the insulation on structural mass in order to reduce heat gains from the slab by increasing the roof thickness, so the roof shall comply with assembly U-value factor 0.25 W/m^2K as an indispensable to design requirement.

8.4 Limitation of the Study and Findings

Although the present research study has generated some useful findings, a number of limitations need to be mentioned as follows:

1. The study examined only ventilation, walls and roofs, therefore further study on other aspects such as window size, glazing, window orientation and shading features are needed to include the effects of the heat transfer through the building.
2. The current study investigated a modern prototype house in Ghadames and that is limited as one type of house in the new urban City. Other types of residential buildings constructed as standalone high rise buildings could be considered in a future research and also, it will be useful to study the bioclimatic application and building regulations.
3. The study has only examined the thermal behaviour of NS orientation of a case study house in summer and winter, however, it is necessary to consider all the orientations to build a big panorama of thermal behaviour inside the residential buildings.

8.5 Recommendation for Future Work

Additional research studies that might be considered in future work include a number of design variables to get further potential research along with the following points:

1. CFD analysis would provide an opportunity to analyse ventilation strategies if a mechanical system is used to implement night ventilation, further consideration will be useful in terms of the impact on the energy consumption.
2. In the light of the thermal comfort, there is a lack of information about comfort zone criteria especially for certain climatic regions in Libya. Therefore, research in this area is of much significance.
3. It would be very interesting if further research examines the impact of adding a shading canopy to the roof.

4. Another very interesting perspective in future work might use programs that can model a number of buildings on an urban scale, say 1km x 1km, to simulate the building groups, vegetation and microclimate interactions from urban viewpoints. However, in the vernacular City of Ghadames, the integration between urban pattern and housing design optimized the thermal behaviour of the City and buildings, which provided good indoor and outdoor thermal comfort. ENVI-met is an example of software that can be utilised for such studies considering urban environments, and some initial work has been done by the author in this area (Fahmy et al, 2009).

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APPENDICES

APPENDIX 1: QUESTIONNAIRE

QUESTIONNAIRE FOR RESIDENTS IN MODERN HOUSING OF GHADAMES CITY

Date........ / .... /.........

GENERAL INFORMATION

Dweller name..

Length of stay in the house..☐.. Less than 5 years..☐.. 5 ~10 years...☐. Over 10 years

House type..

Location..

Number of family members...☐..2 ~ 4 ..☐. 5 ~ 8..☐. 9 ~ 12...........................

Family ages category..

Other Notes..

....

....

HOUSE INFORMATION

The number of floors in the building☐.One storey..☐Two storeys..☐..Three storeys

Number of the rooms in the house..☐.One room..☐.Two rooms...☐..Three rooms

☐.Four rooms.☐.Five rooms..☐.. Six rooms...☐..Over Six rooms.........

The number of hour's occupancy in the building..☐.4 ~ 6 hours.☐.. 7 ~ 9 hours..☐10 ~ 12 hours..☐..Over 12 hours

How many bedrooms in the house..☐.. One room..☐. Two rooms..☐..Three rooms.

Number of users in each individual's room..☐. 1 ~ 2 Persons in room 1 ....

☐ 3 ~ 4 Persons in room 1..☐..1 ~ 2 Persons in room 2 .☐..3 ~ 4 Persons in room 2..............

☐..Room 2 is not used..☐..1 ~ 2 Persons in room 3 ☐..3 ~ 4 Persons in room 3...................

☐.. Room 3 is not used ....

The number of sleeping hours..... ***Noon time***..☐. 1 ~ 2 hours..☐. 3 ~ 4 hours....☐.No sleep......... ***Night time***..☐.6 ~ 9 hours...☐..10 ~ 12 hours.............

Sleeping time.... ***Noon time***.☐.. 2 PM ~ 4 PM.☐. 3 PM ~ 5 PM..☐.. No sleep........

Night time..☐.10 PM ~ 7 AM..☐..12 PM ~ 7 AM...

The number of hour's occupancy in the living room..☐.. 2 ~ 5 hours..........

☐..6 ~ 12 hours...☐..Over 12 hours..

Other Notes..

....

INFORMATION OF BUILDING CONSTRUCTION

Type of construction (concrete structure .... bearing walls............)

Is there any heat insulation (Yes)..................... (No)..............................

Places that include heat insulation (walls)......... (Roof)........ (Floors)........

Other Notes..

....

....

VENTILATION SYSTEM

Quality of internal ventilation.☐Natural......☐..Mechanical...........................

Do you get natural ventilation through the..☐...External windows.☐..Light well..

☐...Yards...

Favoured hours for natural ventilation..☐..Morning (5:00 a.m. – 9:00 am.)..........

