Thermal Comfort and Building Design Strategies for Low Energy Houses in Libya

Lessons from the vernacular architecture

Nadya M. S. Gabril

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Abstract

Since the last century a growing movement of individuals and organizations that seek the redefinition of how buildings are designed, built and operated to be more responsible to the environment. The critical contribution of the residential building in this matter emphasizes the need to study the houses thermal performance and its impact on environment, considering the human thermal comfort requirements. The reduction of the energy demand for heating and cooling is the key factor in the low energy houses and minimizing environmental damage caused by the emissions of carbon dioxide.

In this thesis the traditional vernacular houses in Libya have been used as a vehicle of the research. The houses have been selected from three cities, Tripoli, Ghadames and Gheryan; analyzed and appraised to the climate and culture requirement in addition to context, house form and building materials. The study endeavors to examine the Traditional Vernacular Architecture in Libya, which is conceptually understood as a shelter that fulfilled people's needs according to their socio-cultural criteria as well responding positively to the climatic factors. Therefore, studying the socio-cultural forces that form the vernacular houses outlines the guidelines for a low energy building that encounters people's contemporary need.

The research has been assessed by means of computer monitoring, field Survey and computer energy simulation. Monitoring the thermal performance of the traditional vernacular houses provides lessons that act as catalyst and model for future low energy house. Sets of passive heating and cooling strategy have been underlined from each of the three vernacular houses in three climatic regions in Libya. The field survey of thermal comfort has been conducted to examine the thermal comfort in Libya's traditional houses. The outcome of the survey is two main findings, first it sets the value of thermal insulation of the Libyan traditional clothing, and secondly, the survey assigns the thermal comfort temperature in three climatic zones in Libya. The energy simulations results of the three models induced that the vernacular traditional houses can augment the future low energy housing in Libya.

A low energy house models have been proposed by the author and tested with positive results in the three cities, using the available local building material and the traditional environment solutions can establish an indoor comfort environment that is acceptable.

The findings of the study fill part of the gap in the thermal comfort standards for Libya, and prove the possibility to lower the energy use in the future house compared to the contemporary house in the three climatic region of Libya, with nearly 80% in winter and 60% in summer. The study also provides guidelines for use in building standards in Libya. It also concludes that number of research avenues should be carried out for a comprehensive answer to the issue of thermal comfort and building design strategies for a low energy house in Libya.

Table of Contents

List of figures

CHAPTER ONE

CHAPTER TWO

CHAPTER THREE

Chapter Four

Chapter Five

CHAPTER SIX

CHAPTER SEVEN

CHAPTER EIGHT

List of Tables

CHAPTER TWO

CHAPTER FOUR

CHAPTER FIVE

CHAPTER SEVEN

CHAPTER EIGHT

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DECLARATION

I declare that all the material contained in this thesis is my own work. No portion of the work referred to in the thesis has been submitted in support of an application for another degree or to qualification of this university or any other institutions.

LIST OF ACRONYMS ABBREVIATIONS

AMV	Actual mean thermal sensation vote
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers.
ACSAD	Arab Center for Studies for Arid zones and Dry land
CDIAC	Carbon Dioxide Information Analysis Center
CEN	Comite Eurpeen de Normalisation - The European standards body
CIBSE	Chartered institution of building services Engineers.
Clo	The thermal insulation unit for clothing (1 clo = 0.155m2K/W).
EPBD	Energy Performance of Buildings Directive
G.E.C.O.L	General Electric Company of Libya
IASTE	The International Association for the study of Traditional Environment
iButtun	Computer chip used to record temperature
ISO	International Standard Organisation
MET	The body heat production unit, which is equal to 58.2 W/m^2
MRT	Mean Radiant Temperature
NCEUB	Network for Comfort and Energy Use in Buildings
PMV	Predicted mean vote
PPD	Predicted percentage dissatisfied
RCREEE	Renewable Energy and Energy Efficiency
RH%	Relative Humidity
SCATs	Smart controls and thermal comfort. Database of field survey in five EU countries.
SET	Standard effective temperature
T_{comf}	Comfort temperature
Tg	Globe temperature
Ti	Indoor dry bulb temperature
T_{db}	Dry bulb temperature
Time Lag	The time difference between the maximum outdoor temperature and the maximum indoor air temperature
Tn	Temperature judged by population to be neutral on ASHRAE thermal sensation scale. It is also known as comfort temperature.
To	Out door temperature
Top	Operative temperature
Trm	Running mean temperature is a mean calculated for a given period of time. As time progresses, new values are incorporated in the mean.
ESP-r	Energy Simulation Programme- research
K	Unit of degree Temperature
HDD	Heating degree days
CDD	Cooling degree days
T_b	The base temperature or the balance point temperature
ρ	Density, Mass per unit volume Kg/m^3
c	Specific heat capacity Thermal capacity per unit mass and unit temperature difference J/kg·K
ρc	Volumetric specific heat Thermal capacity per unit volume and unit

	temperature difference J/m^3.K
λ	Conductivity Thermal transmission in unit time through unit area for unit temperature difference between surfaces W/m.K
r	Resistivity Reciprocal of conductivity (1/K) - M K/w
C	Conductance Thermal transmission in unit time through unit area for a material or component of given thickness for unit temperature difference between surfaces. W/m^2 K
R	Resistance Reciprocal of thermal conductance m ^{2}K/ W
U	Transmittance U- value, Thermal transmission in unit time through unit area for a given element of construction including surface resistance for unit temperature difference. W/m 2 K
C_s	Surface conductance Thermal transmission in unit time and area through surface in contact with air due to convection and radiation per unit temperature difference W/m 2 K
R_s	Surface resistance Reciprocal of surface conductance m^2 K/W
ε	Emissivity Rate of thermal radiation from surface to that from same area of full emitter
α	Absorptivity Preparation of incident radiation absorbed by surface
D	Diffusivity Conductivity divided by volumetric specific heat capacity m^2/s
Y	Admittance Reciprocal of impedance of an element to cyclic heat flow W/m^2 K
$\propto$	A constant between 0 and 1 control how quickly the running mean respods to the outdoor temperature
A_D	The Du Bois area
$\mathbf{P_a}$	Vapour pressure of ambient air
$\underline{v}$	Air velocity m/sec

1. Chapter One :Introduction

1.1. The need for the Study

The thesis is founded on the basis that understanding human comfort requires an approach of examining buildings based on a critical examination of the design processes and the impact of thermal performance on human physiological, psychological and environmental satisfaction. The intention is that an examination of climatic issues together with the socio-cultural aspects of design will enable a comprehensive understanding of approaches to the design of both past and future housing in Libya.

The study endeavors to examine the Traditional vernacular architecture in Libya, which is generally understood conceptually as “shelter that meets people’s needs according to socio-cultural criteria as well responding to climatic factors”. Traditional vernacular house forms in Libya will be used as a vehicle for the research, directing the outcomes to the design of low energy houses for Libya.

Traditional house forms in Libya can be categorized into three different prototypes of vernacular dwellings; the coastal (open courtyard), the mountain (earth-sheltered), and the Saharan (compact) dwelling. These examples are to be utilized as case studies characterized by their special socio-cultural aspects, and the combined climatic conditions of temperature, humidity, mean radiation, velocity of air movement, and level of light intensity and its distribution.

Social behavior has had a great impact in the global environment through the generation of polluting gases, waste, energy consumption and resources shortage. Pollution caused by energy such as the emissions of carbon dioxide, which is one of the green house gases that absorb and emit radiation within the thermal infrared range, this process is the fundamental cause of the greenhouse effect.

On one hand human thermal comfort, the sensation of being satisfied within the surrounding environment, is affected by the indoor thermal environment of a building and, in terms of space heating and cooling, is responsible for a majority of building energy consumption. On the other hand, houses are responsible for a majority of total energy consumption, as pointed out by the General Electric Company of Libya "GECOL", in their report for Libya national study (Energy Efficiency and Renewable Energy)-figure (1.1), Energy used in houses for cooling, heating and water heating is responsible for 39% of total Libya's energy consumption.(G.E.C.O.L, 2006)

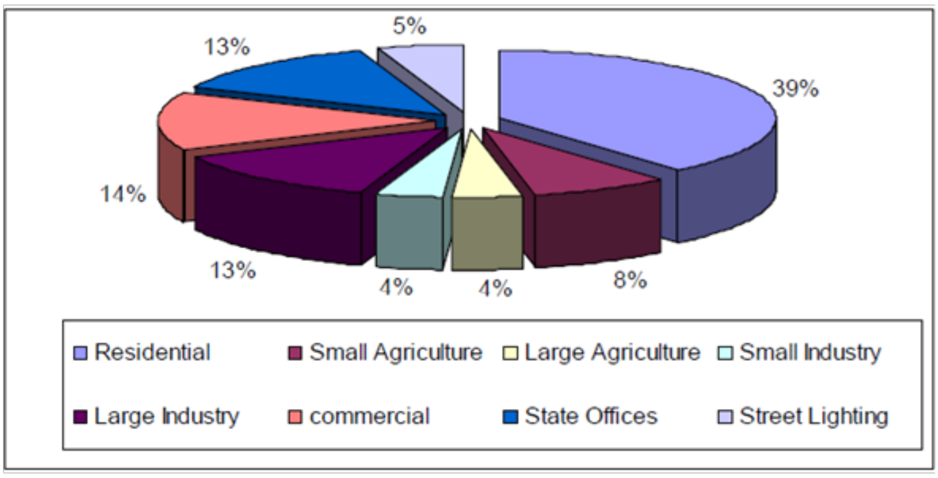


Figure (1. 1) Energy consumption distribution in Libya. Source GECOL report 2006

This critical contribution of residential zones to the emission of CO_2 is due to the rise in the number of new houses that are being built to accommodate decreasing household sizes. Continued stable and low cost energy has led the population as whole to be careless both with consumption of energy particularly electricity, and neglectful of the consequences of pollution and CO_2 emission.

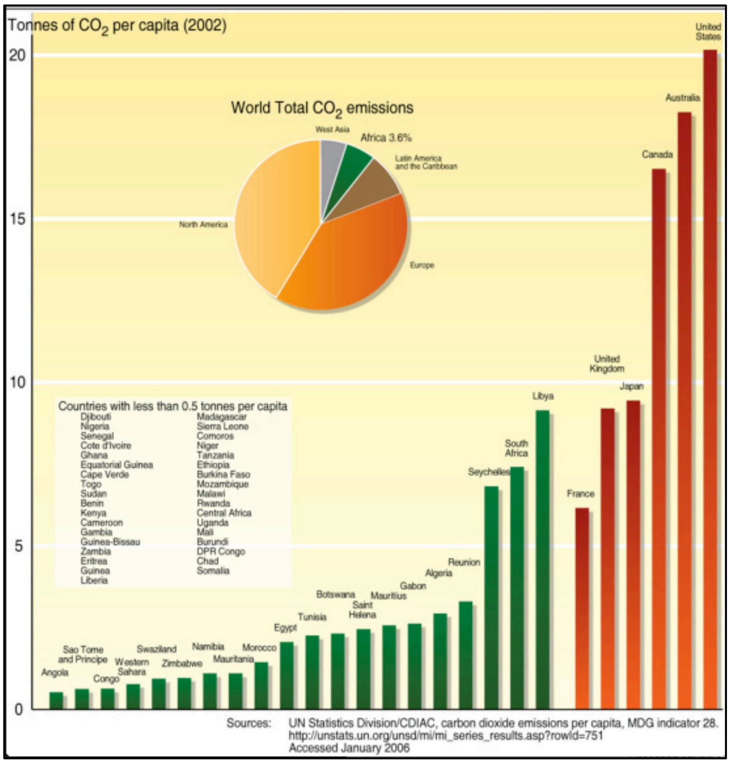


Figure (1. 2) Carbon dioxide emission per capita, MDG indicator. Source UN statistic Division/ CDIAC

In 2006 Libya was listed as the 11th country in the world in terms of carbon dioxide emissions per person living there, with a (1.98 tones) per capita carbon dioxide emissions, higher than the global average of 1.13 tones a year according to (UN Statistics Division/ CDIAC) report 2006, figure (1.2).

This emphasises the urgent need for the study to explore such a situation and to point out the need for the adoption of technology that is essentially nonpolluting, simple in principle and socially and culturally acceptable.

Consequently, intelligent house design decisions would help us to use resources more sparingly, saving an equivalent quantity of greenhouse gases through adoption of a low energy house form.

1.2. Aim of the study

This doctoral research aims to examine the potential relevance of the vernacular in informing future low energy housing design in Libya. The central theme of this study is the role of tradition and technology in the development of Libyan House form, with a particular emphasis on the environmental aspects of dwelling and design so as to develop low energy and sustainable solutions. Within this framework, the research aims to:

- Investigate the relationship between culture, environment and house form as variables associated with comfort and a sustainable built environment.
- Study and analyse the traditional vernacular architecture in Libya, and endorse the lessons to inform the low energy house.
- Investigate thermal comfort temperatures in three regions in Libya, including the cultural aspects.
- Use the above points to set guidelines for future low energy houses in Libya.

Explicitly, the research will provide a better understanding of the potential of a sustainable modern house form in Libya, and its integration in achieving comfort at socio-cultural and physical levels. The aim is to systematically evaluate characteristics of vernacular houses and the existing knowledge of vernacular architecture, and contribute by providing a better understanding of how such lessons can inform the design of modern low energy houses.

Implicitly, the outcome of the study should be beneficial in establishing criteria for the development of appropriate house forms that are responsive climatically to the three different zones of Libya, as well as receptive to cultural dimensions.

The research thus explicitly sees environmental design as something that exceeds technical issues alone. In this it builds on work by scholars such as Hawkes (Hawkes, 1995) who understand environmental design in a holistic manner that combines knowledge of context, comfort, society and tradition.

1.3. Hypothesis: the research question

"Lessons from the Vernacular: Sustainability and comfort in future Libyan house form"

Rapoport argues that the unspecialized nature of vernacular buildings and their consequent success over the time may be the great lesson of vernacular building for our own day, (Rapoport 1969). It is imperative to address the question "What can be learned from it?". The vernacular building is an environmental wisdom (Mete Turan 1990.) and the answer can be revealed through examining the potential relevance of the vernacular in informing future low energy housing design.

Libya as a region will be introduced as the background of the research, the vernacular built environment, as evidenced in the case of 'Libyan houses', shows clearly how house form has been determined by the intersection of socio-cultural issues with climatic conditions.

The constraints of the given climate, limited materials and technology, and scarcity of economic resources have all affect the way that vernacular dwellings have evolved However, beyond these technical contexts, the importance of climate and socio-cultural factors has played a determining role in the creation of vernacular house forms. In addition, recent house forms in Libya have shown a tendency to overlook the role of the climate and social-cultural contexts, and have generally moved towards to universalized solutions in which technology has enabled specific climatic conditions to be overcome, and which ignore the lessons of the vernacular in terms of material use, the conditions of dwelling and environmental responsiveness.

1.4. The structure of the study

The analysis of the development of the form of the Libyan house requires an exploration of the relationship between a number of variables, and the way that their interaction has influenced the process of making and modifying the house form. There are two principal contexts to be considered: the socio-cultural meaning and use, and the physical form, in particular, the impact of environment, materials, skill and technology on the creation of house forms.

These variables are illustrated in figure (1.3), within three macro contexts; the research will examine these relationships in terms of cause and effect, as well as associational links. Mixed-method approaches are to be utilised to collect and analyse data. The design of the research methods is based around the aim to examine the relationship of environmental and socio-cultural contexts in the design of housing form, both in the past and in the contemporary era.

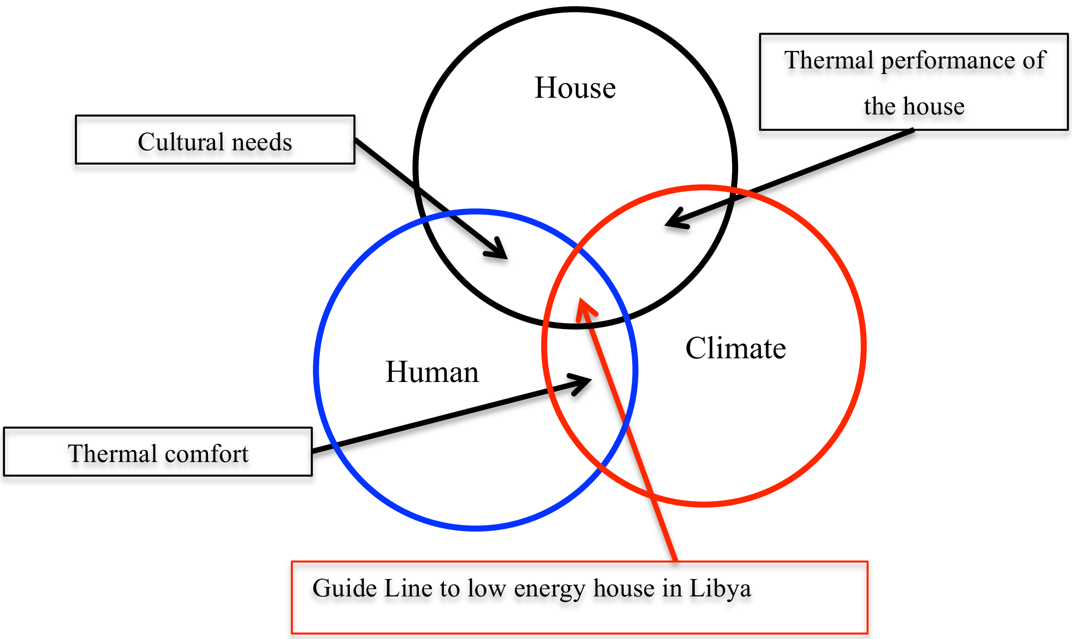


Figure (1. 3) the research concept

The relationship will be explored as follow:

1. Studying the impact of the cultural and social needs on the house form, analyzing the traditional vernacular and contemporary house forms.
2. Studying the impact of the environment on the morphological characteristics of Libyan houses by analyzing the thermal performance of the houses.

3. Studying the impact of the environment on the socio-cultural context, investigating thermal comfort in Libya.

As the study attempts to explore a complex pattern of interaction, the disaggregation of the three interdependent variables becomes an essential step. These variables are introduced as three problems within the components of the study.

1.5. Research methodology

“The general rule is that the data determine the research method". Referring to the above diagram of variables, the study will adopt a number of data collection techniques. Moreover, the research will use surveying tools adequate to the data qualities and quantities. The research methodology can be exemplified as follows:

1.5.1. Literature review

To understand the relationship between the socio-culture aspect and the house form. This variable was subdivided into sections according to cause and effect.

The impact of the socio-cultural aspect on house form was studied in this research in order to understand the morphology of the Libyan houses. Rappaport argues,(Rapoport, 1969), that in order to describe the socio cultural component that affects the house form, the term “genre de vie” can be used. Genre de vie is a term used by Max Sorre and others that includes all the cultural spiritual, material, and social aspects which effect form. The term is the sum of: Culture, Ethos, worldview and national character. However, these can be demonstrated in the important aspect of the genre de vie which affect built form, which are basic needs, family structure and position of women, religion, tradition and social associations.

Consequently, the study explores the house elements that reflect the socio-culture forces, such as space organization and use and artifact organization, craftsmanship and decoration. Within the study (house form index) is established to understand the house morphology.

1.5.2. Survey methods

Two field studies were conducted in this study. Firstly the thermal performance of traditional vernacular houses was monitored for three house forms:

- Courtyard house in Tripoli

- Compact house in Ghadames
- Earth sheltered house in Gheryan

Secondly a thermal comfort field survey was conducted in three cities representing the three climatic regions in Libya to evaluate the following:

- Thermal comfort equation for the three regions of Libya.
- Social behavior adaptation.
- The thermal insulation properties of the Libyan traditional clothing.

1.5.3. Computer energy simulation modeling

The research proposes a model driven from the vernacular houses in three regions; the models have been analyzed by using ESP-r (Environmental Systems performance). As a design oriented thermal simulation appraisal programme, ESP-r is one of the best-validated packages of its kind (Clarke, 2001). The programme has been used to evaluate:

- The thermal performance of the proposed model in the three regions.
- Calculate the Degree hours for cooling and heating.
- Estimate cooling and heating energy requirements in order to attain a low energy house in the three cities to reach thermal comfort temperature.

1.6. Study Parameters

For the purpose of this investigation, the following delimitation is made:

- Houses in three cities will be included in this study as illustration of the three climatic zones in Libya the coastal, mountain and desert zones.
- The coastal region will be represented by Tripoli, Gheryan presents the mountainous region, and the desert region is presented by Ghadames.
- The house in this respect is introduced to the study as a vehicle .The study will be limited to the house only and will not include any housing projects. This is thought appropriate as 60% of domestic buildings in Libya are houses (row houses, semidetached and detached houses) .
- The environmental element will be limited to that affected by the thermal performance of the houses and subsequently the energy consumption, these will be determined by climatologic elements, topography and materials.
- Discussion of human comfort will be limited to thermal comfort, as it is the main aspect that controls the space heating and cooling, which in turn is responsible for a majority of domestic building energy consumption.

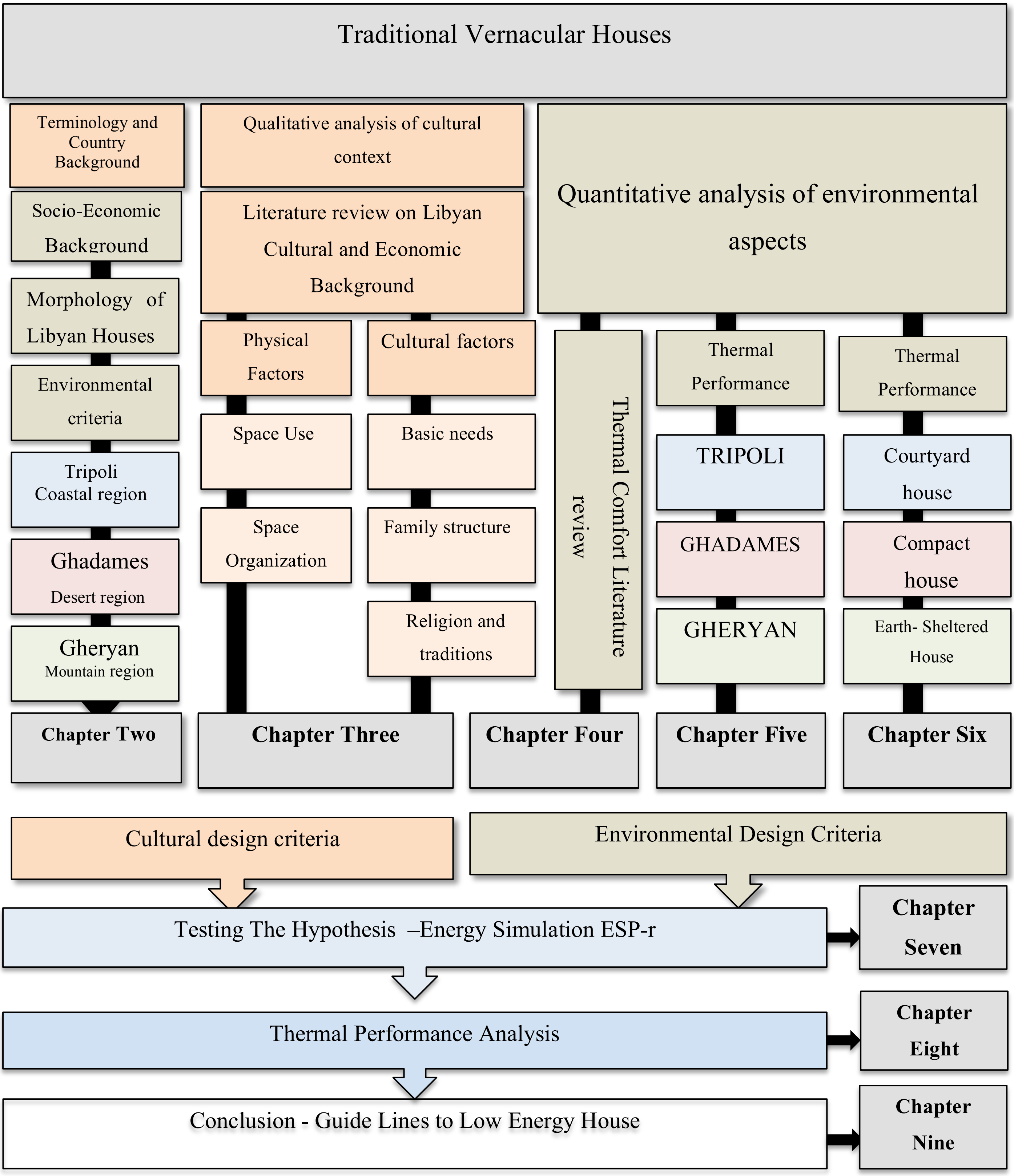


Figure (1. 4) the research structure

1.7. The Research structure

In seeking to achieve the objectives of the study, this research will be structured into nine chapters; each chapter deals with the particular argument of influential variables and their levels of interactions and relationships, building up towards the final findings and concluding recommendations. Figure (1.4).