☐..Evening... (5:00 pm. – 8:00 pm.).☐..Night... (8:00 p.m. – 5:00 am.)..............................

☐..Evening & Night..(5:00 p.m. – 5:00 am.)..☐. Night & Morning..(8:00 p.m. – 9:00 am.)...........

☐..Evening & Night & Morning..(5:00 pm. – 9:00 am.).☐...All day..................................

Which direction is preferable for getting natural ventilation.☐. All directions

☐..North..☐...South....☐....East....☐...West..

What percentage is good for opening windows to get natural ventilation..

☐..25%...☐...50%...☐..75%....☐..100%...

How many times do you open the windows for ventilation every day.......

☐ All day.......☐ morning time ....☐.Noon time ....☐..Evening time.................

☐ Night time........☐..Evening and Night...

How many times do you open the doors for ventilation everyday............

☐ All day.......☐ morning time ....☐.Noon time ....☐..Evening time.................

☐ Night time........☐..Evening and Night...

What qualities of mechanical cooling are preferable?............................

☐ Air condition..........☐. Fans.............☐. Air condition & Fans........☐. No...........

How many hours of using of mechanical cooling? ....

☐ All day.......☐ morning time ....☐.Noon time ....☐..Evening time.................

☐ Night time........☐..Evening and Night...

What rate of electrical energy does you consumption by using

mechanical cooling in summer session..☐. High......☐.. Medium...........

....☐.Low...

Is natural ventilation covering all the parts of the house.☐..yes...☐. No...

Is there any integration between natural and mechanical cooling..........

☐..Yes.....................☐. No..

If yes (How many hours take advantage of natural ventilation and Mechanical cooling):

Natural ventilation.. ☐. 2 ~ 4 hours morning.. ☐.. 5 ~ 7 hours evening. ☐..... 8 ~ 12 hours night. ☐.....No..

Mechanical cooling.... ☐ ~ 4 hours morning...... ☐ 7 hours evening.............

☐ ~ 12 hours night......... ☐...No...

In which part of the dwelling prefer ventilation. ☐.Natural ..... ☐. Mechanical cooling..... ☐.Both...

Bedrooms .... Time ....

Living room .... Time ....

Saloon .... Time ....

Kitchen .... Time ....

Bathrooms ....Time ....

How your vote the comfort inside the dwelling through the ventilation technique used.. ☐...Dissatisfactory....... ☐... Satisfactory.... ☐...Very satisfactory........

.. ☐. Highly satisfactory...

Is the natural ventilation is the optimal solution within the dwelling in all seasons of the year (winter - spring - summer - fall).. ☐..Yes.... ☐...No..

Why..

Which seasons of the year is necessary to use mechanical cooling.................. and why..

....

Other Notes...

....

THERMAL PERFORMANCE INSIDE THE HOUSE

Are the temperatures inside the house appropriate in all seasons of the year ☐...yes.......... ☐... No..

If the temperature is appropriate, what seasons are consider critical

....

What orientation of the house is considered more vulnerable to external heat ☐.North ....☐...South.......☐.... East......☐..... West ...☐... East & South....

.☐..East & South & West...

Is the ground floor more affected with eternal climate than the upper floor or vice versa ....

Is there canopy provided shading on the top of house or not.................

....

What about the availability of the shadows around the building............

....

Are trees playing an important role in mitigating the external environment around the house, which helps to maintain indoor temperature...

Do you think that the style of construction and building materials used have a positive or negative role on the thermal performance of house...

Which rooms are more influential with rising internal temperatures

.☐..Bedrooms...☐. living room ..☐..Saloon...☐. Kitchen....☐..Bathrooms..................

What is your vote for the thermal comfort inside the dwelling?

Winter /Ground Floor..☐.Cold......☐..Cool......☐. Slightly Cool.......☐Neutral ...

.☐....Slightly Warm...☐.Warm.....☐.Hot...

The Upper Floor..☐.Cold....☐..Cool...☐...Slightly Cool....☐ Neutral ...☐..Slightly

Warm....☐.Warm.....☐.Hot...

Summer /Ground Floor..☐.Cold...☐..Cool......☐. Slightly Cool.......☐Neutral.....

...☐.....Slightly Warm...☐..Warm...☐..Hot..

The Upper Floor..☐.Cold........☐.Cool......☐. Slightly Cool.....☐. Neutral.......

....☐.Slightly Warm☐.....Warm...☐..Hot...

Do you think that the use of natural ventilation helps to reduce the peak of internal temperatures on hot days or the use of mechanical cooling and fans much better ....

....

What time of the day in the summer season is considered very high temperatures inside the house...

.☐..Morning.........☐. Noon......☐. Evening.....☐. Night.........☐. Noon & Evening........

Other Notes..

....

....

WEARING CLOTHES

Winter...

....

Spring...

……………………………………………………………………………………………

Summer………………………………………………………………………………………

……………………………………………………………………………………………

Autumn………………………………………………………………………………………

……………………………………………………………………………………………

APPENDIX 2: Chi Square scores

Partitioning the Sums of Chi Square scores of ventilation plan / [A] ground floor [B] first floor

A

Time	Outside Dry-Bulb Temperature	Full-Day vent		Day-time vent		Night-time vent	
	Ref		Chi Square scores A		Chi Square scores B		Chi Square scores C
6.00	27.4	32.4	0.9	35.1	2.1	29.3	0.1
7.00	27.0	31.9	0.9	34.8	2.2	29.2	0.2
8.00	28.3	32.1	0.5	34.6	1.4	29.6	0.1
9.00	31.1	33.2	0.1	35.1	0.5	30.3	0.0
10.00	34.5	35.0	0.0	36.7	0.1	31.0	0.4
11.00	37.7	36.7	0.0	38.2	0.0	31.3	1.1
12.00	39.9	37.9	0.1	39.3	0.0	31.7	1.7
13.00	41.5	38.9	0.2	40.2	0.0	32.0	2.1
14.00	42.9	39.8	0.2	41.0	0.1	32.5	2.5
15.00	44.5	40.8	0.3	41.9	0.1	33.4	2.7
16.00	46.2	41.9	0.4	43.0	0.2	34.5	3.0
17.00	46.4	42.5	0.3	43.5	0.2	35.2	2.7
18.00	45.6	42.5	0.2	43.6	0.1	35.6	2.2
19.00	44.2	42.2	0.1	43.6	0.0	35.8	1.6
20.00	40.9	40.9	0.0	43.6	0.2	35.6	0.7
21.00	38.1	39.7	0.1	43.3	0.7	35.5	0.2
22.00	36.4	38.9	0.2	42.6	1.0	35.3	0.0
23.00	34.9	38.1	0.3	42.2	1.5	34.7	0.0
0.00	33.3	36.9	0.4	41.4	2.0	34.2	0.0
1.00	31.7	35.9	0.6	40.8	2.6	33.8	0.1
2.00	30.5	35.1	0.7	40.5	3.3	33.3	0.3
3.00	29.1	34.1	0.9	40.1	4.1	32.6	0.4
4.00	29.1	33.7	0.7	39.8	3.9	32.0	0.3
5.00	28.5	33.2	0.8	39.0	3.9	31.4	0.3
6.00	27.2	32.4	1.0	38.0	4.3	31.3	0.6
		Sum of Squares	9.7	Sum of Squares	34.7	Sum of Squares	23.3

B

Time	Outside Dry-Bulb Temperature	Full-Day vent		Day-time vent		Night-time vent	
	Ref		Chi Square scores A		Chi Square scores B		Chi Square scores C
6.00	27.4	34.0	1.6	35.8	2.5	32.9	1.1
7.00	27.0	34.1	1.9	35.5	2.7	33.0	1.3
8.00	28.3	34.3	1.3	35.6	1.9	34.0	1.1
9.00	31.1	34.3	0.3	35.2	0.5	35.6	0.6
10.00	34.5	35.1	0.0	35.9	0.1	37.1	0.2
11.00	37.7	36.2	0.1	37.0	0.0	38.4	0.0
12.00	39.9	37.2	0.2	37.9	0.1	39.5	0.0
13.00	41.5	38.1	0.3	38.8	0.2	40.4	0.0
14.00	42.9	39.0	0.4	39.6	0.3	41.5	0.0
15.00	44.5	39.8	0.5	40.4	0.4	42.6	0.1
16.00	46.2	40.8	0.6	41.3	0.5	43.1	0.2
17.00	46.4	41.3	0.6	41.8	0.5	42.9	0.3
18.00	45.6	42.0	0.3	42.3	0.2	42.4	0.2
19.00	44.2	42.0	0.1	42.5	0.1	40.8	0.3
20.00	40.9	41.3	0.0	42.4	0.1	39.2	0.1
21.00	38.1	40.3	0.1	42.0	0.4	38.2	0.0
22.00	36.4	39.7	0.3	41.5	0.7	37.3	0.0
23.00	34.9	38.3	0.3	40.3	0.8	36.5	0.1
0.00	33.3	37.4	0.5	39.5	1.2	36.1	0.2
1.00	31.7	36.7	0.8	39.1	1.7	35.4	0.4
2.00	30.5	36.1	1.0	38.6	2.2	35.1	0.7
3.00	29.1	35.4	1.4	38.1	2.8	34.8	1.1
4.00	29.1	35.0	1.2	37.7	2.5	34.4	1.0
5.00	28.5	34.6	1.3	37.2	2.6	34.3	1.2
6.00	27.2	34.3	1.8	36.7	3.3	34.1	1.7
		Sum of Squares	16.7	Sum of Squares	28.2	Sum of Squares	12.0