1.8. Chapters summary

The thesis was divided into three sections; a literature review, a field survey and a computer energy simulation. The study was presented in nine chapters as follows:

Chapter one: Introduction

Chapter two: a literature review on Libyan history and socio-economic background. In addition, a review of the terminology of the vernacular traditional architecture and low energy house, finally a summary of the morphology of the Libyan house.

Chapter three: the descriptive analysis of the vernacular traditional houses in Libya The outcome of the survey conducted about the three traditional vernacular house forms in Libya suggests several determinants that formed the house in Libya (basic needs, family structure, position of women, privacy, social intercourse).

Chapter four: the chapter includes a literature review on the concept of thermal comfort and the parameters that determine human thermal comfort, in addition an outline the comfort standard and a review on pervious field studies conducted in the region.

Chapter five: a thermal comfort field study, a survey has been conducted in the three cities representing the three region of Libya during three seasons. The survey includes a questionnaire and monitoring of the climate factors in order to establish the thermal comfort equations for the three regions. The chapter also includes an experiment to evaluate the thermal insulation of Libyan traditional clothing.

Chapter six: a field study was conducted in order to investigate the effect of the environment variables on the thermal performance of the house, in other words, the force of the climate and location in forming the traditional vernacular house. Monitoring the thermal performance of the traditional vernacular houses in three cities can inform us on the effect of the external environment on the houses and the internal heat gains due to human behavior, in addition to the design variables; geometrical dimensions of building elements such as the building envelope, orientation, shading devices, and layout context.

Chapter seven: In this chapter a house model has been chosen and analyzed using a computer programme (ESP-r) to examine the thermal performance of buildings in three climatic zones of Libya. The layouts for the house were modified according to the environmental and cultural requirement in the three cities of Tripoli, Gheryan and Ghadames. The energy simulation results were analyzed to achieve the lowest energy consumption within the comfort zone of the region.

Chapter eight: this chapter documents an evaluation of the energy efficiency of the model in the three cities. Firstly, a calculation was made of the heating and cooling degree-days for the three regions, that being considered an effective method to estimate and analysis the energy demands of heating or cooling for a building. Then a comparison analysis was made between the energy demands of heating and cooling in the contemporary houses and the proposed model by calculating the cooling and heating degree hours using ESP-r. The results of this analysis show, in percentage terms, the reduction of energy consumption in the proposed model in the three regions.

Chapter nine: This chapter abstracts the finding and conclusions of the study; in addition it outlines a potential future research path for low energy technology in Libyan houses. The study describes in detail the strategy and pathways to follow in order to obtain a lower energy house in Libya using local materials and the vernacular passive strategies for cooling and heating in three different region of the country.

2. Chapter Two: An overview of Libyan climate and architecture

2 Chapter Two: An overview of architecture in Libya.

This chapter outlines firstly the historical and economical background of the country in additional to the climate and topology. The second section discusses the terminology of the traditional vernacular architecture, and outlines the meaning of the term low energy house. Finally the chapter includes a review of Libyan house morphology during the last century.

2.1 Country background

In his book ‘Colors of Libya’ Angelo Pesce introduces Libya as “a nation with a rich artistic and cultural heritage: The silent voices of its glorious historical past are embodied in the Garamantic, Greek, Roman, Byzantine, Berber and Arab cities and monuments, widely known for their uniqueness and conditions of preservation.” (Pesce 1970)

Many historians have written about Libya in the past and present. Their main conclusions are that it is a country with a great variety of influences in all areas, none more than in its architectural heritage, beginning with the Phoenician, Greek and Roman empires, extending to the Turks and Italian colonization. Independence was proclaimed in December 1951 but before that date, following the conquest of the Italians, Tripolitania, and Cyrenaica had been ruled by a British administration, and France administered Fezzan.

2.1.1. Socio-economic background

Libya is a country with small population of nearly 6.4 million according to the 2011 Report. This is distributed unevenly as result of its physical features, with 90% of the land uninhabitable, being mainly desert. The remaining 10% of the land area contains about 90% of the population, mainly occupying the northern coastal area with the distribution illustrated in figure (2-1) (Surveying department of Libya 1985).

In 1951, after the discovery of oil, the nation faced great changes and extensive widespread development. The Libyan economy is now mostly dependent on oil and gas for its source of income. Also throughout the last decade a number of industries have been developed, most of which are based on oil, such as the petro-chemical industries, iron and steel production and some light industries.

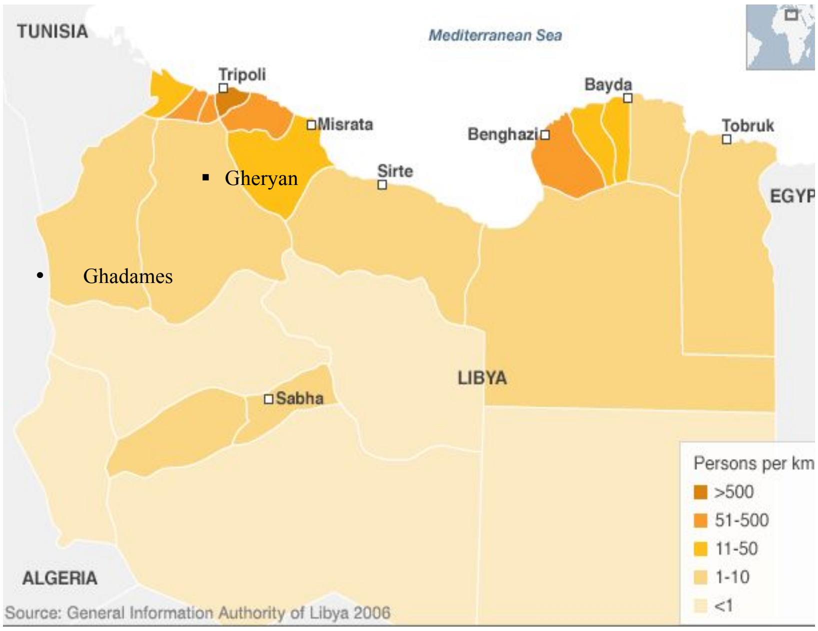


Figure (2. 1) Population distribution in Libya

Since the discovery of oil, Libya has enjoyed a high per capita national income and has benefited from a cheap source of energy both for industrial, domestic and commercial use. Continued stable and low cost energy has led the population as a whole to be careless both with consumption of energy, particularly electricity, and neglectful of the consequences of pollution and CO_2 emission.

Cheap electricity coupled to improved living standards and expectations has resulted in an increase in energy demand from 40 million GJ in 1965 to 270 million GJ in 1986, and it is projected to reach 2500 million GJ in the year 2025 (CSES, Report, 1991).

The present energy supply in most countries cannot be considered as a sustainable sources of energy, as the energy costs are exploding, the sources are limited, and because of the environmental issues. For Libya the conventional sources of energy are limited to two sources; oil and natural gas.

The oil resources of Libya will not last more than 50 years as of today production and discovered resources, while the natural gas reserves are expected to last more than that. Libya is an oil exporting country and most of the produced energy is exported.

2.1.2. Topography

Libya is located in the northern part of Africa, covers area of about 1,759,540 square km and has the longest coastline in Africa, stretching well over 1770 km, on the northern border. The western border is 1100km long, lying next to Tunisia and Algeria. The eastern border is 1400km long, lying next to Egypt and Sudan while the southern border lies next to Niger and Chad. The presence of the great Sahara desert and Mediterranean sea are the important factors in conditioning the geography in Libya. The country possesses a number of topographic areas, each with different soil characteristics. These can be characterized into to three significant topographic regions as illustrated in figure (2-2) (Surveying department of Libya 1985).

Firstly, the north coast and Jefara plain: this is the most recognizable region, which extends from the east to the west of the country. Its width ranges from 3km to 100km narrowing close to Al Akhdar Mountain and expands to 100km width before Naffusa Mountain. This area is associated with the greatest cultivation in the country. Apart from the Gulf of Sirte where the coastal region projects far into the desert, this coastal strip is the richest of all Libyan regions in water and fertility, and is the most densely populated. There are hardly any plain lands in Libya and there are very few agricultural tracts. The Jefara plain is located in the north west of the country. It has an area of 22000 km^2 and accommodates about 60% of the whole Libyan population. Economically the region is very important since the agriculture sector produces more than half the country's agricultural products. The plain slopes toward the sea, ranging in height from 200m to 300m near the mountains down to 20m close to Tripoli. Other parts are more level and in some cases merge with the desert.

Secondly the mountains: There are a number of highlands in Libya, the highest point in Libya being the Tibesti Massif. There are two main mountains, Naffusa Mountain and Al Akhḍar Mountain. Naffusa Mountain is located about 50 to 100 km south of Tripoli, to the south of the Jefara Plain where it rises steeply above the Jefara plain. Its average width is around 20km, extending towards the east about 400 km from the Tunisian border to 110km west of Tripoli and containing a high range of hills from 500m to 960m high. These mountains are associated with old olive trees, which cover many mountains and valleys. Moreover, the land is composed of basalt, volcanic rock, limestone-loess and gypsum-marl. On the southern edge exists some red stone desert. The second mountain is Al Akhḍar located in the north-east of the country. It extends along the Mediterranean coast for about 100 miles (160 km). Rising sharply in two steps, the first reaching 985 feet (300 m) and the second about 1,800 feet (550 m), the limestone range (about 20 miles [32 km] wide) then blends into a plateau crowned by hills, attaining elevations of nearly 3,000 feet (900 m). It descends eastward to the barren, stony terrain of Buṭnān and southward to the Libyan Sahara.

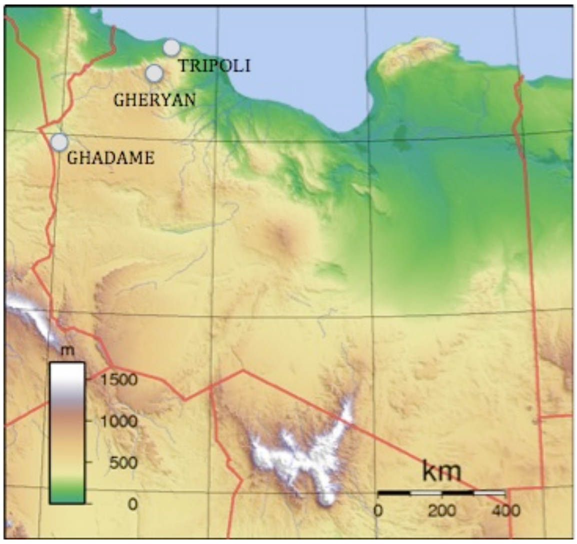


Figure (2. 2) Topography of Libya

Finally, the Sahara desert: this begins just south of the gulf of Sirte, an area from which the two mountains regions rise up toward the east and west of Libya. The desert is the dominant part in terms of area, as it covers about 90% of the country. It is an isolated area, with hills ranging from 700 to 1000m in high. There are a number of oases situated in shallow basins and valleys, where ground water reaches the surface, forming natural springs. Palm trees form the vegetation of the oasis, and the foundation land is limestone, sand stone, gypsum and fine sand hills. Most of the desert contains unstable sand that migrates from one place to another. (Surveying department of libya 1985)

2.1.3. Climate of Libya

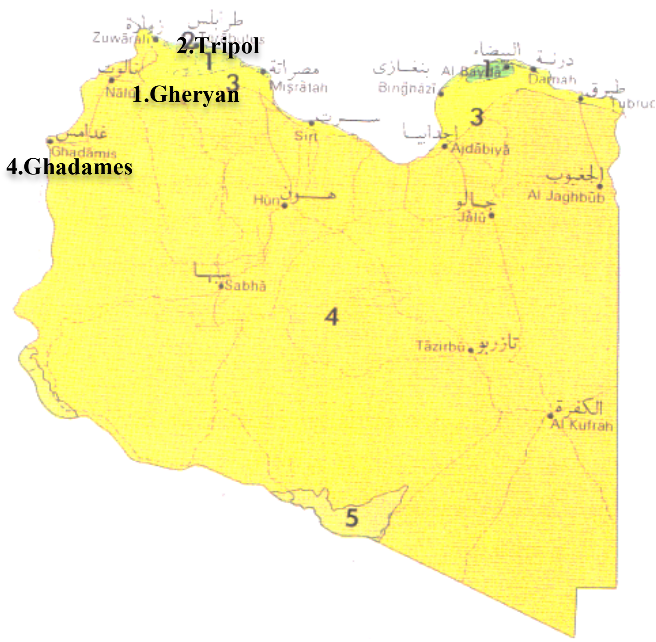
A number of different classifications of climate zones have been developed by geographers, the common factor that has been shared is that classifications have always been related to the vegetation zones or the rate of precipitation and temperature. However, one of the most well-known and widely used classifications is based on the vegetation that may be grown, rather than the vegetation that exists in the zone and the extreme diurnal temperatures.

In relation to building needs, Atkinson's classification (Evans 1980) of hot climate is the most commonly used classification. The major zones and sub-zones are distinguished according to the average monthly and annual average temperature together with the minimum and maximum monthly rainfall and annual average rainfall. The hot climate classification includes three main climate types, warm humid (W.H), hot dry

(H.D), and composite or monsoon (C). Their sub-groups are tropical island climate, maritime desert climate and tropical upland climate.

The climate of Libya is characterized by its aridity and by its variation in temperature. As a result of its location and the lack of high mountains barriers, the country is open to the influences of both the Sahara desert and the Mediterranean sea. In addition, the size of the country causes climate variation even in the same region, such differences also associated with the contrast between the low lying areas and the mountains. However, the climate generally can be divided into four types, plus an unclassified mountain climate. Within Libya, as many as five different climatic zones have been recognized, Libya's climate is dominated by the hot, arid Sahara, but it is moderated along the coast by the Mediterranean Sea. The Saharan influence is stronger in summer. From October to March, prevailing westerly winds bring cyclonic storms and rains across northern Libya. A narrow band of semi-arid steppe extends inland from the Mediterranean climate of the Al-Jifārah Plain, the Naffusa Plateau, and the Al-Akhḍar Mountains. The desert climate of the Sahara reaches the coast along the southern fringes of the Gulf of Sidra, where the Al-Ḥamrāyah (Sirte) Desert borders the sea. Periodic droughts occur, often lasting several years. The weather is cooler in the highlands, and frosts occur at maximum elevations. In the desert interior the climate has very hot summers and extreme diurnal temperatures.

Rainfall is scanty, and the dry climate results in a year-round 98-percent visibility; most of the country receives less than 400 millimeters, and, in the Sahara, 50 millimeters or less occurs, the heaviest precipitation occurring in the Al-Akhḍar mountain zone in the north east of the country, where an annual rainfall of 400 to 600 millimeters is recorded. Shortage in rainfall is reflected in an absence of permanent rivers or streams, and the approximately twenty perennial lakes are brackish or salty. There are also numerous springs, those best suited for future development occurring along the scarp faces of the Nafusah and Al-Akhdar mountains.



1. Mediterranean climate- on the mountains (cold zone)
2. Semi-Mediterranean on the coastal area (Hot-humid)
3. Steppe (semi-arid)
4. Desert (hot-arid)
5. Unclassified mountain climate.

Figure (2. 3) the general classification of Libya's climate, after Buxtehude, 1981

In conclusion, by plotting the general classification of Libya's climate, on the population distribution map, we can conclude that the Libyan population is mainly distributed in three climatic zone: Mediterranean climate on the mountains (cold zone), Semi-Mediterranean on the coastal area (hot-humid) and Steppe (semi-arid). In this study three cities were selected each featuring these main climatic zones, respectively Gheryan, Tripoli and Ghadames. (Surveying department of libya 1985), this selection will focus on three main climatic zones in Libya represented by

- Semi-Mediterranean on the coastal area (Hot-humid) case study Tripoli.
- Mediterranean climate- on the mountains (cold zone) case study Gheryan.
- Desert (hot-arid) case study Ghadames.

Since this study is concerned with the thermal performance of the building, the focus will be on the effect of the four major components of mesoclimate and their importance in this respect: Air Temperature, Relative Humidity and Precipitation, Solar radiation and Air movement and speed.

2.1.3.1. The coastal area (Hot-humid) Tripoli case study

Tripoli is the capital of Libya and is located at latitude of 32.54 North and a longitude of 13.11 East. As the largest city in the country it is inhabited by 65% of the total Libyan population. A significant factor of the city is derived from its strategic location on the Mediterranean. The classification of Tripoli's climate is a maritime desert climate, which comes as a subgroup of the hot-dry climate as a result of the city's coastal location on the edge of a desert.

A relatively high diurnal range in air temperature, and a relatively high humidity characterizes the result of the combination of desert and sea effects. The rainfall in winter does not normally exceed 250 mm, and summer is normally dry. The sky is clear most of the year except in the cooler season where the level of diffuse radiation is higher. In addition to the global wind Tripoli experiences on-shore and offshore breezes.

Since this study is concerned with the thermal performance of buildings, the focus will be on the effect of the four major components of mesoclimate and their importance in this respect.

2.1.3.1.1. Air Temperature

From the data below (Meteonorm-7) it can be seen that the minimum temperature is found during the months of January and December, where the mean minimum temperature is nearly 18°C during the day and nearly 7°C during the night. The temperature can drop below 0°C in extreme conditions. Mean maximum temperature occurred during the months of June and July with a mean maximum temperature rising to 38°C. In extreme conditions the temperature rose to 45°C.

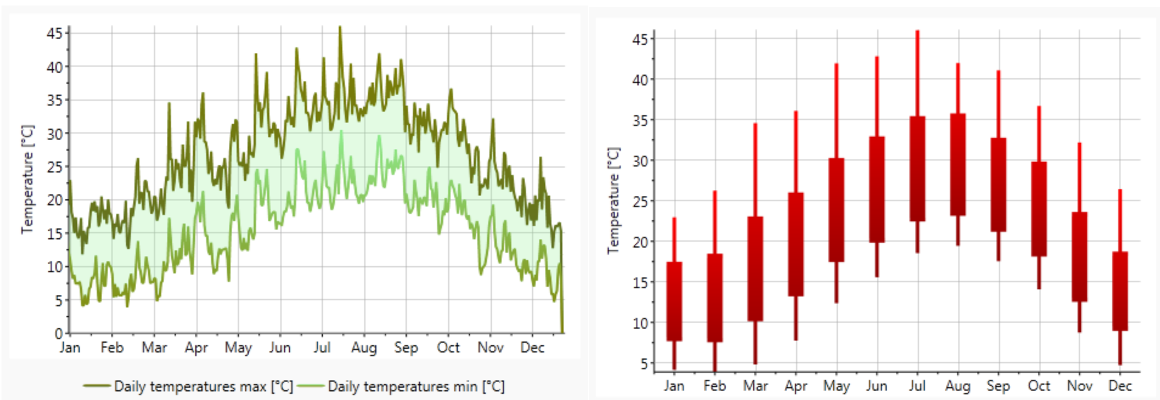


Figure (2. 4) Daily and monthly temperature - Tripoli

2.1.3.1.2. Relative Humidity and Precipitation

Relative Humidity in winter is affected by Tripoli's location and relatively high temperature, with monthly average of 66% in winter and can rise to 100% in extreme conditions. In summer the humidity is relatively low; it dropped to nearly 46% and can drop to 20% in extreme conditions.

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
66.2	54.4	50.1	47.4	47.4	47	46.5	46.3	55.3	56.3	58.5	64
Averaged Value (January 2000 - December 2008) **53%**											

Table (2. 1) relative humidity RH -Tripoli

2.1.3.1.3. Air movement

During the summer months in Tripoli, there are two type of desirable cool breeze, one from the N-NE with a speed range from 2m/s to 3m/s, and other from the NE-E with a speed between 1m/s and 4m/s, which are present for almost 50% of the year. The lack of barriers around the city also causes it to be influenced by the undesirable hot and dry sandy wind (Gibli) from the desert, having a direction of S-SE and speed range from 2m/s to 7m/s. This wind is present for few weeks from late March to mid-May; there are approximately fifty days when Ghibli may blow. Sometimes it is just a hot dry dusty wind but at other times it is much more ferocious and carries great quantities of sand and dust. The Ghibli can last from one to four days. These winds can force local temperatures up by as much as 50°C in just a few hours. Winter brings undesirable cool winds from the NW-W with a speed range from 3m/s to 3.5m/s. The most frequent wind direction is from the north and west with speed range from 3m/s to 6m/s.

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
12.1	12.4	13.5	16.2	17.0	15.5	13.3	12.8	13.4	11.2	11.6	13.3
Averaged Value (January 2000 - December 2008): **13.5 kph**											

Table (2. 2) Wind speed - Tripoli

N	11 %	
NE	13 %	
E	16 %	
SE	11 %	
S	14%	
SW	13 %	
W	11 %	
NW	9 %	

Table (2. 3) Wind direction -Tripoli

2.1.3.1.4. Daily radiation and sunshine duration

The average daily sunshine duration in Tripoli is about 9 hours. With a high level of solar radiation, the average daily solar radiation over the years 1981-1987 was approximately 6.948kWhm-2.

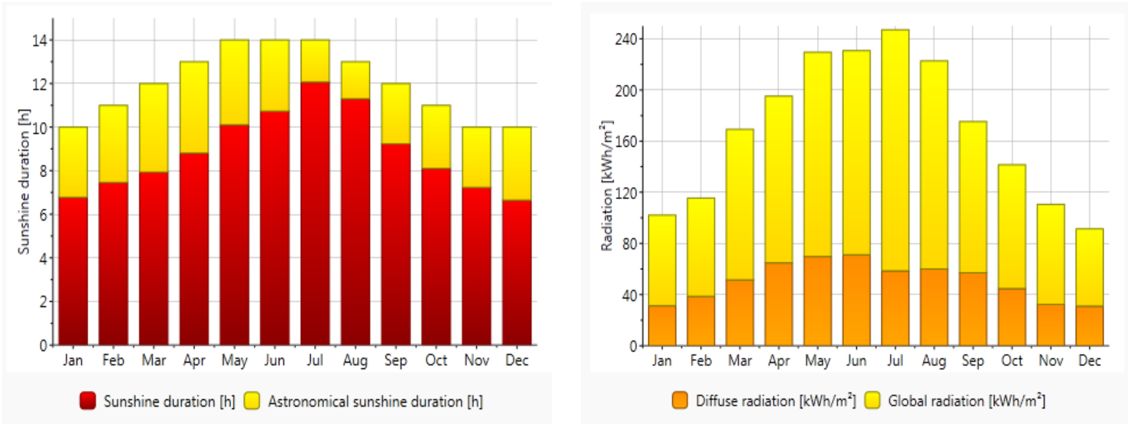


Figure (2. 5) solar radiation and diffuse radiation -Tripoli

2.1.3.2. Desert (hot-arid) case study - Ghadames.

The location of the city on the west edge of the Libyan oasis zone in a rocky desert region of Al Hammada al Hamra, situates the city in a harsh climate - an arid hot (desert) climate, where two periods are distinguished; summer, an eight month arid hot period and winter, a slightly cooler four month period of temperate cold conditions. The city's geographical co-ordinates are 30^{o} 08, Latitude north and 9^{o}30 longitude east.

2.1.3.2.1. Air Temperature.

The temperature of the air in the shadows during the summer period rises quickly after dawn, up to the monthly mean maximum temperature of 43°C in July and 38°C in September, and monthly mean minimum temperature of 22.3°C. Moreover in extreme conditions the ambient temperature rises to 50°C.

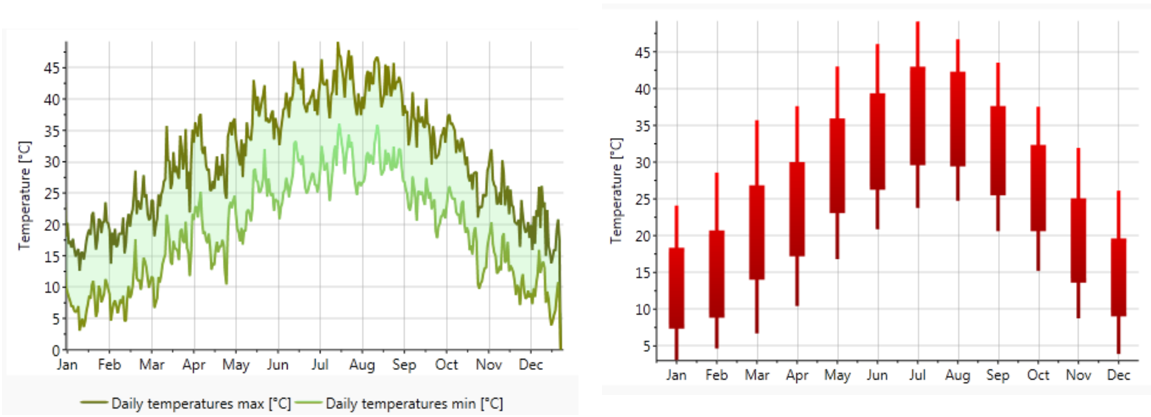


Figure (2. 6) Daily and monthly temperature - Ghadames

In winter, the monthly mean maximum temperature dropped to 3°C in January to 4°C in December, and mean maximum up to 18°Cand 19°C.

This indicates a considerable fluctuation of average daily temperature with the amplitude between daytime and nighttime temperature ranging from 14K to 20K.

The Ghadames environment experiences some of the world's highest temperatures but perhaps more surprisingly they also undergo some of the greatest temperature contrasts to be found on the planet. The lowest temperature recorded in the city and also in Libya during the last 50 years was -8 °C; the biggest temperature span was 58.6°C.

2.1.3.2.2. Relative Humidity and Precipitation

Relative Humidity (RH) in Ghadames as a desert city is relatively low with an average annual Relative Humidity of 27%. The mean RH in December rises to 35% in winter; it can reach up to 84% in maximum conditions while in summer it drops to 15% in summer, and the minimum RH goes down to 10% .

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
31.9	34.4	30.7	23.1	23.1	15.4	15.6	17.4	29.9	34.4	38.2	35.2
Averaged Value (January 2000 - December 2008): **27.4%**											

Table (2. 4) Relative humidity

2.1.3.2.3. Air movement.

The prevalent winds are from the north- east, but there is frequent local turbulence. The lack of barriers around the city also causes it to be influenced by undesirable hot and dry sandy winds (Gibli). The most frequent wind direction is from the north and east with a speed range from 3m/s to 6m/s.

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
11.6	13.1	15.4	16.6	18.8	17.7	15.9	15.4	15.9	13.2	11.2	10.7
Averaged Value (January 2000 - December 2008) : **14.6 kph**											

Table (2. 5) wind speed - Ghadames

N	10 %	
NE	19 %	
E	23 %	
SE	12 %	
S	10 %	
SW	8 %	
W	11 %	
NW	7 %	

Table (2. 6) wind direction

2.1.3.2.4. Daily radiation and sunshine duration

The sun shines very strongly, but in the absence of clouds the heat accumulated during daytime can be easily released in form of long waves radiated directly toward the cold night sky. The daily duration of exposure to sunlight ranges from 8.5 hours in December to 12.5 hours in summer.

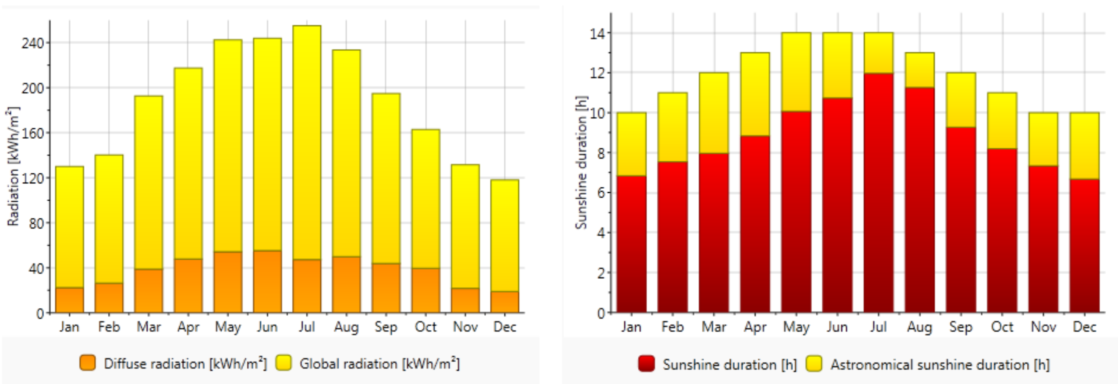


Figure (2. 7) Daily radiation and sunshine duration Ghadames

2.1.3.3. Gheryan Climatic data

The City's climate is Mediterranean with mean and maximum summer temperatures of 23.4°C and 40.1°C respectively. Mean and minimum winter temperatures fall to 12.7°C and 0.9°C respectively. The mean annual temperature is 18°C. An average 351.5 mm of rain falls between the months of September and March. The prevailing wind direction is from north to west.

2.1.3.3.1. Air Temperature.

During the summer period the average monthly maximum temperature is in the range of 35.7 °C to 26°C in September.

During winter, the average monthly temperature range is from 17.1°C to 24.4°C while at night the temperature drops to an monthly minimum temperature of -1°C.

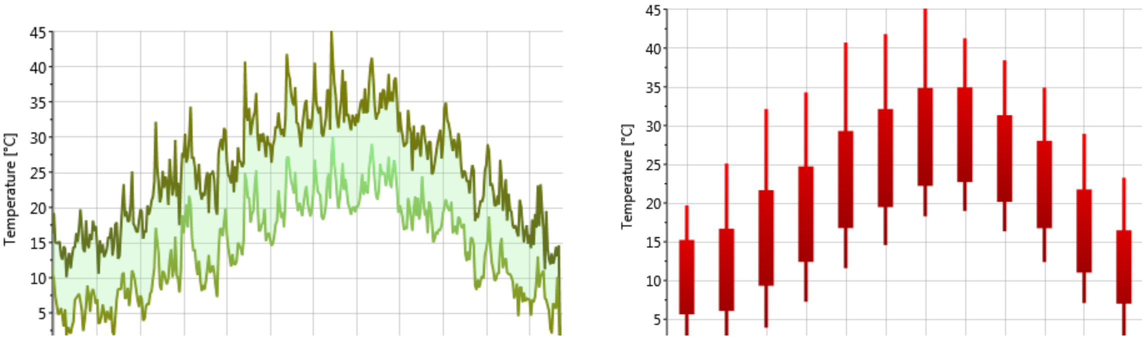


Figure (2. 8) Mean monthly temperature - Gheryan (METANORM)

2.1.3.3.2. Relative Humidity and Precipitation

The mean Relative Humidity of the air is 61 % in winter, the maximum reading for RH could rise up to 80% and in summer the mean monthly RH is nearly 28%, and the annual average is nearly 41%.

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
61	45.2	40.3	35.9	40.5	28.1	29	32.1	45.3	49.2	44.9	41.8
Averaged Value (January 2000 - December 2008) **41%**											

Table (2. 7) relative humidity - Gheryan

2.1.3.3.3. Air movement.

The prevalent winds are from the northeast, but there is frequent local turbulence. Strongly heated air directly above ground results in the inversion of temperature, which in turn result in the formation of local whirlwinds.

Wind-force per Day (January 2000 - December 2009).

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
15.5	16.0	15.9	17.0	16.5	14.6	13.5	13.1	14.0	12.3	12.3	15.3
Averaged Value (January 2000 - December 2009) : **14.7 kph**											

Table (2. 8) wind speed - Gheryan

N	22 %	
NE	20 %	
E	11 %	
SE	6 %	
S	14 %	
SW	9 %	
W	13 %	
NW	5 %	

Table (2. 9) wind direction –Gheryan

2.1.3.3.4. Daily radiation and sunshine duration

The sun shines very strongly, but in the absence of clouds the heat accumulated during daytime can be easily released in form of long waves radiated directly toward the cold, night sky. The duration of exposure to sunlight ranges from 7 hours in December to 12.6 hours in summer.

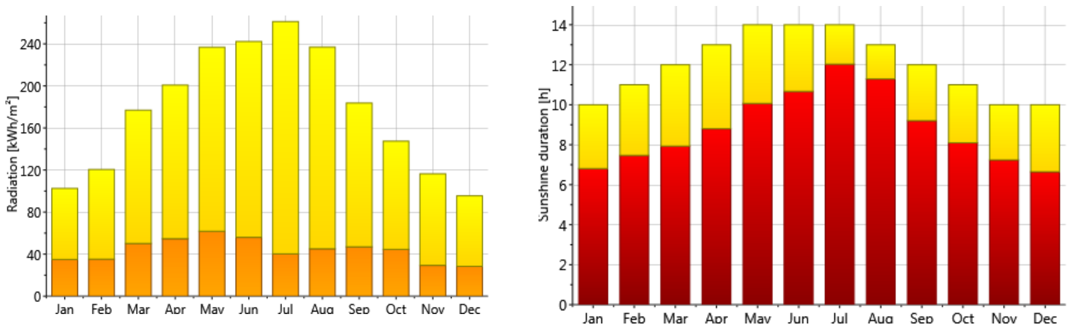


Figure (2. 9) Radiation and sunshine duration- Gheryan (METANORM)

2.2. Terminology

Classifications, taxonomies, and definitions are not panaceas; they clearly help to describe the domain and establish the nature of what one is dealing with (Turan 1990, 74). The terminology in the early stages of the field survey are defined according to a single characteristic (Monothetic classification) then is gradually adjusted as more is learned about the field, which led to a definition based on multiple characteristic “Polythetic classification”(Kaplan 1964). In this research, an assumption is made that studying the vernacular dwellings through the history of Libya is a way to improve the design of future dwellings. In order to examine the role of vernacular architecture in informing future low energy house design in Libya, it is useful to define both the vernacular architecture and the low energy house in order to help to understand the nature of the research.

2.2.1. The Definition of Vernacular Architecture

Although Vernacular considerations have great influence on architectural designs, architects had widely varying opinions of the advantages of the vernacular, and what vernacular architecture is and what it is not. These arguments led to a growing body of literature about the definition of vernacular architecture. In order to study the vernacular architecture and to learn from it, we need to first define the term vernacular in the Libyan architectural context.

In general, the term 'Vernacular Architecture' has been used by scholars to categories methods of construction that use locally available resources and which have been shaped by traditions to address local needs. Vernacular Architecture tends to evolve over time to reflect the changes in the environmental, cultural and historical context in which it exists.

In fact most scholars agree that defining vernacular architecture is still in a state of confusion, and there have been and continue to be debates on defining "vernacular architecture". (Mercer 1975) (Oliver. 2006) (A.Rapoport 1969) (21 v A). Nezar Al Sayyad explained the cause of this state of confusion in his forward to the book "Vernacular architecture in the twenty first century"; he argued that the explanation of the difficulty in defining vernacular architecture could be associated with the "etymological and epistemological limitation of the concept"

In 1964, Rudofsky was the first to draw attention to the term in his book "Architecture without Architects" (Bernard Rudofsky 1987). However, Oliver indicates that the term 'Vernacular' was the oldest, having been used by Giles Gilbert Scott in his book "Remarks on Gothic Architecture" in the mid nineteenth century, (P. Oliver 1990, p14). Oliver accepts the phrase, as it "embraces all the types of building made by people in tribal, folk, peasant and popular societies where an architect, or specialist designer is not employed" (Oliver. 2006, p4), but, referring to the other terms such as traditional architecture, which have been used in many countries, Oliver stated in his talk at the first conference of the IASTE (The International Association for the study of Traditional Environment) that "there is no such thing as traditional building but rather buildings that embody certain vernacular traditions". Hassan Fathy pointed out that tradition is not necessarily old-fashioned and is not synonymous with stagnation and that it may have begun quite recently and became a tradition (Fathy 2000).

The definition of vernacular architecture went through stages, starting from defining the term according to single characteristic of the process characteristic. Monothetic classification were produced by architects such as Ronald William Brunskil, Frank L. Wright and Bernard Rudofsky, Afterward, as more was learned about the field, the term was redefined by Mercer as a social as well as an architectural phenomenon (Mercer 1975). Moreover, defining the term vernacular by classifying the built environment, Brunskil divided the built environment into 'vernacular' and 'polite' architecture, and later Edwards added the term 'folk' architecture. Finally Amos Rapoport classified the built environment, into the "four-fold division" 'primitive; (preliterate), 'vernacular' (preindustrial and other) 'popular' and 'high-style' (with a number of subsets) (A. Rapoport 1990, p74). Consequently, he argued that a "polythetic classification", based on multiple characteristics to define the built environment, is the more advanced classification. Therefore, he defined the vernacular architecture by comparison with the 'high-style' architecture, using the process characteristics and product characteristics These characteristics were explained in his paper (Learning from the vernacular) as follows . Moreover, Rapoport implied that product characteristics offer possibilities for learning from the vernacular whereas process characteristics do not. Therefore he set a number of the product characteristics such as the degree of cultural, place-specification, specific model, plan forms, shapes, morphology, transitions, use of specific materials, textures, colours, in addition to the effectiveness of response to climate.

In theory, he compares the product characteristic of the "four-fold division" and points out that the study is only a set of hypotheses of 'the product characteristics of vernacular environments' and it is permissible to be tasted. Moreover, in his essay "Vernacular design as a model system" he adds an additional product characteristic dealing with the level of 'meaning', which emphasis that "the process and product characteristics represent a preliminary, hypothetical open-ended set." (Lindsay Asquith, and Marcel Vellinga. 2005., 181) (Turan 1990)

Paul Oliver's Encyclopedia of the vernacular architecture of the world (EVAW) marks the end of the first stage of vernacular studies, which is the natural history stage

(Lindsay Asquith, and Marcel Vellinga. 2005., 179), he points out that it is seems impossible to find a definition that would be applicable to building traditions in all continents, and to communities of differing sizes and diverse environment, and encompass all forms of building, every structural system and innumerable functions in the world. In his book, (Dwelling: the Encyclopedia of Vernacular Architecture of the World) he defines vernacular architecture as:

"...comprising the dwellings and all other buildings of the people. Related to their environmental contexts and available resources they are customarily owner or community built, utilizing traditional technologies. All forms of vernacular architecture are built to meet specific needs, accommodating the values, economies and ways of life of the cultures that produce them." (P. Oliver 1990, 30).

Finally, Simon J Bronnes pointed out that this definition emphasizes the building as a context within the environment context and available technologies, and stated that the tradition is an answer to why buildings look the way they do and why they are located where they are, but also addresses the question of why they come into being and how they changed along the way" (Lindsay Asquith, and Marcel Vellinga. 2005., 24).

In conclusion, learning what vernacular is and how to learn from it can be outlined in the product characteristics of the building, which in turn may offer possibilities for learning from the vernacular in order to obtain a low energy house that not only responds to the climate but also to cultural requirements. With reference to Oliver's definition the term "Traditional Vernacular Architecture" will be used in this study to define three types of traditional vernacular houses in the three climatic regions: the courtyard house in the coastal region, the earth shelter house in the mountain region and the compact house in the desert region each of which uses locally available resources and has been formed by traditions to address local needs.

2.2.2. Definition of Low energy

Since the last century the world has used up as large a share of the Earth's mineral resources as have all previous generations put together; this would seem to indicate that human beings have little respect for the environment, particularly energy and natural resources. From this perspective the sustainable design philosophy was established by the growing movement of individuals and organizations that literally seek to redefine how buildings are designed, built and operated to be more responsible to the environment and responsive to people (McLennan 2004). During recent years, initiatives have been developed to create an international policy framework of environmental improvement leading to sustainable development. In 1997 the United Nation adopted the Kyoto protocol as an international agreement linked to the United Nations framework convention on climate change, which commits its parties to action by setting binding international emission reduction targets.

As powerful as this movement is, the definition and terminology is still ambiguous, although the basic concepts are widely known. There is no global definition for a low-energy house; research and development in different countries has led to various interpretations of the low energy house concept. In the UK it is sometimes referred to as the “eco-house” and “carbon-neutral housing”, whereas in Australia it is known as “smart housing”. All countries seem to have a similar but subtly different interpretation of the relationship between the form and fabric of housing and living organisms and climate.(Forster and Hawkes 2002; B. R. Anderson et al. 1985; Kibert 2007; J. Clarke 2001)

Moreover, national standards vary considerably; 'low energy' developments in one country may meet 'normal practice' in another. In Europe alone, low energy buildings are known under several different names. A survey carried out in 2011 by Concerted Action (Energy Performance of Buildings), supporting EPBD (Energy Performance of Buildings Directive) identified 17 different terms in use to describe such buildings used across Europe. All terms were related to one of three terms; low energy consumption, low emissions and sustainable or green aspects.

Central to the explanation, the definition “Energy efficiency is a primary mechanism to limit the environmental damage caused to our planet by energy use” (Roaf and Hancock 1992) can be considered the first step toward a sustainable design process. As pointed out by Richard Hyde, “Bioclimatic housing is a corner stone to achieving sustainability” (Roaf, Fuentes, and Thomas-Rees 2013). All definitions refer to a building that has a better energy performance than the standard alternative/energy efficiency requirements in building codes.

Archetypally, low energy can be defined by comparison to current regulation. For example, in England &Wales, the definition for a low energy house is gradated in levels toward minimum requirements over time from 25% better than current regulations. In 2010 level 3, 2013 level 4 (44% better than current regulations and almost similar to PassivHaus), 2016 level 5 (zero carbon for heating and lighting) and 2016 level 6 (zero carbon for all uses and appliances), (the SBI (Danish Building Institute), 2008). Recently, the Nearly Zero Energy Building (NZEB) has been set to become the norm for all building in EU state members by the end of 2020.

The "Energy Performance of Buildings Directive" has been established by the EU to endorse the improvement of energy performance of buildings within the EU, and to enhance the their building regulations and introduce energy certification schemes for building, with four main aspects: establishment of calculation methods, regulations for minimum energy performance requirements for buildings, energy performance certificates, and regulation to require inspections of boilers and air conditioning systems.

Many labels or design processes have been developed in order to standardize, control, and promote best practice concerning low energy demand dwellings. The first environmental certification system was created in 1990 in the UK by the Building Research Establishment (BRE), it is known as the Building Research Environmental Assessment Method (BREEAM). Since then many labels have been developed, include such schemes as: the German PassivHaus label, the American LEED label and the Green Globes System.

As pointed out in the previous chapter, Libya's built environment is a significant contributor to greenhouse gas emissions per person living there, with a figure of 1.98 tonnes per capita carbon dioxide emissions higher than the global average of 1.13 tonnes. In December 2006 Libya approved the Kyoto Protocol, and has since established policies for global warming prevention that aim at improving automotive fuel quality and reducing CO_2 emissions. (G.E.C.O.L, 2006).

Moreover, Libya is one of the thirteen Arab members of The Regional Center for Renewable Energy and Energy Efficiency (RCREEE). RCREEE is an independent not-for-profit regional organization that aims to enable and increase the adoption of renewable energy and energy efficiency practices in the Arab region, established in 2008. ("RCREEE Annual Report 2012")

Libya is also a member of the Arab Maghreb Union, and is hence involved in COMELEC, the regional power project, aiming at increasing inter-connection between the Maghreb states, as well as further development of inter-connections with Europe for the purposes of power trading.

Nevertheless, Libya, as a developing country, does not have an official definition of the low energy house. Therefore, this study will consider the word "better than current regulations", as a starting point of the search for the best solution that can balance environmental concerns with comfort and a host of traditional architecture or design concerns. In these terms, a low energy house is a building that reduces energy consumption for cooling and heating in the building, by provision of high levels of thermal insulation, energy efficient windows, and other passive techniques to achieve a house with good thermal performance. The approach makes the level of thermal comfort of the users living or working in buildings the central theme, with specific energy consumption used as the main indicator to quantify the required building quality.

2.3. The Morphology of the Libyan houses

The morphology of Libyan houses can be related to three forces: social, environmental and availability of construction materials. However the three forces affect the houses in different degrees. In this study the Architecture of Libyan houses is divided into three main categories; the traditional vernacular architecture forms in Libya, the dwellings of the people that relate to their environmental contexts and the available resources. In this category there are three different prototypes of traditional vernacular dwellings; the coastal (open courtyard), the mountain (earth-sheltered), and the Saharan (compact). Secondly, the Italian colonial architecture: colonial style houses built mainly for the Italian colonial population during the Italian occupation from 1911. Finally the Contemporary architecture, (from 1951 – present days). In this study the contemporary can be categorized into two prototypes; 'Courtyard' row houses 'Arabic Housh' and detached and semidetached houses 'Villa'.

2.3.1. Vernacular Architecture

As discussed earlier in the chapter describing Libya's topography, the location and area of the country creates a variation in the climatic categories, which have influenced the form of the Libyan vernacular architecture. There are three different prototypes of traditional vernacular dwellings: the coastal (open courtyard), the mountain (earth-sheltered), and the Saharan (compact) dwelling

First, the courtyard house, known as (Al haush), reflects the tradition, heritage and history of the city that dates from the 16th century to the present day. This type of houses can be found in the coastal cities of Libya from Darna and Benghazi in the eastern part of the country to Tripoli in the western part. Influenced by the long and rich history of the country under the Phoenicians, Greeks, Romans and Turks, a significant number and variety of heritage buildings were generated.

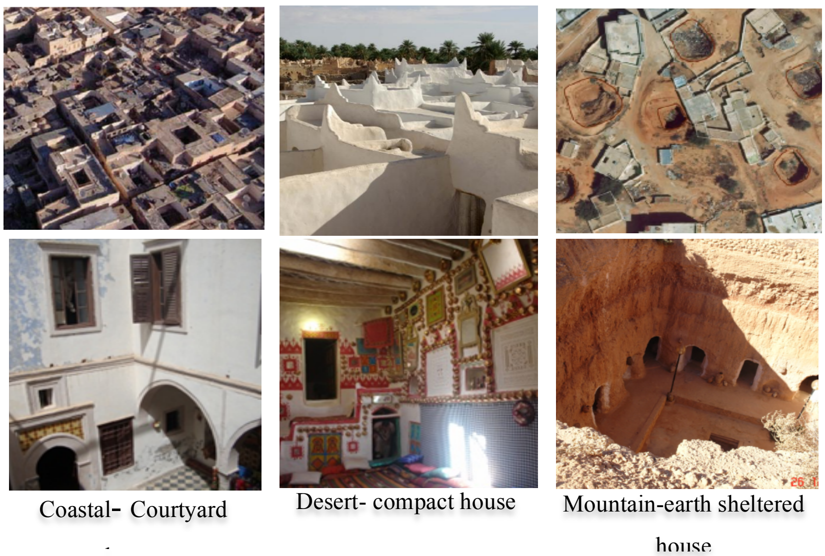


Figure (2. 10) Traditional vernacular architecture

Secondly, the desert compact house can be found in number of desert cities, such as Ghat and in Ghadames. Life in the desert towns and cities of Libya is dominated by the scorching sun, by the ever present threat of storms, by ferocious winds and the need for water. The compact house can be considered one of the brightest solutions in order to cope with this harsh environment. Paul Oliver points out "People in isolation from other cultures have evolved construction techniques and discovered for themselves fundamental structural principles". The dense fabric creates a thermal time-lag, keeping the interior of town and houses relatively cool during daytime and warm during the night.

Finally the earth sheltered house, the idea of using the earth as a passive cooling technique was widely utilised in the earth houses which have been used by ancient civilizations in many parts of the world (Oliver 2003). The earth sheltered dwellings (Troglodyte houses) spread over many cities on the western mountains such as Gheryan and Alqwasem were mainly built (excavated) by the Berber population in ancient time.

The three prototypes of traditional vernacular dwellings in Libya will be studied and analysed in the following chapters.