APPENDIX 3: Table of Chi-Square Probabilities[1]

The areas given across the top are the areas to the right of the critical value. To look up an area on the left, subtract it from one, and then look it up (ie: 0.05 on the left is 0.95 on the right)

df	0.995	0.99	0.975	0.95	0.90	0.10	0.05	0.025	0.01	0.005
1	---	---	0.001	0.004	0.016	2.706	3.841	5.024	6.635	7.879
2	0.010	0.020	0.051	0.103	0.211	4.605	5.991	7.378	9.210	10.597
3	0.072	0.115	0.216	0.352	0.584	6.251	7.815	9.348	11.345	12.838
4	0.207	0.297	0.484	0.711	1.064	7.779	9.488	11.143	13.277	14.860
5	0.412	0.554	0.831	1.145	1.610	9.236	11.070	12.833	15.086	16.750
6	0.676	0.872	1.237	1.635	2.204	10.645	12.592	14.449	16.812	18.548
7	0.989	1.239	1.690	2.167	2.833	12.017	14.067	16.013	18.475	20.278
8	1.344	1.646	2.180	2.733	3.490	13.362	15.507	17.535	20.090	21.955
9	1.735	2.088	2.700	3.325	4.168	14.684	16.919	19.023	21.666	23.589
10	2.156	2.558	3.247	3.940	4.865	15.987	18.307	20.483	23.209	25.188
11	2.603	3.053	3.816	4.575	5.578	17.275	19.675	21.920	24.725	26.757
12	3.074	3.571	4.404	5.226	6.304	18.549	21.026	23.337	26.217	28.300
13	3.565	4.107	5.009	5.892	7.042	19.812	22.362	24.736	27.688	29.819
14	4.075	4.660	5.629	6.571	7.790	21.064	23.685	26.119	29.141	31.319
15	4.601	5.229	6.262	7.261	8.547	22.307	24.996	27.488	30.578	32.801
16	5.142	5.812	6.908	7.962	9.312	23.542	26.296	28.845	32.000	34.267
17	5.697	6.408	7.564	8.672	10.085	24.769	27.587	30.191	33.409	35.718
18	6.265	7.015	8.231	9.390	10.865	25.989	28.869	31.526	34.805	37.156
19	6.844	7.633	8.907	10.117	11.651	27.204	30.144	32.852	36.191	38.582
20	7.434	8.260	9.591	10.851	12.443	28.412	31.410	34.170	37.566	39.997
21	8.034	8.897	10.283	11.591	13.240	29.615	32.671	35.479	38.932	41.401
22	8.643	9.542	10.982	12.338	14.041	30.813	33.924	36.781	40.289	42.796
23	9.260	10.196	11.689	13.091	14.848	32.007	35.172	38.076	41.638	44.181
24	9.886	10.856	12.401	13.848	15.659	33.196	36.415	39.364	42.980	45.559
25	10.520	11.524	13.120	14.611	16.473	34.382	37.652	40.646	44.314	46.928
26	11.160	12.198	13.844	15.379	17.292	35.563	38.885	41.923	45.642	48.290
27	11.808	12.879	14.573	16.151	18.114	36.741	40.113	43.195	46.963	49.645
28	12.461	13.565	15.308	16.928	18.939	37.916	41.337	44.461	48.278	50.993
29	13.121	14.256	16.047	17.708	19.768	39.087	42.557	45.722	49.588	52.336
30	13.787	14.953	16.791	18.493	20.599	40.256	43.773	46.979	50.892	53.672
40	20.707	22.164	24.433	26.509	29.051	51.805	55.758	59.342	63.691	66.766
50	27.991	29.707	32.357	34.764	37.689	63.167	67.505	71.420	76.154	79.490
60	35.534	37.485	40.482	43.188	46.459	74.397	79.082	83.298	88.379	91.952
70	43.275	45.442	48.758	51.739	55.329	85.527	90.531	95.023	100.425	104.215
80	51.172	53.540	57.153	60.391	64.278	96.578	101.879	106.629	112.329	116.321
90	59.196	61.754	65.647	69.126	73.291	107.565	113.145	118.136	124.116	128.299
100	67.328	70.065	74.222	77.929	82.358	118.498	124.342	129.561	135.807	140.169

[1]https://people.richland.edu/james/lecture/m170/tbl-chi.html