2.3.2. Colonial houses

On November 11, 1911 Italy began its occupation of Tripoli city and the whole of Libya. The influence of Italian principles and actions showed itself in new architectural and planning forms and spread throughout the country. Libya was considered the display window of the fascist regime, a living laboratory for a new modern Mediterranean state.

Architectural development in Libya was more directly influenced by contemporary architectural discourse in Italy; new architectural and urban forms were constructed outside the walls of the old cities (particularly in the south and east) such as new houses, hotels, offices banks, shops and units for light industry. New means of transportation were also introduced, resulting in the widening of streets. New ideas were introduced in the fields of building construction techniques and materials, such as concrete, iron for structural support and decorative gates and windows. The regime also introduced the concept of multiple occupancy flats to the country; many housing projects were built in the colonial style with total ignorance of the local culture. This had been pointed out by the Italian architecture Carlo Enrico Rava. In an essay included in his eight part series of articles published in Domus magazine in 1931 under the heading “Panorama del Razionalismo”, he argued that the Italian architects working in the Libyan colonies should avoid the direct copying of Roman models. He also argued that instead of following these historian approaches, they should adopt the forms and materials of the “native architecture" of Libya. One of the crucial reasons behind the appropriation of these local sources, he noted was that they were modern. This modernity was to be found in their suitability to climatic condition, their lack of superfluous elements, and their ability to harmonize with the colonial context.

However in 1939 Libya became the 19th region of Italy; supported by this modernization program was’ politica indigena’ or indigenous politics, that called for preservation and protection of the environment and cultural of the Libyan. During this period the Italians built many housing projects all around Libya, houses designed to accommodate the Italian population in the cities and houses located outside the colonial cites to accommodate the Libyan population.

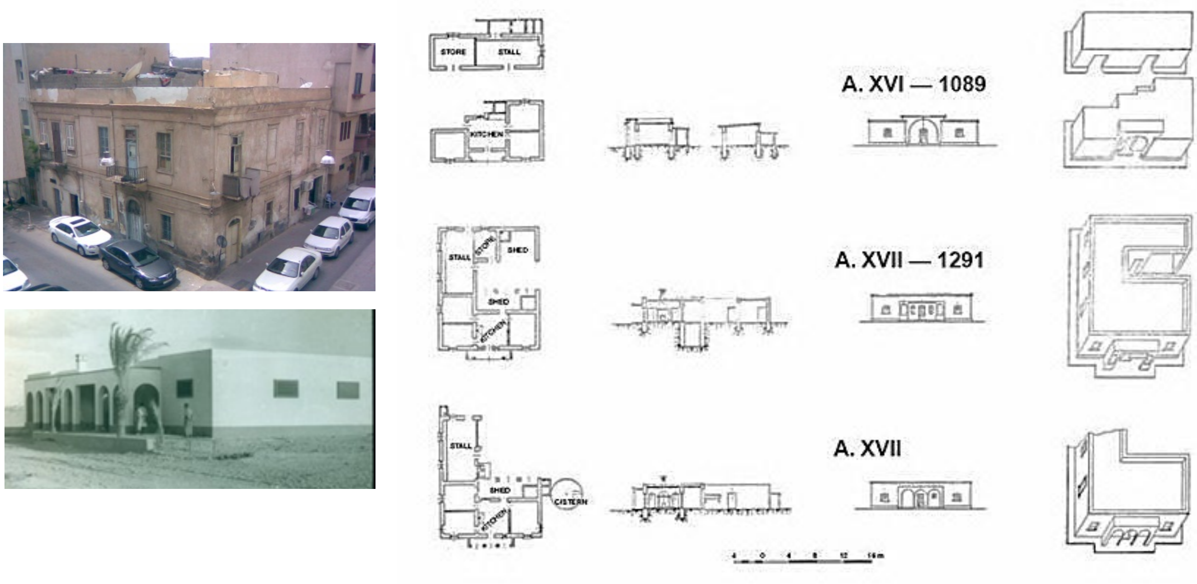


Figure (2. 11) three models of houses for Italian settler (Ente per la Colonizzion della), 1938-1939

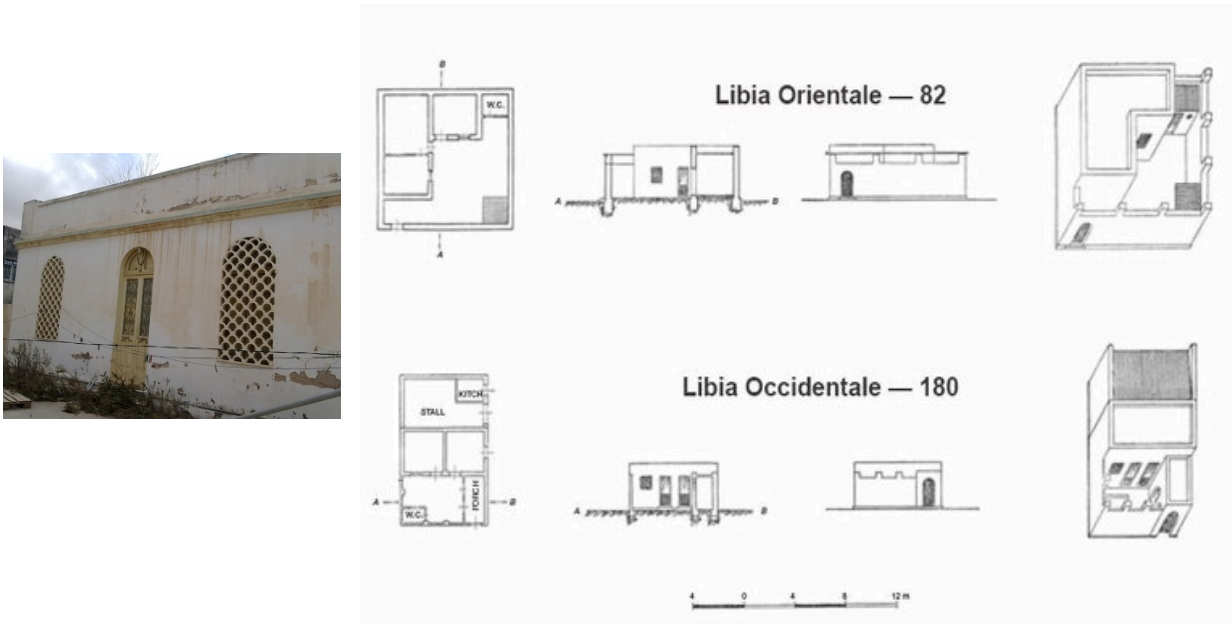


Figure (2. 12) Houses for Libyan settler (Ente per la colonizzion della Libia)

2.3.3. Contemporary Architecture

The written material on contemporary Libyan architecture, especially in the period of the last four decades is remarkably limited. However, the study found a few attempts but these were found to have covered in detail the issue of Libyan contemporary house architecture. The evolution of modern housing design and types in Libya has been influenced greatly by the discovery of oil in Libya. Although most of the important institutions in Libya were designed by foreign architects, as the vast number of commissions were given to architects from England, Finland and Japan and recently Korean and Indian practices, while the contributions by Libyan architects remain insignificant. This has created a discrepancy in Libya that is greater than in any other Arab state. Indeed, Libya has a long way to go in gaining an architectural identity, as do all other Arab states.

In his article entitled "Man-Environment Interaction: a Review of Modern Architecture of Libya in Transition" Tošković explores architectural examples of what he described 'transitory phase' that shows functional, structural, and aesthetical evolution from the old patterns to a new architecture.(Toskovic 2006)

Figure (2. 13) Arabic housh - Traditional (popular) house type 1950-1960

The first example was the 'Haush' traditional (popular) house type of the 1950s and 1960s developed in certain districts of cities in Libya labeled as 'Taqasim', where adjacent plots were planned in areas of 120-140 square meters. Tošković described the 'Haush' as a type of privately built house that began to open more space onto the street, losing the advantages of the courtyard, as it has now been reduced in size and lost its principal importance as the core of domestic life. The main rooms are accessible through a corridor, the secondary rooms are located in the rear, and the courtyard serves mainly utility functions. The stone masonry walls or concrete blocks are loadbearing walls supporting mainly concrete or ‘travetti’ roofs. He concludes aesthetically on this house type as an‘unimaginative’ and ‘uniform design made by geometers’ moreover that the environmental factors were neglected due to ‘to the designer's limited knowledge, experience and feeling for a specific local habitat’.

The second house type called ‘Villa’ it is a modern type of accommodation in libya replacing the old "Mansion" house, It is a detached house surrounded by garden. Quite frequently, though, high masonry walls surround villas, in order to ensure privacy. Functionally speaking, it is seen as a reflection of the European model and it has no central courtyard. This house type has openings into a garden, and the main rooms are accessible through an entrance hall, utility rooms are reachable through small corridors and bedrooms are often placed upstairs.

Figure (2. 14) Villa- detached and semidetached houses

The structure of this house type is basically stone masonry walls; reinforced structure frames or concrete blocks form load-bearing walls supporting mainly concrete or ‘travetti’ roofs. Tošković classifies villa models as ‘cosmopolitan’, ‘neo-classic’, and ‘a modern version of Saharan style’. These three models dominated the architectural trends of villa designs in Libya. The ‘cosmopolitan’ villa style seems to be the dominating trend. Their aesthetic measure are achieved through the influence of modern and contemporary architectural movements; however reasonable modifications to the climatic environment are done, resulting in a lack of domestic flavor to stamp them as distinctly local designs. The ‘neo-classical style’ was adopted on a narrow scale as a style, Tošković argues, that is neither suitable environmentally nor culturally for Libya. This particular style, as the argument continues, is “artistically not related to the capacity of the state being able to afford giving birth to a significant domestic architecture, adapted to the contemporary need of people as well as to modern technology.

Additionally, it is a break in the evolution and progress of the architectural thought" (Toskovic 2006). Apparently, this style is not familiar to the majority of Libyans, and only few can afford this costly type of building where decoration of walls demands skillful craftsmanship.

The modern version of 'Saharan style' emerges as a promising trend. For Tošković, it is an architectural awakening, as the source of inspiration is deeply rooted; he compared the tendency of 'cosmopolitan style' towards the adjustment to the climate requirements, but that it lacks a feeling of local expression. He states that "in these cases of modern version of the 'Saharan Style' is reversed attention (though) should be paid to the environmental factors as far as living under burning sun and sand-storm conditions is concerned".

Incorporating contemporary building materials into the traditional Arab architectural elements has formed a modern version of vernacular architectural vocabularies. Tošković, in this light, refers to the combination of "clay-musharabiah" with reinforced concrete. It can be summarized that the multistory dwellings of eight floors were built in Tripoli and Benghazi, and they are designed in a character driven by economic and visual constraints that failed to offer Libyan pattern of living as well as privacy.

Figure (2. 15) the modern version of the Saharan style

In conclusion, it seems that the contemporary architecture of Libyan house is an issue of great debate among Libyan architects. Apparently, it is not the matter of contradiction in design tendencies, but rather a question of suitability to culture and climatic concerns. The vernacular solutions of Libyan house offer an enormous source of inspiration; it has far deeper roots to borrow from.

2.4. Conclusion

Libya as a country located centrally between Africa and Europe has led to a great variety and influence in all areas, none more so than in its architectural heritage. In addition it is large, covering an area of about 1,759,540 square km, with different topography extents from plain to mountains to desert. Its varied climate can be divided into five classifications. Most of the population is distributed in three areas in Libya, the coastal (semi-Mediterranean - hot-humid), the mountains (Mediterranean climate - cold zone) and the oasis steppe (semi-arid). Within these three areas flourished many civilizations that affected the morphology of the Libyan houses. Therefore in this study these three areas were selected in which to study the traditional vernacular houses, which themselves can be categorized into three different prototypes of vernacular dwellings; the coastal (open courtyard), the mountain (earth-sheltered), and the Saharan (compact). Through studying the role of tradition and building technology in the development of Libyan house forms, with a particular emphasis on the environmental aspects of dwelling and design, it is hoped to develop low energy houses with 50% better performance than current regulations. Also it is hoped that the study will be a starting point of the search to find the best solution that balances environmental concerns with comfort and a host of traditional architecture or design concerns.

Therefore the next two chapters in this research include an analytic study and empirical study of the three traditional vernacular houses, in order to outline the characteristics of these houses. The studies include the main aspects such as the cultural and environmental requirements, which may offer possibilities for learning from the vernacular in order to obtain low energy houses that not only response to the climate but also to cultural requirements.

3. Chapter Three: The Descriptive Analysis of Case Studies

3.1. Investigating the Traditional Vernacular House Form in Libya

Traditional vernacular houses are shaped by different factors: the climate, building construction material, and the culture. In the view of the Vitruvian tripartite model of the environment, "This model, in its great simplicity, is sufficient to describe the nature of environmental control as exercised by buildings for many centuries, in which the building's fabric, its architecture, was the primary agent of mediation between the external and internal environment" (Hawkes 1995. p13) .

With the purpose of the study being to investigate and learn from the traditional vernacular houses of Libya, the socio–cultural aspect will be studied in this chapter to understand the user needs and activities and their role in shaping the house. An analytical analysis for the three types of traditional vernacular houses have been carried in order to understand the cultural force that has formed these houses.

3.2. Case study and selection criteria

As pointed out in chapter two, Libyan traditional vernacular houses may be categorised into three different prototypes, the coastal (open courtyard), the mountain (earth-sheltered), and the Saharan (compact) house. These examples are addressed as case studies of the research as they represent the three climatic zones of Libya, with the largest population of the region, and well-preserved traditional vernacular architectural forms.

In addition, the selection of the house form studied in each region is basically determined by a number of criteria, such as the similarity in terms of size in the three different regions, resemblance within space arrangement and organization as spaces around a large room, and still in use by its inhabitants. Thus, one traditional vernacular house is from each selected climatic zone. The selected sample of buildings has been chosen among free running houses with the following criteria

- The layout of the house has its original layout with no modifications.
- The house should be free running house, naturally ventilated.
- The occupants of the house are a Libyan family.
- The building material should be of the traditional local variety.

3.3. The courtyard house (Tripoli – Coastal region)

As in most Muslim cities the courtyard house in Tripoli was built of local construction materials, influenced by the local tradition and modified by the local environmental factors. Magda Sibley pointed out that "The Courtyard house is a sustainable form of housing that has existed for thousands of years and in various geographical regions".(Edwards et al. 2005)

Figure (3. 1) the old city of Tripoli Source (Tripoli old city rehabilitation project, 2010)

In his travel book Abu Mohamed Al-Tejanee describes Tripoli as a city with strong towers, wide streets, flourishing gardens and courtyard houses which reflect an awareness of the advantages of the natural environment in the community both in the way they care for trees and plants and the arrangement of their gardens. In the Islamic era the city was known as the white city, as in summer people tend to paint their houses a white color using Lime wash (Al-Meloudy, 1993). As also pointed out by Al-Meloudy Amura many structures in the old city have been used, re-used and modified over the centuries. This multi-period built heritage has given the old city of Tripoli a unique character.

The street pattern of the old city is ancient, dating to the Roman Period and developed during the Arab, Ottoman and finally the Italian period. In addition to archaeological factors, the street network in the old city has been influenced by the topography. (Tripoli old city rehabilitation project- city code, 2010). Clusters of courtyard houses form the main component of the urban fabric of the old city of Tripoli, a compact city with a building density of 48 buildings per hectare.

3.3.1. The Courtyard House (Housh) - Case study

The case study house is located almost in the center of the old city near by a main cross road known as "Arba'aArsat", on a small covered street, Bit-Almal Street, which is located between two main streets, Souq Al-ttruk Street and Al-dduroj Mosque Street. By contrast with the deterioration of significant parts of the old city, the case study site can be considered to be in fair condition.

The case study offers the opportunity to investigate the common prototype of house form and its spatial relationship to the urban form of the city, as well as the space organization in terms of approach and entrance.

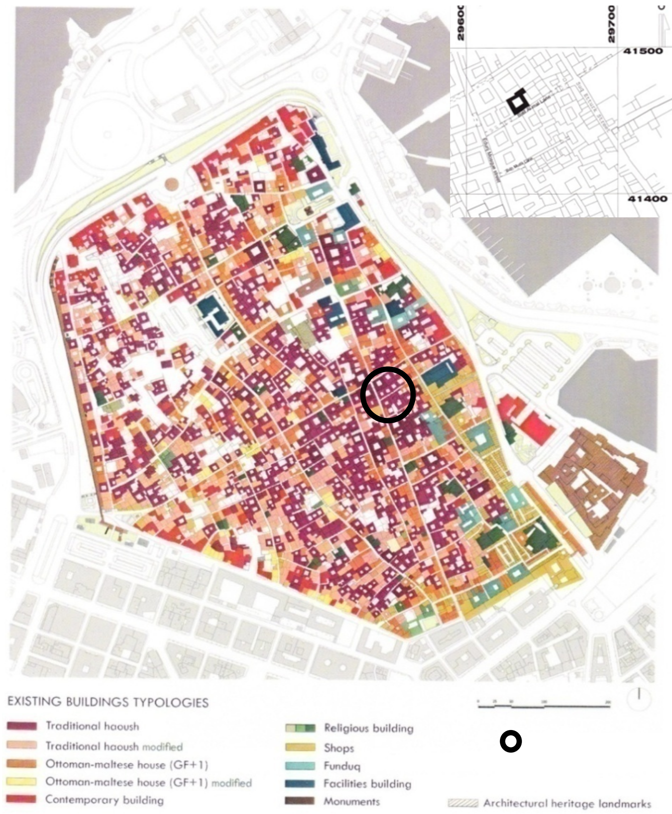


Figure (3. 2) existing Building Typologies. Source (Tripoli old city rehabilitation project, 2010)

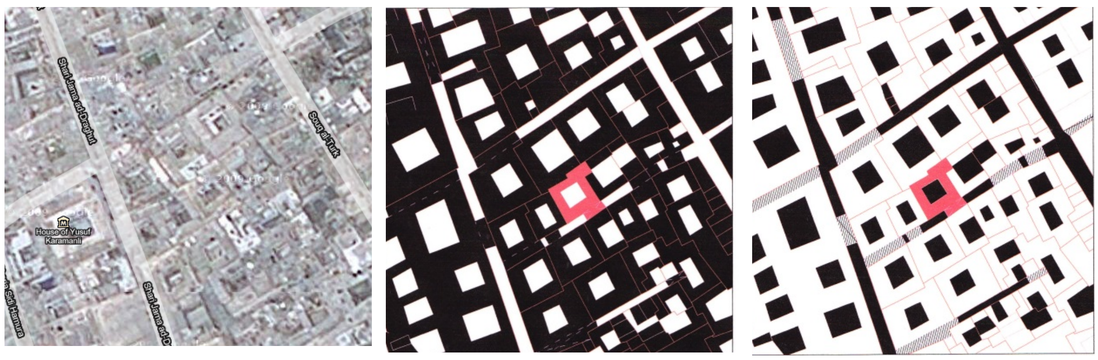


Figure (3. 3) the urban context, built and open spaces

The main characteristic of the urban fabric is based on the grouped pattern of courtyard houses. The courtyard house layout generates a dense urban fabric, showing a clear separation between the public and private open spaces. Magda Silbey pointed out that “the courtyard houses of North African medinas display different characteristics than those of Egypt, Syria and Iraq as they feature the most formalized configuration with an absolute centrality of the courtyard”. The case study courtyard house is built around an almost square-shaped courtyard, in an irregularly shaped house.

The courtyard house has only one façade facing the narrow covered street. The width of the street is nearly two meters, and the other sides of the house are shared with other houses.

The upper floor of the house spans over the street with an extension that reach the wall of the opposite houses forming a shaded, covered street.

Figure (3. 4) the external facade on the narrow covered street

The courtyard house has always been built with a concept from outside in, and the central private courtyards form the departure point of the design, which consist of two long and shallow rooms that occupy a full side of the square court on the ground floor, and three rooms on the first floor, the layout of the room around the courtyard leaves free the four angles of the plot which house the essential home services - toilets, a storage room, stair case, and entrance.

The courtyard has one arched gallery on the first floor that creates extra shade on the wall facing the south, whereas the upper floor has two arched galleries overlooking the courtyard, and giving access to the rooms on the upper floor.

Figure (3. 5) the courtyard entrance and the staircase to the upper floor

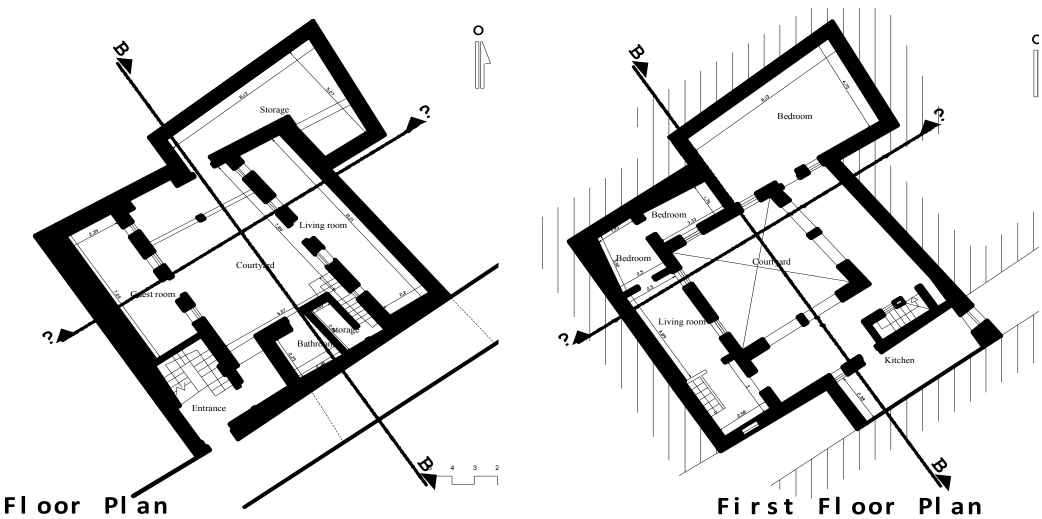


Figure (3. 6) Plans - courtyard house-Tripoli

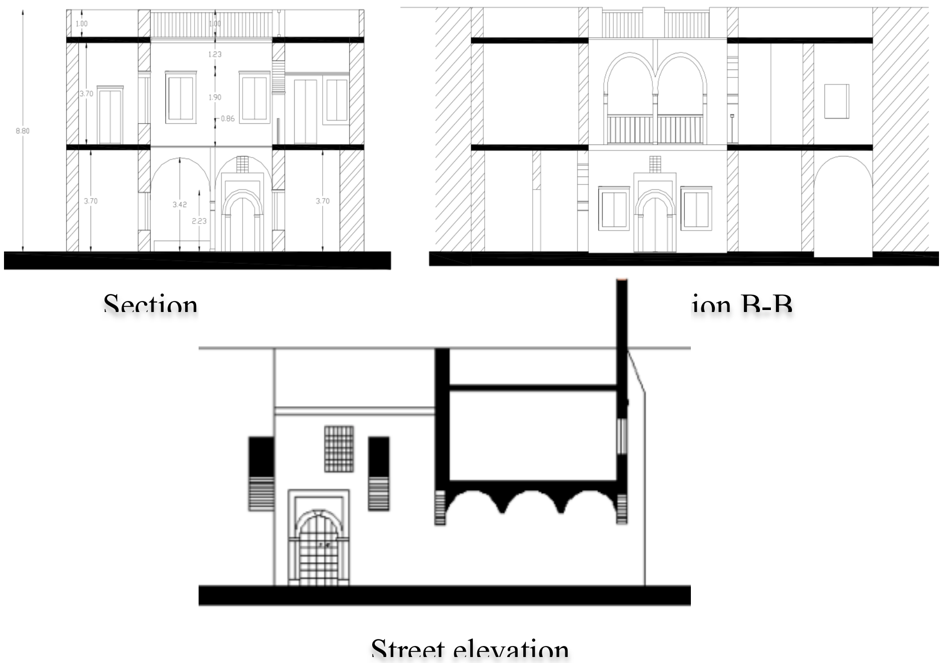


Figure (3. 7) courtyard house-sections and elevation

3.3.2. Spatial use and distribution

The way space is used and re-used over time is influenced by social needs. Paul Oliver points out that "The way which dwellings are organized and used are expressive of the specific cultures which have developed them" (Oliver, 1990). In the case study house the space was periodically re-organised and used within the dwelling to meet the demands of daily living.

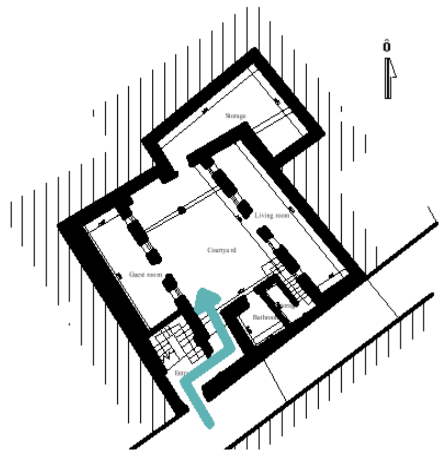


Figure (3. 8) Privacy- Courtyard house

After the adoption of Islam in Tripoli, domestic architecture showed a traditional Muslim tendency and in particular the idea of privacy and the need for separation between the private and public lives, which gives special attention to the location of the entrance and to spatial organization. The doorways of Houses in traditional Islamic society can be recognized by their openings into an angled passageway leading to the corner of the courtyard, providing privacy to the courtyard, while the stair case is positioned just offset from the exterior door leading to the male guests' room in the upper floor, to conform with the traditional need to entertain male guests, while at the same time, barring their access to and contact with the females of the household. This requirement has given rise to additional complexities of design particular to Islamic domestic architecture (Al-Shahi 1986).

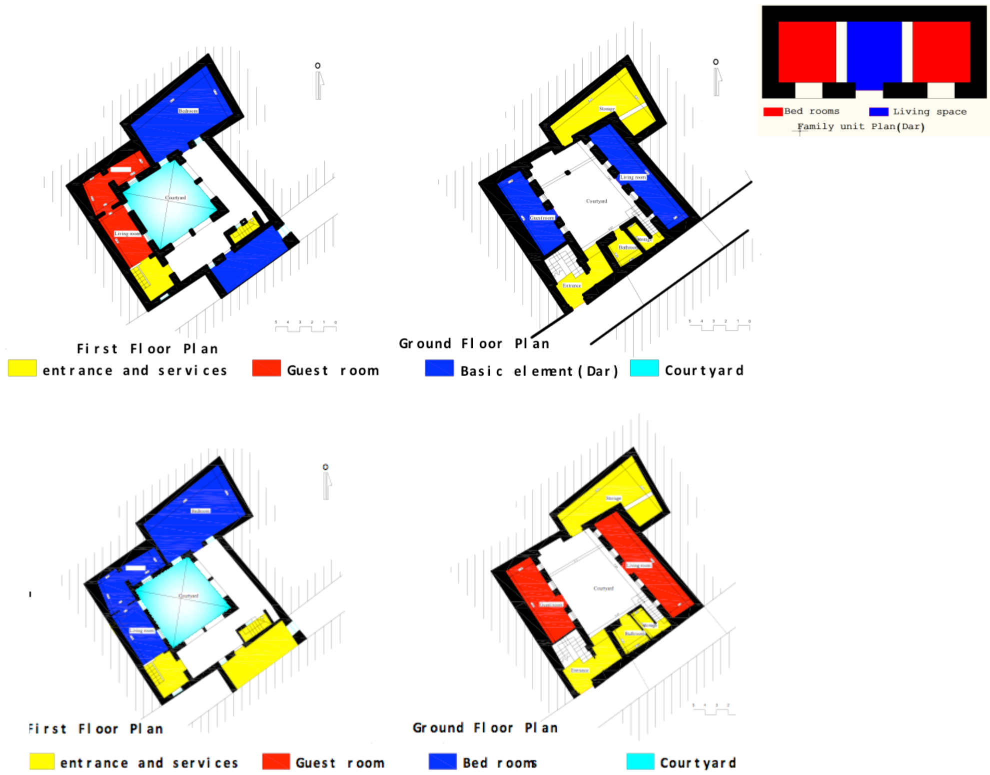


Figure (3. 9) the original and contemporary space use arrangements.

The spatial arrangement of the house was influenced by the family's needs; the courtyard is the core of the spatial arrangement of the house, where everyday living activities such as cooking, eating and housework are usually based. Family units were organised around the sides of the courtyard; the house consist of four residential units known as (Dar), two positioned on the ground floor while the other two bedrooms are located on the first floor and are accessed through a separate staircase. The family unit is divided by two arches, to create three separate spaces, the middle space used as second reception area, Dar El Kobool used by women guests, and two side rooms used as bedrooms and storage for the family. In recent times the house was re-organised to meet the modern family's needs. Firstly, the function of the rooms as dwelling units (Dar) has changed as a result of the reduction of the number of families living in the house to one family. Secondly, the kitchen was moved to the upper floor to conform with the modern way of cooking, using gas cookers instead of coal and the need for more natural light and ventilation, and hence the courtyard space became of limited functionality. Finally, the male guest room (Marboaa) is now positioned on the ground floor. The new space organisation creates new private zones by moving the living area and the kitchen to the upper floor to create a new private zone, while the courtyard has become less private. In conclusion the spatial use of the house as a whole was modified by modern needs and this has led to more activity on the upper floor compared to the ground floor.

3.4 The compact house (Ghadames- desert region)

Ghadames is a city located 630 Kilometers southwest of Tripoli near the Tunisian-Algerian borders, separated by a hundred kilometers from other towns. Ghadames, one of Libya's major desert cities played an important role as a cultural and trade center between the Mediterranean and Africa for over 1400 years. In 1986 the old city of Ghadames (OCG) was declared by UNESCO as a World Heritage Site. The city consists of two urban fabrics, the old city and the new city that was built in the 1970s.

Ghadames is located on the Ghadames Basin, which is a large intra-cratonic basin, covering portions of Algeria, Tunisia and Libya with an altitude of 350 meter above sea level, on an latitude 30 N and longitude 9 W. The city is surrounded by a sandy and rocky desert between the great oriental Erg and the arid plateau of al Hamada-al hamra (Aalund, 1983). Alzubaidi points out that “Planning can be seen on the levels of the oasis, the city, the neighbourhood, the street and finally, the individual house. The built up areas are centered to the south-west of the oasis, forming one large complex of houses .The built fabric of the city is tightly interwoven, where alleys, passing underneath, function as main pedestrian throughways that vary in width up to two meters and are naturally lit by regularly spaced light wells”. (Alzubaidi, 2002). Vegetation is the main aspect in the survival of the city; farms found around the city are integrated with the houses, providing protection to the city against desert storms and the harsh environmental conditions.

Figure (3. 10) the old city of Ghadames. Source, (Photographer Georg Steinmetz Biography-National Georaphic-2013)

The dense fabric of the buildings protects the city from the harsh external environment. Moreover the street pattern of the old city is curved and covered to protect it from desert storms. In addition to the climatic factors the street network in the old city is influenced by social factors. This is seen where the roofs are used as another network of level pedestrian movement in order to provide a passage for the women. The variation in sun exposure in the streets creates different pressure zones, which in turn cause air movement from high pressure zones to low pressure ones, where hot air is replaced with cooler air in the shaded passageways. The interior of the town and its houses are relatively cool during daytime and warm during the night.(Mezughi and A Dawi 2003)

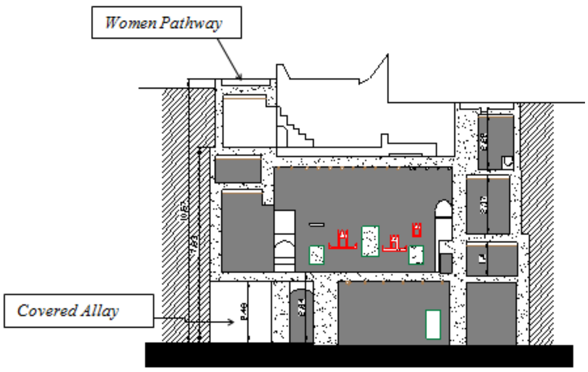


Figure (3. 11). The pathway in the streets level and upper level

The height of the buildings is related to the their use. The mosques and services buildings have a height range of between 4 and 5 meters. While houses in Ghadames are based on the principle of multiple-level buildings with height of 10-12 meters, all the houses are interconnected to provide a level roof passage for the women of the town.

The house is known as (Den), According to a famous phrase, “Man plants a palm for his child, eats from his father’s palm, and cuts up his grandfather’s palm to build his house”. The built environment in Ghadames reflects such a view of the built environment as a living entity. This is evident in the level of the city planning and architecture. Traditionally, building a new house for the next generation is one of the family obligations. At the birth of a son the father plant a palm tree for his son to use in building a house, the city’s community enforced this rule in order to build new houses. The new dwelling must be connected to the existing complex of houses, and a number of palm trees would be cut down from the agricultural area that surrounded the city. However this agricultural land would be replaced with fresh agricultural land in the outer borders. Houses are tightly grouped together, with the average size of a house plot being between 100 and 250 m^2. All the houses are of a standard (three story) height to provide a level roof passage for the women. The Ghadames house (Den) is usually occupied by one family.

The old city houses were abandoned in 1982 and people were moved into modern houses that were built by the government, to the south side of the old town. Therefore finding an occupied house for study is difficult especially one occupied by a young generation. Furthermore, number of houses have been damaged or have partially collapsed as result of the abandonment of property.

3.4.1 The compact house (Den), case study

The house is located in the centre of the old city, on one of the city’s main roads. It is part of a unit of clustered houses, grouped together with one façade or two to the narrow alley, in some cases with only a small path leading to the houses through a closed alley.

The house has two façades facing the narrow covered alley, with a width of nearly two meters. The other sides of the house are shared with other houses and the site is of an irregular shape. The area of the site is nearly $70m^2$ (6.3m wide and 11.2 long) and extends on the first floor to cover around $85m^2$ ($6.3m \times 13.5$m). The total covered space is nearly 230 m^2. The first floor extends to the alley in order to provide shade to the road and in the same time a pathway on the roof.

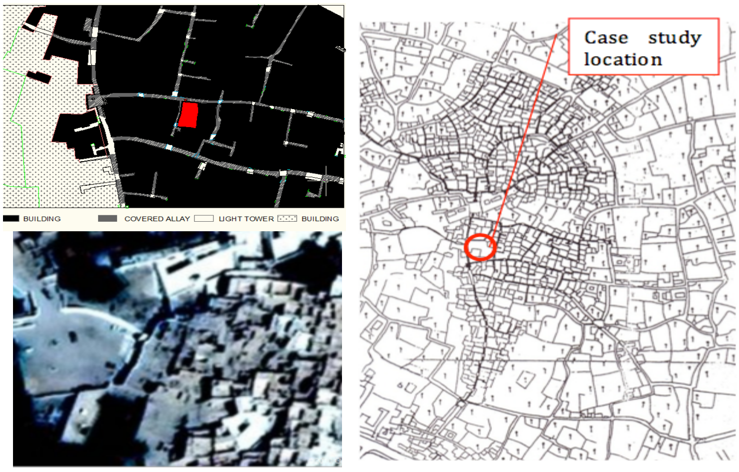


Figure (3. 12) the case study location within the existing context of the old city of Ghadames

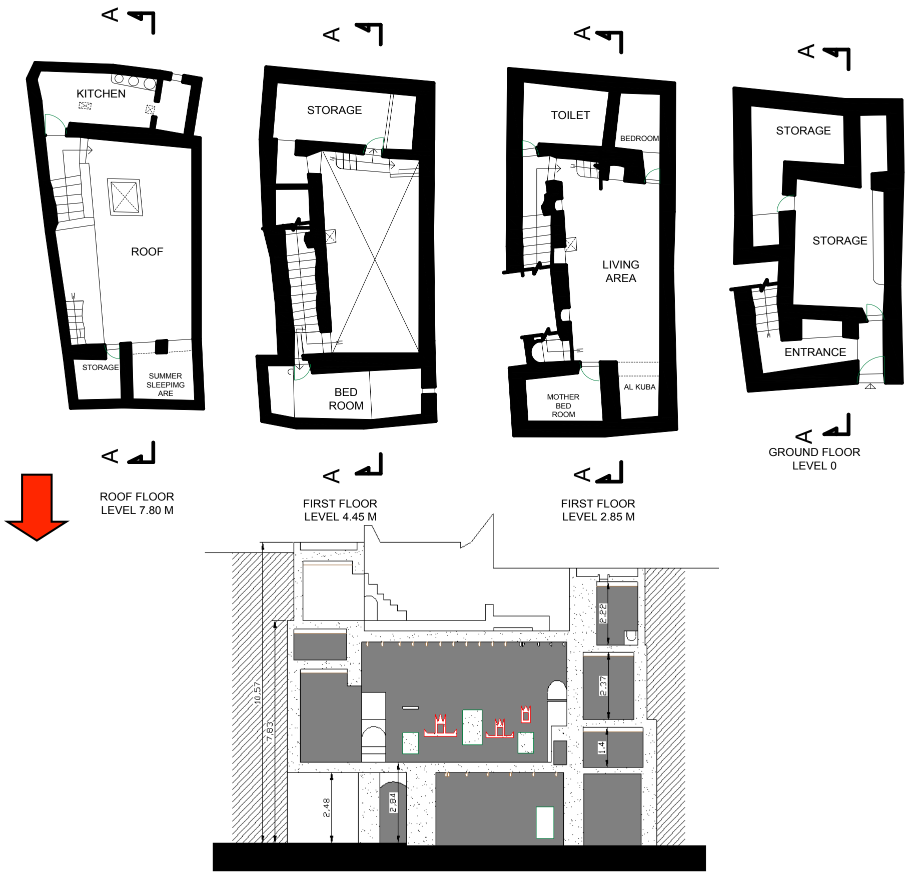


Figure (3. 13) case study plans and section- Ghadames

The house is composed of a number of areas extending on three levels from the ground floor, through the central hall (covered courtyard) to the roof level. Light and ventilation to the house is through a skylight opening in the center of the courtyard roof.

The light is distributed to the surrounded rooms by mirrors, copper plates and shiny metal covering the courtyard walls to reflect light toward the room.

3.4.2 Spatial organization

The house is composed of a number of areas extending on three levels from the ground floor, through the central hall (covered courtyard) to the roof level. The external door leads to a small space which acts as distribution space to the internal spaces. The staircase to the upper floor leads to the living area positioned just offset from the exterior door, while the storage room is positioned in front of the door. The stairs lead to the corner of the living area on the first floor, in order to provide privacy as well as space for the surrounded rooms.

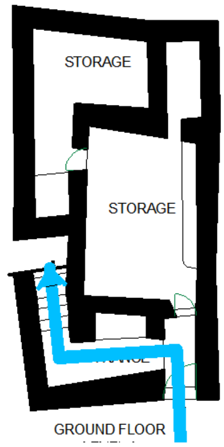


Figure (3. 14) Privacy-entrance in the compact house

The covered courtyard (living room) acts as a core of the spatial arrangement of the spaces of the house, it has a rectangular shape, nearly 25m^2 in area, with a double height ceiling of nearly 4.2m. The living area is surrounded by two levels of rooms with a direct access; the lower floor's rooms are used as bedrooms, while the upper floor's rooms are used for storage. Light and ventilation to the house is through a skylight opening in the center of the courtyard's roof. The light is distributed to the surrounding rooms by mirrors, copper plates and shiny metal covering the courtyard walls to reflect light toward the dark rooms and light is distributed to the lower floor through an opening in the living room floor.

Figure (3. 15) ground floor, first floor and the roof

Three bedrooms are found on the first floor, the bigger room is for the parents, while the children's bedroom is very small and used only for sleeping. With no windows the light and ventilation accrue through the door opening to the living room. The height of the door is nearly 1.40 m and the bedroom area is between 2m^2 and 2.5 m^2.

In order to cope with the harsh environment the kitchen, which is a source of heat, is located on the roof to protect the house from overheating. Moreover, the summer sleeping area is covered with arcades facing the North, with an area of nearly 5.5m^2.

In the vernacular house the space use and organisation is optimised to meet the demands of daily living, Paul Oliver states that "Each culture has different expectation of its dwellings, and makes demands on them which are related to its social structure and the way in which its members organise their daily lives".

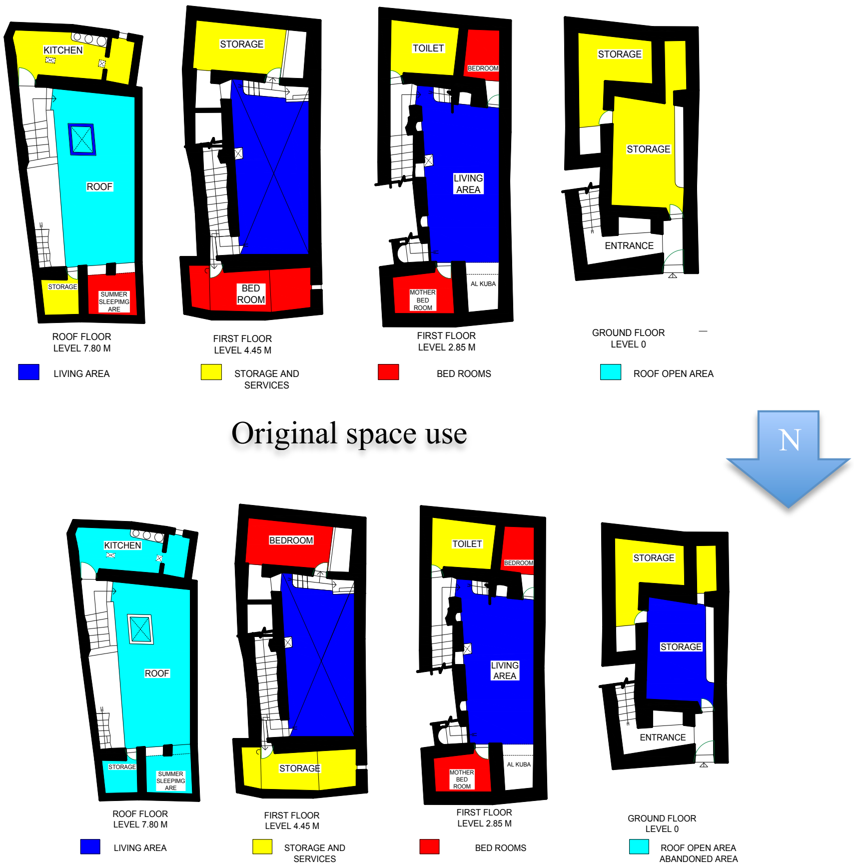


Figure (3. 16) the original and contemporary space use - compact house

Accordingly the original way the space was used can be highlighted as shown in the layout (figure 3-15); the use of space was changed to meet the family modern needs; the ground floor storage formerly used for storage and animals was converted to a living room to get the cooler temperature. The roof is abandoned and the storage on the first floor is used as a small kitchen, and finally one bedroom on the lower level on the first floor was converted to storage.

3.5 Earth shelter house case study (Gheryan)

The settlement of Gheryan is situated on the southern edge of the western mountain (JabalNafusah) 300 meters above the Jifarah Plain. Unlike those in Tripoli and Ghadames, the vernacular traditional (earth shelter) houses in Gheryan are merged with the new settlement. People built their new houses over the earth shelter houses or next to their old houses using the old house as a storage area.

The earth shelter houses are spread all over the Southwest side of the new center, from south-east to south-west of the city, and there are also a few located outside the settlement to the north-east (National Consulting Bureau 2009). The houses were distributed according to the family origin and the land topography. Families usually extended their houses by digging a new house next to their old one, therefore we can find five houses together, creating a cluster of houses for brothers and their extended families.

The building strategy of the earth shelter building was used only for houses, so we cannot find other facilities built with the same strategy. Animal stables and guest rooms are found on the ground level. However, the new city was built over the old settlement; the old pathways were wiped out and new streets were laid. Most of the shelter houses have a small building at the ground level with a height of three to four meters. This includes the entrance to the earth shelter, guest room and animal space, while the shelter is usually 8-10m deep under the ground. Gheryan is famous for its olive trees and its agricultural soil. However planting and vegetation can only be found on the ground level of the earth sheltered dwellings with no vegetation at the courtyard level.

Earth sheltered dwellings (known as troglodyte houses) are spread over Gheryan and were mainly excavated by the Berber population in ancient times. For centuries, residents of Gheryan in Libya have carved into the soft rock to create atrium houses in which several excavated rooms with vaulted ceilings open out into a single sunken courtyard. The design of earth shelter houses gave the inhabitants refuge from the cold winters and the hot summers, and also gave good protection against invaders – the houses are invisible to all but those within a few hundred metres.

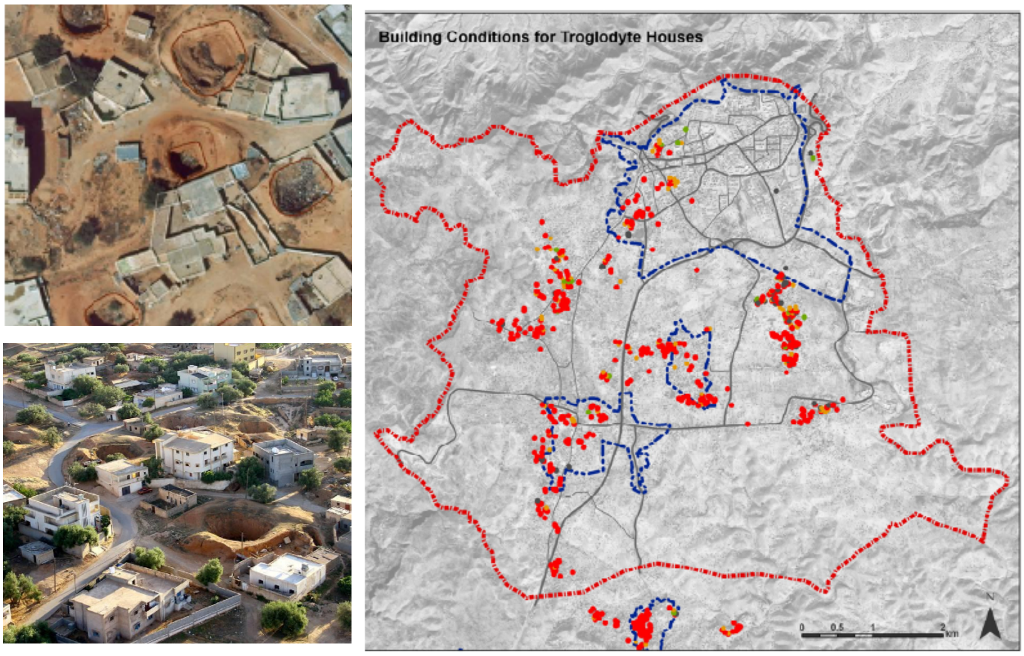


Figure (3. 17) the distribution of the vernacular houses in the city of Gheryan

The house can be divided in to two levels: the over ground level and the underground level; most of the houses serve a number of generations, therefore they have three or four separate residential units, each assigned to a family. The house organisation allows the house to be extended, by adding new rooms through an extra excavation on the courtyard wall, which is limited to 10 rooms as they excavate the four walls. Then a new courtyard will be dug out next to the father's house and the elder son can have a house for his extended family. Each house has a minimum of 3 rooms and maximum 10 rooms, three rooms on each side of the courtyard and the 10th on the entrance ramp (Alhanaya).

As culture changes attitudes, the basic need changed also, therefore, the old houses in Gheryan were abandoned years ago and people were moved into modern houses, usually on the site of the old house. However in some cases the old houses have been used for storage next to the new houses. Therefore, finding an occupied house is difficult, especially one occupied by the younger generation. A number of houses have been damaged or partially collapsed as result of the abandonment of property and recently the case study house collapsed as a consequence of the Libyan revolution of 2011.

3.5.1 Earth shelter House (housh El hafer) - case study

The house is located on the western edge of the city and is surrounded by earth shelter houses as well as modern ground level houses. The earth shelter houses found were approximately 25 to 40m apart. Most of the other houses were in a bad condition or had collapsed.

Figure (3. 18) the case study location -Gheryan

Figure (3. 19) the entrance and courtyard opening- street level.

The house has two levels, the ground level comprising the entrance, guest room and toilet. The three spaces opened into an open area. Firstly, the guest room is divided into three parts: each with dimensions of $3\times 4.5m$ and 3m in height. The central space is a living room whilst the two ends (defined by an arch and by a rise in floor level, but open to the living space) are used as guest sleeping areas. Each space is divided structurally into two parts by an arch. A window faces the door and a small aperture is found next to the door. Secondly, a small room is found next to the entrance on the ground level. In the past a small cave next to the house was used as a lavatory. Finally, the entrance has a flat doorway behind which is a long sloping staircase pathway that leads to the corner of the courtyard. With 2m height and 0.8 to 1.0m width the door is made of an old olive tree,

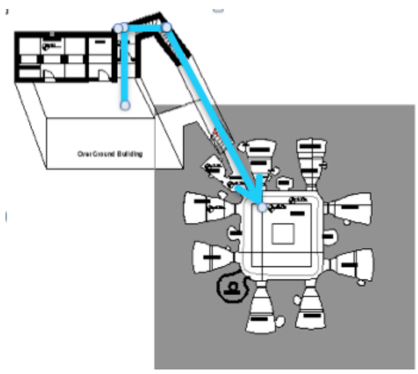


Figure (3. 20) Privacy- the entrance in the earth-sheltered house

the pathway consists of two long sloping corridors, one built above the ground, the other is excavated into the ground. A second door is installed at the end of the second corridor.

At the end of the entrance corridor is an area used as distribution space for the storage room (Alhanaya) and the entrance to the courtyard. The Alhanaya is customarily reached before the entrance to the courtyard and is used mainly for storage and occasionally as an animal shelter.

Figure (3. 21) passage to the courtyard and the rooms

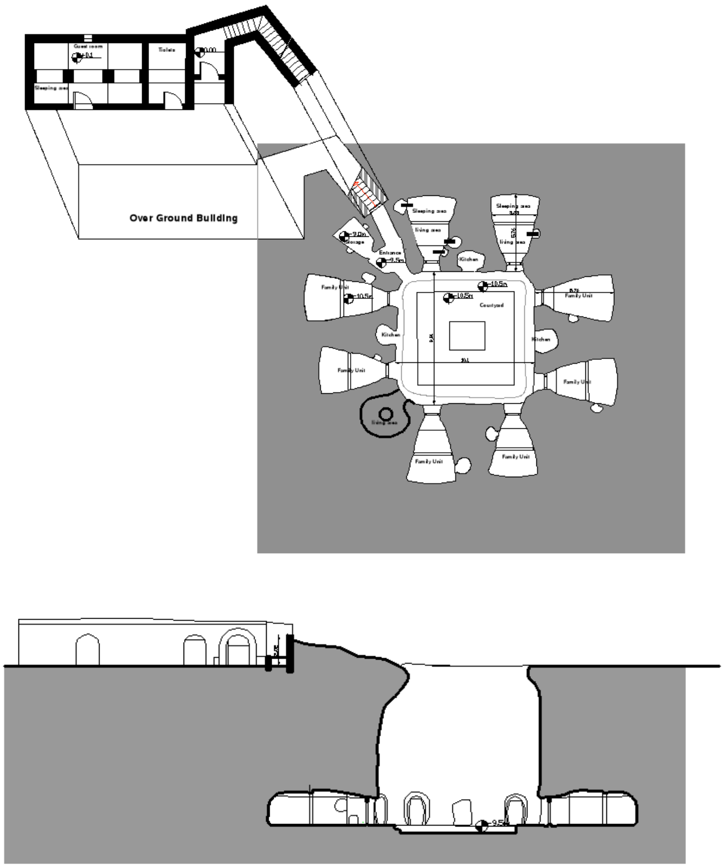


Figure (3. 22) the case study, plan and section.

The courtyard is the core of the spatial arrangement of the house. It has a rectangular shape whose dimensions are 10m long by 8m wide and 10m deep. This configuration provides shade for the courtyard for most of the day. The courtyard floor is divided into two main levels, the upper level used for circulation and the lower level used for every day activity. The lower level is deeper than the upper level by nearly 0.5m with dimensions of (6m by 8m), in addition there is a central hole with dimension of (1m by 1.5m) used to collecting rainwater.

The rooms are more or less trapezoidal in shape, where the shortest dimension is at the entrance area, which is about 1.5m to 2m wide. It then gets wider towards the inside, reaching a width of 5.0m to 7.0m, the room depth is designed in order to provide ventilation as it should not exceed 6 m in depth.

The house consists of six rooms (family units); all the rooms open into the courtyard, the master room is found in the wall that faces north-east. Each room is divided into two parts; the front space is a living room whiles the end is used as sleeping area. The rooms had additional excavated storage linked to the sleeping area used for the families' valuable artifacts.

Finally, the utility area; the house has three kitchens located next to the rooms, with a shallow depth allowing ventilation to the cooking area. The storage area for grains is located on the north corner of the courtyard and is elevated 2m above the courtyard level.

3.5.2 Spatial use organization

Although living underground is a novel idea for many people it is hardly a twentieth century phenomenon. Therefore the current spatial use of the shelter house has been influenced by the needs of the modern family. The original spatial use of the house was to divide it into two parts, the ground level part used by guest males, while the underground level used only by the family female guests. The original house was built for an extended family group, each room considered as a family unit consisting of living and sleeping areas.

At the present time the house is occupied only by one family, a 70-year-old male and his 60-year-old wife, therefore, only three room are in use. The family uses the ground level as a small house, utilised during the morning as living area and kitchen, while the underground level is used as a sleeping area, taking advantage of the moderate temperature.

In the past the property of each family was defined by social and traditional boundaries. In other words, no physical boundary was found. However as a result of the complex societal changes that have taken place, more privacy and security is required; for instance, adding a boundary wall around the house is considered essential. Finally, the lack of running water services and modern hygienic needs are considered critical points that cause the abandonment of earth shelter houses.

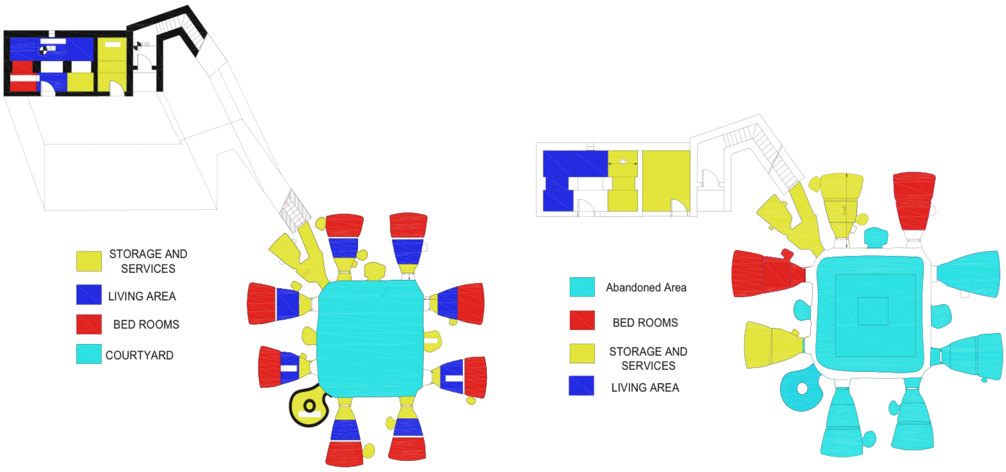


Figure (3. 23) The original and contemporary space use - earth sheltered house.

3.6 The cultural aspect as modifier to the traditional vernacular houses

Ramond J. Cole and Richard Lorch have pointed out "The built environment can be categorized as the embodiment of human value and ingenuity, as represented by knowledge and priorities of its creators". (Lorch, 2003). Therefore studying human values and behaviour, thermal comfort as well as technological adaptation is the key factor to understanding the built environment. In his book on house form and culture, Rapoport points out the term "genre de vie" which has been used by Max Sorre as a term that includes all the cultural spiritual, material, and social aspects which effect form. Furthermore, Rapoport pointed out the specific aspects of the genre de vie which affect built form; basic needs, family, position of women, privacy and social intercourse.

The study of the three houses in the three cities, emphases the effects of the genre de vie on the Libyan house form. Firstly, as basic needs change through the years, the vernacular houses have been abandoned or modified to reflect the peoples changing needs. In Ghadames and Gheryan the need for running water is the main reason that led people to abandon the vernacular houses. In addition, modern living requirements, such as the change of cooking fuel from coal to gas, led to changes in the position of the kitchen in the house. Moreover, externally, the need for accessible wider street for cars is changing the urban fabric.

Privacy is one of the key aspects in the form of the three houses, the separation between external and internal spaces being considered the key aspect in the Libyan houses. This can be seen in the position of the external door and its relation to the internal spaces. In Tripoli the external door position is just offset from the courtyard door, creating the path that act as a barrier between the external common zone and the private spaces. The same layout can be seen in the compact house and the earth-sheltered house with changes in the level of spaces as illustrated in Figure (3-24)

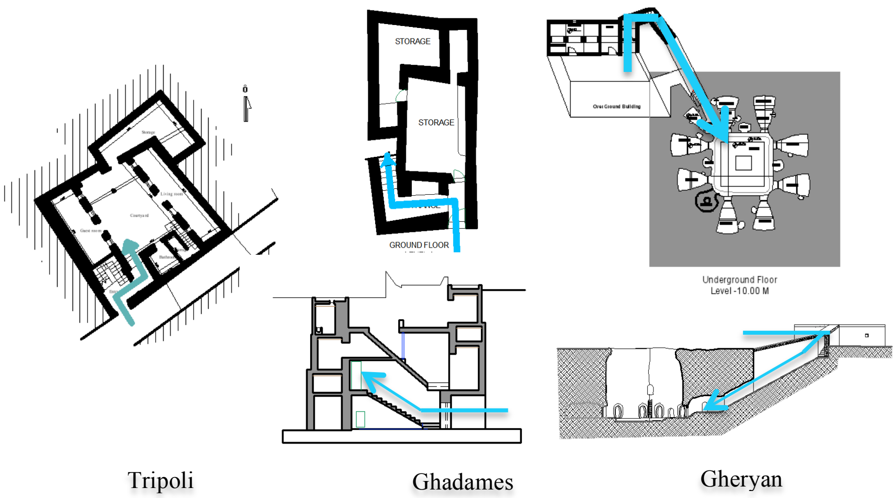


Figure (3. 24) privacy - the indirect pathway into the entrance of the three vernacular houses.

The privacy zoning and space organization in the Libyan house is affected by the changes in the family structure and the change of women's position in society. Extended families living in the same house have become rare. Therefore the number of inhabitants living in each house is reduced. Furthermore, the changing position of women in modern Libyan society is reflected in a great diversity in ways of living, some women have earned positions in management and a number of women are active in modern administration. Libya has encouraged an increase in the number of working women (25% of Tripoli women now work outside their homes, which is an entirely new phenomenon in Tripoli society that only happened in the last three decades [El-

Hawat 2002]). In some cases the woman is the main provider in the family; this has an effect on the space organization as well as on the privacy zones in the houses For these reasons extra rooms were added to houses to allow women to have more social intercourse while at the same time maintaining their privacy from males both outside and inside the family.

3.7 Conclusion

Evaluating, systematically, the characteristics of the vernacular house form and space while considering the existing knowledge of vernacular architecture, offers a better understanding of its qualities. Moreover, such study can help to realize the potential of exploring the future of modern house form in Libya within the context of the sustainable environment, and its integration in achieving comfort at socio-cultural and physical levels.

The outcome of the study of the three traditional vernacular house forms in Libya suggests several determinants that formed the house in Libya. However, it is imperative to point out the "genre de vie" of (basic needs, family, position of women, privacy, social intercourse), as an aspect that has had a vital role in the formation of the traditional vernacular house forms. This is illustrated in Figure (3-25), showing how cultural forces can be classified into two groups of factors that govern the cultural performance of the house. In addition, these forces can be introduced as criteria, derived from the lesson of traditional house form, which can be utilized in the examination of the cultural performance of the contemporary house form in Libya.

Tentatively, through using an investigative procedure that emphasises 'basic needs' and 'privacy' as the main group of factors that formed the shape of the three types of traditional vernacular house forms considered, the study suggests that the re-arrangement of the spaces has resulted mostly from the pressure exerted by people’s modern needs.

Oliver (1979,9) argues, that "there are very few unnecessary buildings in the vernacular and within the building themselves, there are few unwanted spaces". Obviously, in the three case studies of traditional house forms, the spaces were built to fulfill specific needs, and were organized to meet those needs However, the new occupants re-organized these spaces and in some cases were moved to abandon some spaces to meet their needs under the pressure of modern life. Julienne Hanson points out "Houses can carry cultural information in the material form, space configuration and the disposition of household artifacts within the domestic interiors" (Hanson, 1999). Furthermore, the analysis of domestic space configuration introduces the link between the design of the dwelling and their social consequences. It can be concluded though, that, through the comparison between the original and new space arrangements in the three case studies of traditional house forms, the private zoning is changing through time, as a result of two factors; Family and the Position of women. There are major changes in the use of the spaces in the three houses. However, privacy remains the key in the organization of the space.

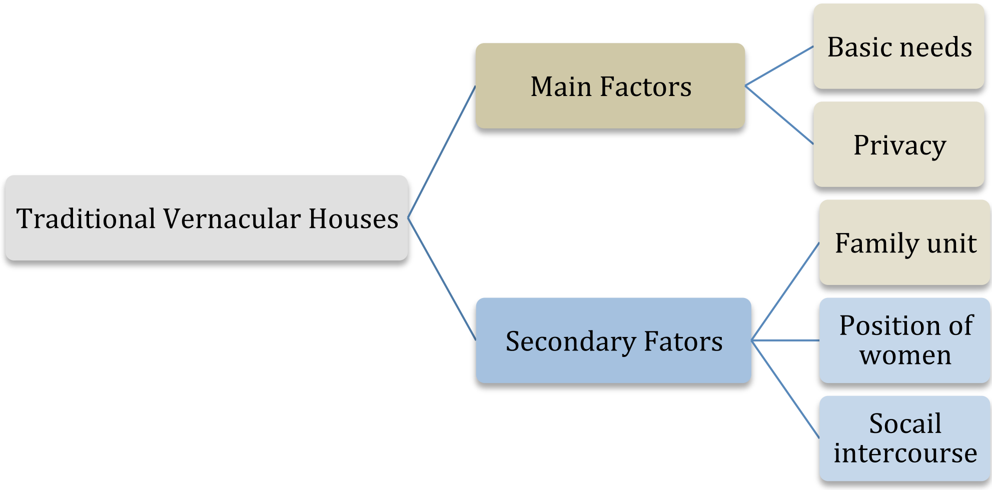


Figure (3. 25) the cultural forces that form the Libyan house form.

In dealing with the second group of forces classified as secondary factors, it appears that, whilst the social factor of the extended families that used to share and live in the same traditional vernacular house form in Libya was a dominant factor of space arrangement, the contemporary social order tends to drive the members of new families towards being as independent as possible, thus the layout of house forms are changing, and family unit rooms are becoming functionally single, instead of multiple purpose, space for sleeping or living.

Reducing the occupancy to a single family instead of an extended family has changed the privacy zoning within the house. The rooms have become less integrated space and pivotal, and more segregated space and private. Enlarging the privacy zoning and separating the function of the rooms is very clear in the three traditional vernacular house forms. Moreover, changes to the position of women in the family, from housewife to working member, has had an impact on the space organization as well as on the privacy zoning in the houses.

Moreover, as pointed by Paul Oliver “Change in the society is physically expressed in the building”. In the three houses considered the change in the social intercourse needs has had a clear effect on the spatial arrangement of the houses. In the traditional vernacular houses the guestroom (al Marbuaa) was mainly used by the male guests only, female guests used the living area or the roof as in the compact houses. Therefore, adding a guestroom for women fulfills the new needs of women for social intercourse. These changes can also be related to the position of women in the family and society. Furthermore, the socio-cultural forces that form the morphological characteristic of Libyan house can be considered the primary forces, while the climate can be a modifying factor.

Paul Oliver pointed out "The vernacular forms aren't arrived at by evolutionary processes. The abstract structural principles may not be known to the builders but they are aware of the expression of these principles in their work". The study of the building structure system and the contracture material in three houses indicates that the Libyan builders were aware of both the available material and its properties, in addition to the building structural principles.

In conclusion studying and understanding the cultural aspects that form the Libyan houses is the first step to learning from the vernacular houses, and reveals the house element that have been formed by cultural requirement. However the role of climate and available materials must be considered vital in determining the form of vernacular houses, where the use of minimum resources to obtain maximum comfort was dictated by social and economic conditions.

The following two chapters investigate the human thermal comfort notion and set local comfort limits for people in the three regions of Libya.

4. Chapter Four: Thermal Comfort Literature Review

4.1 Thermal comfort

Humans can and do survive in a range of climates from tropical to high latitude; this ability of humans to acclimatize to different conditions has led to different concepts of the ideal climate. Therefore, what may be considered an ideal climate in one region could be considered uncomfortable in another region. Accordingly, the thermal comfort differs from region to region. Over the last few decades' researchers have been examining the physical, physiological and psychological responses of people to their environment with the aim to develop an effective model to define and predict comfort temperature.

This chapter endeavors to review the definition of thermal comfort, emphasising the process of thermal comfort, physiological, psychophysical, and physical approaches. In addition, it intends to review the two methods of predicting thermal comfort; the 'static' school of thought that is based on the thermal equations for heat balance in the human using PMV and PPD models, and the 'adaptive' school of thought where adaptive factors are added. Finally, this chapter summarises some previous thermal comfort studies conducted in hot climates.

4.2 The Definition of the Thermal comfort

In 1979, Heschong described 'thermal uniformity' in her book 'Thermal Delight in Architecture'; this led to rigorous field studies on defining thermal comfort. Over recent decades the terminology of thermal comfort has evolved. Initially it was limited to physiological factors then evolved to include physical and psychological aspects.

Fanger defines thermal comfort as a function of physiological strain factors, stating that "the sensation experienced by a person was a function of the physiological strain imposed on him by the environment" (Fanger, 1970). The influence of these environmental factors, such as temperature, humidity and air velocity on the human body, are varied and depend on each other. As noted by Givoni, it is impossible to express human responses to the thermal environment as a function of a single environmental factor. Rather he defines thermal comfort as "the absence of irritation and discomfort due to heat or cold" (Givoni, 1976). This definition is similar to that used by the German Institute for Standardization, the "Deutsches Institut für Normung", (DIN), who defined thermal comfort thus: ‘Thermal comfort for humans being when the temperature, moisture and movement of the surrounding air are agreeable and neither hotter nor colder, drier nor moister, interior air is desired’(Hegger et al., 2008).

As a function of psychological factors, ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) defines thermal comfort as “the condition of mind that expresses satisfaction with the thermal environment” (Engineers, 2009). This definition is the most internationally recognized definition of thermal comfort. However, this definition has been questioned by Heije, through the view of the definition, it is clearly embraces factors beyond the physical/physiological, it indicates that thermal comfort will be influenced by individual differences in mood, personality, culture and other individual, organizational as well as social factors. Heije states that “This description seems to be quite precise but it is not” and explains that “when comfort is regarded as solely as a subjective mental state it seems elusive, both because it cannot be measured objectively and because it is continuously changing”. Heije (1994:41)

Apparently, ‘thermal comfort’ has more than one definition; however it can be argued that the common ground for all definitions is that a range of environmental and personal factors have to be taken into account for people to feel comfortable (Parsons, 2002). As a ‘physical and psychological approach’, Nicol argues that there is no temperature at which everyone will feel comfortable; comfort is a psychological state defined by climate, culture and economics (Nicol, 2008). In conclusion, the definition of thermal comfort is the condition in which the highest possible percentage of a group is in thermal comfort, with respect to the physiological, psychological and physical aspects. Therefore studying these factors may offer a better understanding of the notion of thermal comfort.

4.3 The Notion of Thermal Comfort

The complex interaction between man and the environment has led to numerous studies by researchers from different disciplines; physiologists, psychologists, social scientists, environmental engineers and physicists (Nicol et al., 2012). Each discipline has its own approach to defining thermal comfort. Thus, thermal comfort, as it is based on human subjective perception of a number of external influences such as physiological, psychological, and physical factors, can be perceived as a comprehensive context of the notion of thermal comfort. For the purposes of this research, this comprehensive definition is adopted. Thermal comfort is introduced as a status that is basically influenced by three physiological, psychological and physical factors. These three factors influence the thermal comfort level through various aspects as summarized in the diagram shown in figure (4-1).

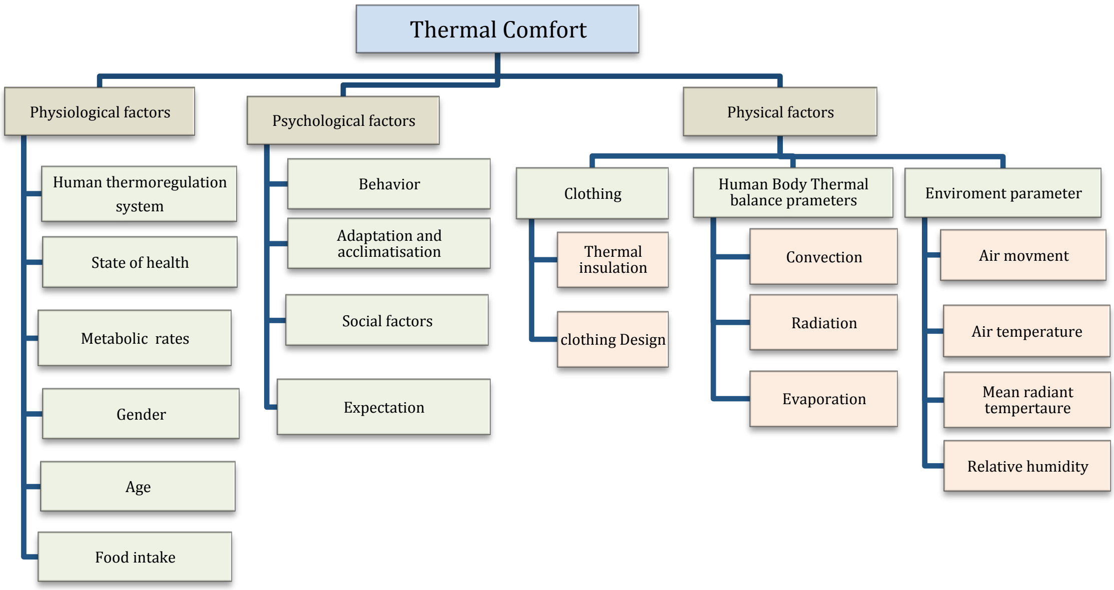


Figure (4. 1) Factors that influence human comfort. After Hegger, 2008

4.3.1 Physiological factors

Physiological factors affect the sensation of thermal comfort, and can be regarded as the first reaction for the human body to restore its thermal condition. Human thermoregulation differs from one person to another and depends on other physiological factors such as age, gender and metabolic adjustment.

4.3.1.1 Human thermoregulation

Human internal temperature has a nearly constant value (37^{o}C). Thus, in order to maintain the thermal balance between the heat lost to the environment and the heat produced by the body, the brain acts like a thermostat to maintain a constant internal temperature. The brain receives information from the body, lungs and spinal-cord but mostly from the skin where cold receptors start to produce sensations of cold if the temperature in a skin area decreases faster than about 0.004^{o}C/s, while the warm receptors start to produce warm sensations if the temperature increases at more than approximately 0.001^{o} C/s. (Olesen. P, 2002)

Heat produced by metabolising food is one of the essential factors for the functioning of organs such as the brain. Therefore, the deep body temperature must be kept constant (Hegger et al., 2008), and the amount of heat produced is usually expressed in watts per square meter of the body surface: the skin surface area of an average adult being about 1.7m^{2} (Nicol et al., 2012), this value changing according to the level of activity.

The body reacts physiologically to restore heat balance when the body temperature changes. It does this by using the blood, which has both a high heat capacity and a high thermal conductivity, to carry and transfer large quantities of heat. The human body initiates vaso-constriction when its temperature drops, this being the process by which the blood circulation to the peripheral part of the body is decreased, reducing the heat loss to the surroundings. On the contrary the body initiates vasodilation when its temperature rises. Here the blood supply to the periphery is increased, flushing the skin with blood and increasing heat loss to the surrounding environment, (Givoni, 1976).

Furthermore, when the core temperature increases, the body produces sweat to increase heat loss by evaporation, in addition to other effects such as evaporation of water via breathing, convection of heat from the surface of the body to the ambient air, conduction of heat from the body to immediate objects (floor, chair, etc.), and radiation of heat to the surfaces enclosing the room and to nearby objects.(Nicol et al., 2012)

4.3.1.2 Age and Gender factors

Studies by Nevins et al. (1966), and Rohles and Johnson (1972) showed that the thermal environments preferred by older people do not differ significantly from those preferred by younger people, (Collins, 1984; Fanger, 1970; Natsume et al., 1992; Parsons, 2002). Although metabolism alters slightly with age and gender both older men and women prefer almost the same thermal environments, where studies showed that the lower metabolism in older people is compensated for by a lower evaporative loss. (Karwowski, 2010; Parsons, 2010). However in practice, because of the lower activity level of elderly people they normally prefer a higher ambient temperature level in the home than that preferred by younger people.

Some field studies show that gender difference are small and insignificant, as de Dear pointes out ‘that men and women prefer almost the same thermal environments’ (Cena and de Dear, 2001a; Parsons, 2002). On the other hand other studies have found significant differences in thermal comfort between the genders (Erlandson et al., 2005; Karjalainen, 2012). Karjalainen states ‘more than half of laboratory and field studies have found that females express more dissatisfaction than males in the same thermal environments. Very few studies have found males to be more dissatisfied than females’. He added that meta-analysis shows that females are more likely to express thermal dissatisfaction, and have, on average, a greater need for individual temperature control and adaptive actions than males therefore he suggests that females should primarily be used as subjects when examining indoor thermal comfort requirements, as, if females are satisfied, it is highly probable that males are also satisfied. (Karjalainen, 2012)

4.3.1.3 Metabolic adjustment

The term 'Metabolic Rate' refers to the amount of chemical energy a person frees from their body per unit time. Parsons defined it as ‘the energy used by the body in the performance of its normal functions, including both maintaining the body itself (replacing tissues, etc.) and using the body to perform external functions such as physical work, sports and daily tasks (Parsons, 2010).

The level of metabolic energy depends on the level of activity; the body’s heat production is often measured in units of metabolic equivalents (MET), which can be expressed as power density per unit body surface area (W/m^2), typically 58.2 W/m^2 for an awake but non-active person)

The level of activity (MET) is determined in the laboratory, based on tables developed from laboratory studies to define the MET rates for specific activities and occupations, (ASHRAE, 1992; ISO, 1990; 1994). Studies asked occupants to record their activities over the last hour, this information being used to develop a more accurate average for the group, or individualized MET estimates for each participant (Cena and Clark, 1981). In most studies, an average MET rate is assumed for the group (usually 1.2 MET for sedentary office work). The current MET tables provide information for the 'average' person, for an average sized man this corresponds to approximately 100W. The table (4-1) shows some typical metabolic rates:

TABLE 1 Metabolic rates at different activities

activity	met	W/m²	W(av)
sleeping	0.7	40	70
reclining, lying in bed	0.8	46	80
seated, at rest	1.0	58	100
standing, sedentary work	1.2	70	120
very light work (shopping, cooking, light industry)	1.6	93	160
medium light work (house~, machine tool ~)	2.0	116	200
steady medium work (jackhammer, social dancing)	3.0	175	300
heavy work (sawing, planing by hand, tennis) up to	6.0	350	600
very heavy work (squash, furnace work) up to	7.0	410	700

Table (4. 1) Metabolic Rates for Typical Task, Based on ANSI/ASHREA Standard 55-1992R

However, a person's body mass, body type, fitness, hormone levels and blood flow can influence the MET rate for a given activity. (Zhang et al., 2001), Moreover, performing mental tasks could increase activity levels up to 1.3 MET and periods of stressful activity resulting in greater muscle tension could increase the MET rates of typical office tasks up to 1.5 MET, (Wyon (1975). Fanger, (1973). Therefore such tables do not accurately reflect differences between people in terms of age, gender or contexts.

4.3.2 Psychological factors

Psychology is the scientific study of the human mind and its functions (Dictionaries, 2013). In thermal comfort study, psychologists take human behavior and thermal sensation as raw data for testing their theories about how the mind works. Therefore, the psychological factor can be illustrated through behavioural and psychophysical approaches.

4.3.2.1 Human Behaviour

During the last few decades a number of researchers have studied the impact of physiological and psychological factors on thermal comfort (Brager and Dear, 1998; Cena and de Dear, 2001b; Glaser, 1966; Nicol et al., 2012). People tend to interact with their thermal environment by changing their clothing or activity when they feel hot or cold, as well as changing their behavior in order to feel comfortable again. Researchers have acknowledged that building occupants will adapt their behaviour and expectations with respect to thermal comfort (e.g. Baker & Standeven, 1996; Benton et al, 1990; Brager & de Dear, 1998; Cena et al, 1986; de Dear & Brager, 2001; 2002; Humphreys, 1994, Nicol 2004).

These behaviours include adjustment to the surrounding such as opening windows, adjusting blinds or shading devices, operating fans, adjusting thermostats, blocking ventilation outlets or moving to a different room, as well as modifying activity levels and changing clothing, and even consuming hot or cold food and drinks (Baker & Standeven, 1996; Brager & de Dear, 1998; Humphreys, 1994; Oseland & Humphreys, 1994). Human behaviour is considered the secondary human thermoregulation in additional to the autonomic physiological system of thermoregulation that interacts and responds to a changing environment, in order to restore the body heat balance. Ken Parsons suggests that 'The most powerful form of human thermoregulation is behavioural: putting on or taking off clothes, changing posture, moving, taking shelter, etc.'(Parsons, 2010). Nicol notes that time is important for behavioural interactions; and identifies four typical time periods (Nicol et al., 2012): Immediate response, Within-day, Day-to-day and Longer term.

4.3.2.2 Psycho-social factors

In each country people have developed their own techniques for adapting to the climate, which may not work in other countries; these techniques are constrained by climate and by socio-cultural factors that restrict the opportunities for occupants to adapt, such as wealth, social norms, or organizational policies. Fountain points out that people's sensations and thermal preferences could be influenced by the culture and climate associated with expectation and thermal adaptation, (Fountain et al., 1996). Some Historians (Crowley, 2000) and (Rybczynski, 1987), have looked at how ideologies and technologies of comfort have co-evolved within societies, suggesting that comfort is as much a cultural phenomenon as a technical innovation.

4.3.2.3 Psychophysical factors

According to the Oxford English dictionary, psychophysics is " the branch of psychology that deals with the relations between physical stimuli and mental phenomena". Psychophysics can be applied to any sensory system, whether vision, hearing, touch, taste or smell (Kingdom and Prins, 2010). In terms of thermal sensation, psychophysics studies the relation between our thermal sensations and the stimuli we receive from the physical world and the ways in which our brains interpret them, though Nicol points out that the relationship between overall thermal sensation and the characteristics of the environment is hard to pin down.

The main difference between thermal sense and the other senses is that results from the five senses give us neutral pieces if information, which may or may not change our experience. However, thermal information is never neutral; it is in fact reflecting what is being experienced by the body. Hence our nerves are a 'heat flux meter' - they cannot read a temperature but they can sense how quickly our bodies are gaining or losing heat (Nicol et al., 2012). A person will consider an object hot or cold depending whether its temperature is higher or lower than that of his or her skin. The skin contains two different kind of receptors, cold and warm receptors, with a ratio of up to 30 cold receptors to 1 warm receptor. The cold receptors respond to decreases in temperature over a temperature range of 5-43^{o}C. Warm receptors discharge with increases of around 45^{o}C (Jones and Berris, 2002).

4.3.2.4 Acclimatisation

Acclimatisation results from regular exposure of the human body to the same climatic conditions. Koenigsberger defines it as follows: "exposed to a new set of climatic conditions, the human body will reach full adjustment in about 30 days and by that time the thermal preferences of an individual will change" (Koenigsberger et al., 1974). The duration of acclimatisation varies with the location and type of climate, the studies showed that people exposed to long-term experience of a humid and warmer climate over several generations have better tolerance to higher temperatures as compared with people in colder regions (Yamtraipat et al., 2005).

Moreover, humans reach full adjustment in about one month. Consequently, people of the same climatic region change their thermal comfort preference seasonally, therefore in summer it is higher than in winter. Thus, there are many non-quantifiable factors that effect thermal comfort sensations, such as the acclimatisation to using home air-conditioners termed as (AC acclimatisation behavior), whereby people in air-conditioned buildings preferred a somewhat lower comfort temperature than in the free running buildings (Yamtraipat et al., 2005)

Humphreys noted that "if there are no constraints placed upon adaptation processes, then, over time, neutral temperatures will come to be similar to air temperatures. The occupant will adapt both the thermal environment and their own expectations, until a comfortable situation exists" (Humphreys et al., 1995).

4.3.2.5 Social and Cultural factors

In developing suitable techniques for adapting, socio-cultural factors and constraints have influential roles. People's thermal sensation and thermal preferences are influenced by culture as well as climate; culture has been proven to have significant influence over the type of clothing, human behavior and technology (Heschong, 1979). As a general rule people have been encouraged in their cultural environment to originate pragmatic building design as well as clothing that adapts to situations, which are appropriate to the outside thermal environment (Lorch, 2003).

The experience of being thermally comfortable in a given situation is partly generated by the socially/culturally acceptable clothing styles that we grow up with, which are part of the norms we learn from our family, and which vary by gender and age (Chappells, 2004).

In cultures such as eastern Asia and the Middle East, western style appliances and practices have replaced their traditional equivalents for many activities in the home. A cross-cultural study may highlight the role of culture on thermal sensation. In his study Wilhite studied the difference between Japanese and Norwegian habits in heating. In Norway, it is common to heat all rooms equally, creating a thermally consistent environment in which to move around. In Japan the use of a "kotatsu" a small heating unit placed under a table, is designed to heat individual bodies rather than surrounding spaces. In both cases strategies of heating were related to culturally relative ideas about comfort, as well as to routine form of social interaction, (Wilhite, 1996)..

In the Middle East the change in the number of family units living in the same house affects the clothing type and therefore the thermal sensations of the occupants. Extended families living in a house create cultural and religious constraints on clothing and behavior. For instance, women tend to wear more clothes and cover their heads in the presence of male relatives and this affects their thermal sensation. Therefore, in order to fully define people's thermal experience, we need to take into account the dynamics and modes of interactivity as well as changes in physical, physiological and psychological factors

In conclusion studying the thermal preferences for groups of people is a matter of culture as well as climate.

4.3.3 Physical factors

Physical factors are considered the most important factors in human thermal comfort, and are the most studied in the field. These factors can be categorized into three groups; Human body thermal balance parameters, clothing parameters and environment parameters

4.3.3.1 Human body thermal balance parameters

The human body produces energy by metabolizing food but only 20% of this energy is utilized, the remaining 80% is 'surplus' heat and must be dissipated to the environment (Koenigsberger et al., 1974). Therefore, to maintain its thermal balance the human body loses heat to its environment in three ways: convection, radiation and evaporation.

4.3.3.1.1 Convection

The heat transmission between the body and the air in contact with the skin is known as convection, it occurs when the body loses heat to the environment when the air temperature surrounding the body is lower than that of the temperature of the skin and the surface of the lining of the lungs. The rate of transmission depends on temperature differences and air movement. The normal skin temperature is between 31°Cand 34; as the air temperature approaches skin temperature convective heat loss gradually decreases to point where there is no more convective heat loss, (Koenigsberger et al., 1974, p. 42).

However if the air temperature surrounding the body is higher than the skin temperature this will reverse the process and the body will gain heat. Air movement can increase heat loss from the skin by helping to strip away the warmed air close to the skin at a greater rate (Hegger et al., 2008). The equation for convective heat transfer is

$$\boldsymbol{C = h_c(T_{cl} - T_a)} \text{ W/m}^2$$

Where (C) is the rate of convective heat flow per square meter of body surface, (h_c) is the convective transfer coefficient in W/m^{2}K ($h_c = 3.1$ for air velocity $v < 0.2$, m/s $h_c = 8.3v^{0.6}$ for air velocity $v > 0.2$m/s). T_{cl} Is the mean surface temperature of the clothed body, (T_a) is the air temperature,(Nicol et al., 2012, p. 20).

4.3.3.1.2 Radiation

The human body emits radiant heat from its surface at a rate proportional to the fourth power of its absolute temperature (Crichton and Nicol, 2012, p. 161). The radiant landscape of a room consists of radiation emitted from heated surfaces, equipment and lighting devices and from the main source of heat gains, direct and indirect solar radiation. The method for calculating radiant heat loss or gain to the body is by integrating the effect of every part of the surrounding surfaces and other radiant sources with every part of the body, this can be calculated by using the mean radiant temperature, which is the uniform temperature of an enclosure where the human body exchanges the same quantity of radiative energy. The equation for radiative heat transfer is

$$\boldsymbol{R = \varepsilon h_r f_{cl} f_{eff} (T_{cl} - T_{rm})} \text{ W/m}^2$$

Where (ε) is the rate of radiative heat flow per square meter of the body surface, (h_r) is the emissivity of the clothed/skin surface (generally close to 1). The linear radiation transfer coefficient W/m^{2}K, for typical clothing h_r is $4.7 \frac{W}{m^2}$, $(f_{cl})$is the effective surface area of the clothed body (greater than one because the surface area of a clothed body is usually greater than a nude one), $\mathbf{f_{cl} = 1 + 0.15\, I_{clo}}$, I_{clo} is the clothing insulation, (f_{eff}) is the effective radiation area factor (less than one because in some parts (e.g under the arms) the body radiates to itself rather than to the environment f_{eff} is 0.7 when seated and and 0.72 when standing , T_{cl} is the clothing surface temperature °C, T_{rm} is the mean radiant temperature°C.(Nicol et al., 2012, p. 20)

4.3.3.1.3 Evaporation

Evaporative heat loss E_{sk} from skin depends on the amount of moisture on the skin and the difference between the water vapour pressure at the skin and in the ambient environment (Parsons, 2010). The total heat lost by evaporation is determined by the amount of sweat actually evaporated. The hotter the air the more water it is capable of carrying. The Vapour pressure at the skin reaches its maximum (saturated vapour pressure) when the temperature of the skin reach its maximum, the different between this saturated vapour pressure and the air vapour pressure is the driving forces for the evaporation of sweat, and therefore the heat loss from the skin (Nicol et al., 2012). The equation for the evaporative heat loss is

$$\boldsymbol{E = wh_e(p_{ssk} - p_a)}$$

Where (E) is the rate of evaporative heat flow per square metre of body surface, (w) is the skin wettedness, (h_e) is the evaporative heat transfer coefficient $h_e = 16.5h_c$ W/m^{2}kPa, (p_{ssk}) is the saturated water vapour pressure at skin temperature (KP$_a$), (P_a) is the water vapour pressure of the air (kPa).

There is also some heat loss evaporation of moisture that diffuses through the skin even when there is no sweating; the process is called insensible perspiration.

The equations for insensible loss have been determined empirically as:

$$\boldsymbol{E_{is} = 4 + 0.12(p_{ssk} - p_a)}\text{W/m}^2$$

In addition, the respiration heat loss has two components, latent and dry, which is calculated by the following equations; ($E_{res} = 0.017M(5.87 - p_a)$ W/m^2 and ($C_{res} = 0.0014\, M\,(34 - T_a)$ W/m^2, (M/s the metabolic rate in W/m^2)(Nicol et al., 2012, p. 22; Parsons, 2010).

4.3.3.2 Clothing insulation

Clothing is considered as a second skin for the human body that offers thermal protection from the environment. It is a thermal resistance layer that controls the level of heat-loss from the body to the surrounding atmosphere(Evans, 1980)

The thermal insulation value is expressed in terms of *clo* units, where one *clo* is the amount of thermal resistance which "is necessary to maintain thermal comfort for a sitting – resting subject in a normally ventilated room (air movement 0.1m/sec) at a temperature of 21.1^{o}C and RH< 50%" (1 *clo* = 0.155m^{2}K/W). International standards have set one *clo* equal to the value of a standard Western business suit.

There are many methods for estimating clothing insulation, earlier studies used to estimate the value of *clo* depending on the season and climate, at 0.35-0.6 *clo* in the summer and 0.8-1.2 *clo* in winter. The most accurate method is by calculating for a complete clothing ensemble by using a combination of garments listed in the table. The occupants were asked to complete a garment checklist, to estimate more appropriate *clo*, or separate *clo* value for each participant, by estimating *clo* value using tables that have been developed from clothing insulation studies conducted in laboratory studies, (ASHRAE, 1992; ISO, 1994, 1995).

The table below shows the insulation value of different western clothing according to ASHRAE.

Man		clo	Women		clo
underwear	singlets	0.06	underwear	bra + panties	0.05
	T-shirt	0.09		half slip	0.13
	briefs	0.05		full slip	0.19
	long, upper	0.35		long, upper	0.35
	long, lower	0.35		long, lower	0.35
shirt	light, short sleeve	0.14	blouse	light	0.20
	light, long sleeve	0.22		heavy	0.29
	heavy, short sleeve	0.25	dress	light	0.22
	heavy, long sleeve	0.29		heavy	0.70
	+5% for tie or turtle-neck)				
vest:	light	0.15	skirt	light	0.10
	heavy	0.29		heavy	0.22
trousers	light	0.26	slacks	light	0.26
	heavy	0.32		heavy	0.44
pullover	light	0.20	pullover	light	0.17
	heavy	0.37		heavy	0.37
jacket	light	0.22	jacket	light	0.17
	heavy	0.49		heavy	0.37
socks	ankle length	0.04	stockings	any length	0.01
	knee length	0.10		panty-hose	0.01
footwear	sandals	0.02	footwear	sandals	0.02
	shoes	0.04		shoes	0.04
	boots	0.08		boots	0.08

Table (4. 2) Thermal insulation clo ASHRAE 1992

However, the table shown in Figure (5.2) was estimated for a standing western person, therefore when dealing with other cultures this table is inapplicable, as there are many factors determined the insulating effect of clothing such as the design of the cloth and the culture of the wearer. Moreover, the meaning of clothing description can vary. Nicol notes that “a suit described as thick in one climate might be counted rather thin in other” (Nicol et al., 2012). Additionally, a sitting posture results in decreased thermal insulation due to compression of air layers in the clothing. This decrease may be offset by the insulation provided by the chair. Adding the factors of the clothing design that allowed trapped air layers within clothing microenvironment contributes to the thermal insulation, (Bouskill et al., 2002).

The clothing design and material are functions of culture and climate; the traditional clothing developed by various cultures often has extremely sophisticated thermal functions (Heschong, 1979). In zones classified as hot dry, people tend to wear different clothing as determined by their culture. For instance, the ‘dishdasha’ and ‘serwal’ are the traditional clothes of the Eastern Arab countries while in other hot parts of the world like South America, wearing light western cloth (shorts, T-shirt) is common. Alternatives are to wear loose multiple-layered clothing to keep the high air temperature and solar radiation away from the skin, whilst still allowing heat loss by evaporation as air is pumped over the body surface and through the clothing as the wearer moves (Vogt et al., 1983).

Therefore, ASHRAE conducted a research to extend the above table to provide data for non-western clothing, as well as the effect of posture on air movement, the 1504-TRP, “Extension of the Clothing Insulation Database for Standard 55 and ISO 7730.”

4.3.3.3 Environmental factors

There are four main environmental parameters that effect thermal comfort condition, the air temperature, mean radiant temperature, air movement and relative humidity.

4.3.3.3.1 Air Temperature.

Without the influence of other environmental factors (radiation, air movement, and relative humidity), the temperature is an important factor in determining thermal comfort, as 2/5 of the heat loss from the body is by convection within the room (Parsons, 2010). It is most often measured using a dry bulb thermometer; hence it is also called the dry bulb temperature (DBT). Griffiths points out that having the ‘right temperature’ was one of the things people considered most important in a building. Thus, in order to maintain the temperature in the thermal comfort zone, it must normally be between 16°C to 30°C for daytime rooms and lower for sleeping rooms. The temperature experienced by a person in a building also includes the effect of radiation from the surrounding walls and possible direct radiation from the openings. However, if the temperature is above or below this level, thermal comfort can only be achieved through increasing or decreasing the level of activity, the thermal resistance of clothing, or the amount of air movement.

4.3.3.3.2 Mean Radiant Temperature (MRT).

Mean Radiant Temperature is the temperature of a uniform black enclosure in which a solid body or inhabitant will exchange the same amount or radiant heat as in the existing non-uniform environment, (Lewis et al., 1992, p. 225). With respect to the human body the ISO standard defines the MRT thus: "the mean radiant temperature is the uniform temperature of an imaginary enclosure in which radiant heat transfer from the human body is equal to the radiant heat transfer in the actual non-uniform enclosure" (Parsons, 2010).

MRT influences heat loss in two ways: the first is by conduction (when the occupant makes contact with the surface). The second is by radiant heat loss. Therefore, discomfort will be experienced when the MRT is above or below the air temperature by a few degrees (approximately 5°C); in addition, an MRT value of 2-3 degrees above air temperature can enhance comfort.

Moreover, discomfort can result from the effect of intense incoming solar radiation on the other side of the surface, causing a high level of outgoing radiation. Using an appropriate thickness of a suitable insulation for the external walls of the room will reduce the MRT to close to the room temperature.

4.3.3.3.3 Air movement (Air velocity)

Air movement affects heat loss from the body through convection. The association of air movement, and air temperature is important. For example in a hot climate, an increase in air movement will increase the amount of heat loss from the body, as well as increasing the evaporative cooling from the skin. This could provide thermal comfort; it is indicated by (Lewis et al., 1992,) that within buildings the air speed is generally less than 0.2m/s. which is generally unnoticed, as under everyday conditions the average subjective reactions to various velocities are:

Air velocity m/s	The average subjective reactions
< 0.25	Unnoticed
0.25-0.50	Pleasant
0.50-1.00	Awareness of air movement
1.00-1.50	Draughty
> 1.50	Annoyingly draughty

Table (4. 3) Air velocity Source thermal comfort by Andris Auliciems

4.3.3.3.4 Relative Humidity

The relative humidity comfort value ranges from 20% to 80%. So, if it is below 20% a distinct discomfort will be experienced because of the dryness, or if it is above 80% it will create a feeling of dampness (ideally the level should not drop below 40% and not exceed 70%). It is known that human tolerance toward humidity is much greater than towards temperature, but at a high level of RH comfort starts to be rapidly affected. At such high levels it is necessary to decrease temperature in order to maintain comfort. For instance, the increase of the relative humidity from 20% to 60% will need a decrease in the temperature of 1^{o}K (Markus and Morris, 1980) to maintain comfort.

4.3.3.3.5 Operative Temperature

Operative temperature (t_{op}) is used in most of the standards such as ASHREA 55 and CEN EN 15251 in the adaptive section to predict comfort temperature. Nicol states that the operative temperature is a sufficient thermal index to define the neutral temperature when the air movement is slight and humidity is not excessive.(Nicol et al., 2012, p. 21)

The operative temperature is a theoretical and not an empirical measure, it is measured as the result of combining the air temperature (dry bulb temperature (t_{db}) and the mean radiant temperature (t_r),in effect it is the weighted average of the two temperatures, the weights depending on the heat transfer coefficient by convection (h_c) and by radiation (h_r) at the clothed surface of the occupant (Nicol et al., 2012, p. 21). The operative temperature can be calculated as follows:

$$t_{op} = \frac{h_r . t_r + h_c . t_{db}}{h_r + h_c}$$

It also can be calculated from the air velocity and air temperature and mean radiant temperature as:

$$t_{op} = A . t_a + (1 - A) . t_r .$$

where t_{op} is the operative temperature °C, (t_a) is the air temperature °C. t_r is the mean radiant temperature °C, A is a factor according to the relative air velocity (A = 0.5 forfor $v_{air} = 0.2\ {}^{m}/_{s}$, A = 0.6, for $v_{air} = 0.2 - 0.6\ {}^{m}/_{s}$, A = 0.7for $v_{air} = 0.6 - 1.0\ {}^{m}/_{s}$), (Engineers, 2009). Therefore, approximately, at indoor air speeds below ($0.1\ {}^{m}/_{s}$), the operative temperature can be calculated as:

$$t_{op} \approx \frac{t_a + t_r}{2}$$

However because it is not an empirical measure, in practice it approximates very closely to the 40 mm globe temperature.

4.3.3.3.6 Running mean temperature – exponentially weighted RMT

A running mean is a mean calculated for a given period of time. As time passes, new values are incorporated into the mean, while older values are dropped from it. The exponentially weighted running mean of the daily mean outdoor air temperature T_{rm} can be calculated from the series:

$$n\, T_{rm} = (1 - \propto)\, T_{od-1} + \propto_{n-1} T_{rm}$$

or

$$T_{rm}(tomorrow) = \alpha * T_{rm}(yesterday) + (1 - \alpha) * T_m\ (today)$$

Where ($n\, T_{rm}$) is the running mean temperature for day (n) and ($_{n-1}\, T_{rm}$) is the daily mean outdoor temperature for the previous day. (T_m) the day mean of outdoor temperature is the average of the maximum and minimum values for the day in question. ($\propto$) is a constant between 0 and 1 that controls how quickly the running mean responds to the outdoor temperature (Nicol et al., 2012). The value of $\propto$ represents the thermal inertia of the building together with the delay behavioural responses of the occupants to temperature changes within the building.

4.4 Thermal balance models

Gagge (Parsons, 2003) was the first to propose a thermal balance model in 1936, which can be summarized as (M ± R ± C ±E = ΔS). This simple equation has been modified and upgraded through the years. The basic equation for thermal balance is:

$$M - W = C + R + E + (Cres + Eres) + S$$

where (M) is the metabolic rate, (W) is the mechanical work done (C) is the convective heat loss from the clothed body, (R) Is the radiative heat loss from the clothed body, (E) is the evaporative heat loss from the clothed body (due to sweat and insensible evaporation), (C_{res}) is the convective heat loss from respiration, (E_{res}) is the evaporative heat loss from respiration, (S) is the rate at which heat is stored in the body tissues

However, most models use the Fanger heat balance equation and the two-node model developed by the J. B. Pierce Foundation (the Pierce Two-Node Model) and researchers at Kansas State University (the KSU Two-Node Model). The thermal comfort equation is only applicable to a person in thermal comfort equilibrium with the environment.

4.4.1 Fanger's heat balance

The simple thermal balance equation has been modified and upgraded through the years. The most used model is Fanger's heat balance equation developed by P. O. Fanger, who in 1967 introduced his thermal comfort equation, setting the storage component to zero, concluding that physiological neutrality is the mean for comfort, (Fanger, 1967). This equation can be written as follows:

$$\frac{M}{A_D}(1-\eta) - 0.35\left[43 - 0.061\frac{M}{A_D}(1-\eta) - p_a\right] - 0.42\left[\frac{M}{A_D}(1-\eta) - 50\right] 0.0023\frac{M}{A_D}(44 - p_a) - 0.0014\frac{M}{A_D}(34 - t_a) = \frac{35.7 - 0.032\frac{M}{A_D}(1-\eta) - t_{cl}}{0.18 I_{cl}} = 3.4 * 10^{-8} f_{cl}[(t_{cl} + 237)^4 - (t_r + 237)^4] + f_{cl} h_c (t_{cl} - t_a)$$

Where M is the metabolic rate, A_D is the DuBois area, $\frac{M}{A_D}(1-\eta)$ (Szokolay e Auliciems, 1997) is the heat generated in the core, $\mathbf{p_a}$ vapour pressure of ambient air (mmHg), I_{cl} is the insulation of clothing in *clo* units, t_s is the skin temperature t_{cl} is the clothing surface temperature, t_r is the mean radiant temperature, t_{cl} is the temperature of outer surface of clothing, f_{cl} is the ratio of clothed to exposed body surface and h_c is the convection conductance ($k_{cal}/m^2h°C$).

Fanger used this thermal comfort equation as basis of his PMV index, (Predicted Mean Vote).

4.4.2 The 2-node model

The model was introduced in 1970 and was developed by the John B. Pierce Foundation at Yale University (The Pierce Two-Node model), followed by The KSU two-node model, which has been developed at Kansas State University, was published in 1977 (10). It was developed specifically to formulate a new effective temperature scale; it determines the heat flow between the environment, skin and core body areas on a minute-by-minute basis. Starting from an initial condition at time=0, the model iterates until equilibrium has been reached (60 minutes is a typical iteration time). The final mean skin temperature and skin wettedness are then associated with an effective temperature, which predicts thermal discomfort using skin temperature and skin wetted ness.

$$\Delta S = M\,[(1-\eta) - 0.0173(5.87-p_a) - 0.0014(34-t_a)] - 16.7(0.06+0.94W_{rsw})\,h_c\,(p_{sk}-p_a)\,F_{pcl} - h\,(t_{sk}-t_a)\,F_{cl}$$

where ΔS is the storage component, M is the metabolic rate, M(1- η) is the heat generated in the core. Respiration removes some of this, partly as evaporative loss (Er_{esp}) = 0.0173 M (5.87-p_a), and partly as sensible heat (Cr_{esp}) = 0.0014 M (34-t_a) where 34°C is the exhaled air temperature and 5.87 kP_a is the vapour pressure at a lung temperature of 35°C. The sensible heat loss from the body surface is R+C = h (t_{sk}-t_a) F_{cl} ... 2.5) where

F_{cl} = insulation value of clothing = 1/(1+0.155 h I*cl*).(Szokolay e Auliciems, 1997)

4.5 Thermal comfort standards

According to ISO 7730 "A standard is a document that provides requirements, specifications, guidelines or characteristics that can be used consistently to ensure that materials, products, processes and services are fit for their purpose". There are three well-known and widely used international standards that relate specifically to thermal comfort: These are ISO Standard 7730(2005), ASHRAE Standard 55 (2004), and CEN Standard EN15251 (2007).

4.5.1 The International Standards Organisation ISO 7730

The European thermal comfort standard organisation (ISO) was set up in 1947 and has over 130 member countries. The standards concerned with thermal comfort are produced by (ISO/TC 159 SC5 WG1) and the main thermal comfort standard is ISO 7730, which is relates to human physiology and heat transfer. The ISO 7730 standard is based upon the Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD) thermal comfort indices. The standard specifies "classes" or categories of buildings according to the range of PMV that occurs within them. The table below illustrates the building categories.

The ISO categorisations have been adapted by other standards, so EN 15251 contains a similar categorization, while it is possible they will be included in the future editions of ASHRAE standards (Arens et al., 2010).

Cate-gory	Thermal state of the body as a whole		Operative temperature °C		Max. mean air velocity m/s	
	PPD %	PMV	Summer (0,5 clo) Cooling	Winter(1 clo) Heating	Summer(0,5 clo) Cooling	Winter(1 clo) Heating
A	< 6	-0.2 < PMV < + 0.2	23,5 – 25,5	21,0 – 23,0	0,18	0,15
B	< 10	-0.5 < PMV < + 0.5	23,0 – 26,0	20,0 – 24,0	0,22	0,18
C	< 15	0.7 < PMV < + 0.7	22,0 – 27,0	19,0 – 25,0	0,25	0,21

Table (4. 4) three categories of thermal comfort environment. Percentage of dissatisfied due to general comfort and local discomfort, Source (ISO EN7730)

ISO 7730 also provides methods for the assessment of local discomfort caused by draughts, asymmetric radiation and temperature gradients. The validity of ISO 7730 can be considered in terms of to whom it applies and over what range of environmental conditions. The standard notes that deviations in the PMV /PPD index may occur due to age, ethnic, national-geographic deviations and for people who are sick or disabled. In addition it applies to indoor environments where steady state thermal comfort or moderate deviations from comfort occur (Olesen and Parsons, 2002).

4.5.2 ASHRAE standard 55

ASHRAE, the American Society of Heating, Refrigerating and Air-Conditioning Engineers, founded in 1894, is an international organization with over 54,000 members (ASHRAE, 2004). The ANSI/ASHRAE standard 55 deals with evaluating thermal comfort; it was established to assist the industry and the public by offering a uniform method of testing for rating purposes [ASHRAE 2004]. Standard 55 deals with thermal comfort in indoor environments. The new effective temperature, ET*, was used to develop ASHRAE 55, however, the ET* relates the room temperature and humidity to provide an index for sedentary persons in standard clothing only. Consequentially, in order to incorporate different activity levels and clothing, the Standard Effective Temperature (SET) was developed. In ASHRAE 55-92, the standard added the PMV-PPD method of calculation to determine the comfort zone, and it became more consistent with other international standard such as ISO EN 7730 (Olesen and Brager, 2004).

ASHRAE standard 55 is based on the assumption that the people prefer a “neutral” thermal sensation (a vote of zero on the 7-point ASHRAE thermal sensation scale), and that discomfort varies symmetrically as sensations differ from neutral on either the warm or cool side. According to ASHRAE “The Standard specifies conditions acceptable to a majority of group of occupants exposed to the same conditions within a space” (Olesen and Brager, 2004) . The “majority” have been defined as 80% overall acceptability, while specific discomfort limits vary for different sources of local discomfort. The acceptable zones for indoor temperature are defined by the indoor operative temperature and mean monthly outdoor air temperature. They are based on comfort equation for naturally conditioned buildings derived from the ASHRAE RP884 database

$$\boldsymbol{T_{comf} = 0.31T_o + 17.8}$$

Where T_{comf} is the optimal temperature for comfort and T_o is the mean outdoor temperature for the survey. The ASHRAE standard was the first international standard to include an adaptive componentand an adaptive standard that applied to naturally conditioned building (Nicol et al., 2012). However, in order to apply the adaptive model the prevailing mean temperature calculated must be greater than 10°C (50°F) and less than 33.5°C (92.3°F) and some other criteria must be met according to the standard (ASHRAE Standard 55, 2010)

The standard can be applied to any type of building (residential or commercial, new or existing) (Olesen and Brager, 2004). Recently, in the newly published ASHRAE thermal comfort standard, ANSI/ASHRAE Standard 55-2010, Thermal Environmental Conditions for Human Occupancy, new requirements regarding air speeds, analysis and documentation are involved.

4.5.3 European Standard EN152521

EN12521 was developed by the *Comité* Europ*é*en de Normalisation (CEN), as a part of a series of new standards intended as a backup to the Energy Performance of Buildings Directive (EPBD, 2003). The standard was developed as response to the effect of indoor environment on energy consumption and productivity (work and learning performance). Studies proved that the cost of poor indoor environment is often considerably higher than the cost of the energy used in the same building. Therefore, the standard specifies the indoor environmental parameters, which have impacts on the energy performance of buildings, such as indoor air quality, lighting and acoustics. However, the major thrust of the standard is its definition of the thermal environment, the sections on other factors confining themselves largely to references to other standards, (Nicol, 2010).

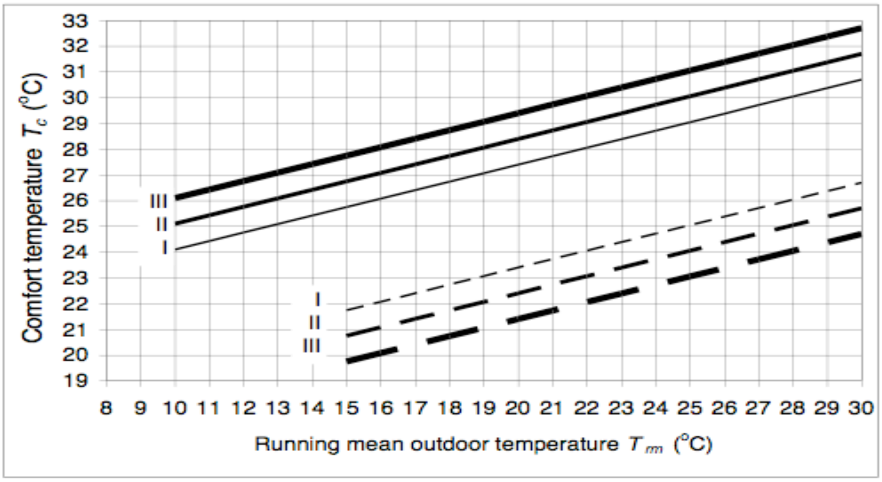
The standard also recognises the different experiences occupants have of thermal environments in mechanically and naturally ventilated buildings. The EN15251 uses categories for buildings, defined by the nature of the building rather than referring directly to the quality of their indoor environment.

The standard categorises buildings in terms of the type and the expectation of the occupants. Its uses the SCATS (Smart Controls and thermal comfort) database for its adaptive standard, the data have been collected from five European countries over the same period of time in the same manner and using a standard set of instrument. (Santamouris, 2007)

The following equation was used to define the comfort temperature limits for building without mechanical cooling

$$\boldsymbol{T_{comf} = 0.33T_{rm} + 18.8}$$

Where T_{rm} is the exponentially weighted running mean of the outdoor temperature which can be found by using the following equation $T_{rm} = (1-\propto)T_{od-1} + \propto_{n-1} T_{rm}$ with value of $\propto of$ 0.8.



Category	Explanation
I	High level of expectation only used for spaces occupied by very sensitive and fragile persons
II	Normal expectation for new buildings and renovations
III	A moderate expectation (used for existing buildings)
IV	Values outside the criteria for the above categories (only acceptable for a limited periods)

Category	Mech vent (PMV)	Free-running (T_{op}°C)
I	±0.2	±2
II	±0.5	±3
III	±0.7	±4
IV	>±0.7	>±4

Figure (4. 2) acceptable operative ranges or free running natural conditioned spaces Source EN 15251

Finally, as input variable for the adaptive model, the ASHRAE-55 2010 Standard introduced the prevailing mean outdoor temperature. It is based on the arithmetic average of the mean daily outdoor temperatures over no fewer than 7 and no more than 30 sequential days prior to the day in question. It can also be calculated by weighting the temperatures with different coefficients, assigning increasing importance to the most recent temperatures. In case this weighting is used, there is no need to respect the upper limit for the subsequent days.

4.6 Predicting thermal comfort.

To predict thermal comfort researchers have categorised the models into analytical "static" and empirical "adaptive" models. The static models build on physics and physiology by analysing the balance between the heat produced by the body and the heat lost from it, whereas the "adaptive" models add the psychology and behavior survey of people's response to environment using statistical analysis from field surveys.

4.6.1 Thermal comfort indices - the static approach

Many indices have been proposed for the definition of thermal comfort in indoor environments; these thermal indices are readily accessible ways of presenting the relationship between thermal comfort parameters and physical parameters.

Over the last few decades, more than 80 indices have been proposed (Carlucci, 2013); Auliciems and Szokolay list 20 major examples (Nicol, 2004). MacPherson grouped the indices according to the assumption on which they are based ; some indices are based on the heat balance of the human body, others are based on physiological strain, and finally there are indices based on the measurement of physical parameters (Carlucci, 2013). Within these many indices the most common types are based on heat balance, and those commonly used for predicting thermal comfort are the PMV (Predicted Mean Vote), PPD (Predicted Percentage of Dissatisfied) and SET (Standard Effective Temperature). Brief descriptions of the two static thermal balance models (are given below:

4.6.2 Fanger's PMV index and PPD

The model, based on the Fanger thermal comfort equation was developed in the 1960's through laboratory and climate chamber studies using the seven-point ASHRAE thermal sensation scale. Fanger defines predicted mean vote (PMV) as "…the index that predicts, or represents, the mean thermal sensation vote on a standard scale for a large group of persons for any given combination of the thermal environmental variables, activity and clothing levels" (Fanger, 1973). Fanger developed a set of correlations giving the PMV as a function of six variables; four environmental parameters and two personal parameters

- Air temperature
- Mean radiant temperature
- Air velocity
- Air humidity
- Clothing resistance
- Activity level

The PMV was adopted as an international standard. ISO7730 recommends for a condition of thermal comfort both in naturally ventilated buildings and air-conditioned ones, that the PMV should be kept to 0 with a tolerance of ± 0.5 in the seven point scale of ASHRAE, and represents the average thermal sensation felt by a large group of people in a space (ASHRAE, 2001; Fanger, 1970). Recent edition of ASHREA Standard 55 used PMV as indicator of thermal comfort, rather than the SET index (Nicol et al., 2012).

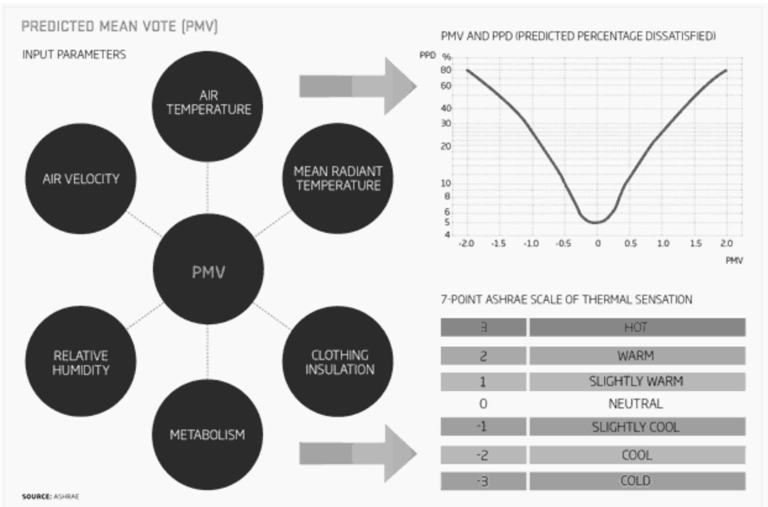


Figure (4. 3) Predicted Mean Vote

In Fanger's studies, the participants were dressed in standardised clothing and completed standardised activities, while exposed to different thermal environments. In some studies the researchers chose the thermal conditions as the independent variable, and participants recorded how hot or cold they felt as a dependent variable. While in other studies, participants controlled the thermal environment themselves, adjusting the temperature until they felt thermally comfort, which is equivalent to voting '0' on the ASHRAE, thermal sensation scale.

The PMV model is often referred to as a static model as it is based on a steady state energy balance. It cannot predict the exact response to a step change. Moreover it is a complex mathematic expression involving all environment factors in addition to the activity and clothing.

The PMV equation = $(0.33e^{-0.36M} + 0.028)$ [(M-W) - H- E_{res}- C_{res}]

Due to its complexity Fanger (1970) provided look-up tables to help practitioners determine appropriate thermal conditions. Information from these tables and graphical representations of comfort conditions is also provided in the thermal comfort standards (e.g. ASHRAE, 55 2010: ISO, 1994). Nowadays, PMV can be calculated using computer programs, and programming code is provided in ISO Standard 7730.

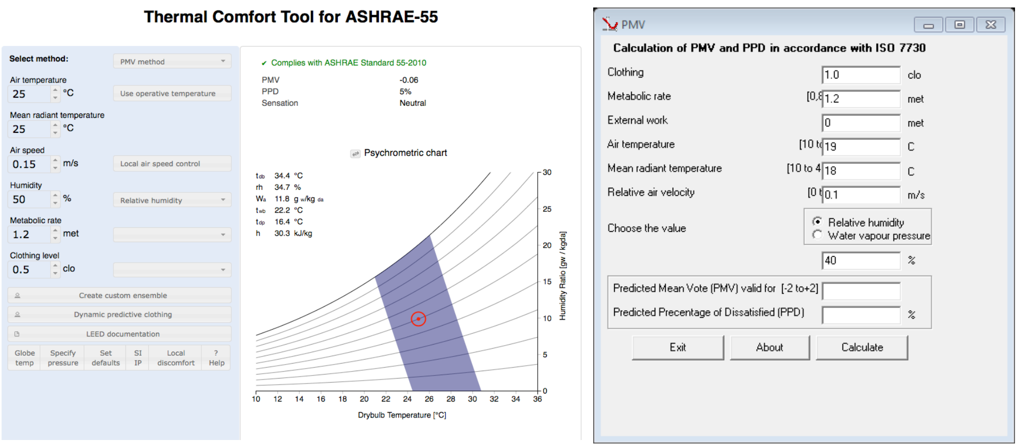


Figure (4. 4) Thermal comfort tool to calculate the PMV

According to Fanger's study of a large volume of test data, some 5% of the population would be dissatisfied even under the "best" conditions. As a departure from this, the PPD index (Predicted Percentage of Dissatisfied) has been introduced to predict how many people are dissatisfied in a given thermal environment as the percentage dissatisfied rapidly increases. The empirical curve (figure 4-4), ("PO Fanger Thermal Comfort.pdf,").

In the PPD index people who vote -3,-2, +2, + 3 on the PVM scale regarded as thermally dissatisfied, and it can be calculated using the following equation

$$\text{PPD} = 100\text{-}\ \mathbf{95}.\,e^{-(0.03353PMV4+0.2179PMV2)}$$

Through the years numerous studies on the validity of the PMV model have been conducted, leading some to criticise the model, others to confirm its validity. According to the PMV model optimal thermal sensation is neutral; however in their research Humphrey and Hancock concluded that thermo-neutrality does not necessarily correspond to the preferred thermal sensation. In many of the studies, researchers have compared the neutral thermal sensation, and associated neutral temperature, predicted by the PMV model, with that given by an actual group of participants (the actual mean vote (AMV)) voting on the ASHRAE thermal sensation scale. Humphreys (1994) noted that the PMV model was most accurate in laboratory studies that used sedentary activities and light clothing, but that the discrepancy between PMV and actual mean vote increased for heavier clothing and higher activity levels. Moreover, several field studies have suggested that occupants' sensitivity to changes in temperature differ from those predicted from PMV, de Dear et al (1993).

Generally, thermal comfort studies suggest that the PMV model does not always accurately predict the actual thermal sensation of occupants, particularly in field settings. There are two factors initiating this discrepancy: measurement errors are mostly in relation to clothing insulation (clo), and in terms of the level of activity (met), secondly contextual assumptions. (Hoof, 2010). Although measurement error certainly contributes to the PMV's inaccuracy, several researchers have shown that the discrepancy between actual and predicted thermal sensation exceeds that which could reasonably be attributed to such errors (e.g. Brager et al, 1994; Oseland, 1994; Rowe, 2001; Schiller, 1990). This suggests that other factors, principally those related to context, affect the validity of the PMV model.

The PMV model appears to be more appropriate for predicting thermal sensation in certain contexts. De Dear and Brager (2001) noted "current thermal comfort standards and the models underpinning them purport to be equally applicable across all types of building, ventilation system, occupancy pattern and climate zone". If these assumptions are incorrect, however, they could act as sources of bias for PMV predictions (Humphreys & Nicol, 2000) these assumptions are the individual differences (the PMV model is designed to predict the average thermal sensation for a large group of people. Within such a group, optimal thermal conditions are likely to vary between individuals and in terms of age and gender), building differences (PMV model predicts thermal sensation more accurately in air-conditioned buildings, as compared to naturally ventilated buildings), climatic differences, and adaptation. (Humphreys & Nicol, 2002), (Fanger & Langkilde, 1975), (Yamtraipat et al., 2005).

4.6.3 The ET* and SET index

The original ET Effective Temperature was developed by Houghten and Yagloglou at the ASHRAE. Pittsburgh research laboratories in 1923, latterly a new effective temperature (ET*) has been developed using the 'two-node model'. It is defined as "the temperature (DBT) of a uniform enclosure at 50% relative humidity, which would produce the same net heat exchange by radiation, convection and evaporation as the environment in question".

The Standard effective temperature (SET) was developed by Gagge in order to incorporate different activity levels and clothing, and as a subset of ET* under standardised conditions. The process of standardisation was continued in terms of metabolic rate and clothing, establish that an inverse change of *clo* can compensate for an increase of met.

At sea level, under the above standard environmental conditions, SET = ET*

At higher levels of ET* the difference between the two scales increases; with greater skin wettedness the influence of barometric pressure increases. In thermal equilibrium (storage component $\Delta S = 0$) between 23°C and 41°C SET is linearly related to average body temperature:

$SET = 34.95\,T_b - 1247.6$ below 23°C the relationship is: $SET = 23 - 6.13\,(36.4 - T_b)\,0.7$ and above 41°C: $SET = 41 + 5.58\,(Tb - 36.9)\,0.87$

The measurement procedure is firstly to determine DBT and MRT, then air velocity (v), evaluate the metabolic rate (M) and clothing level (clo), and then predict the average body temperature (T_b) by using the two-node model. T_b has been calculated for a wide range of metabolic rates, clothing levels, air movement rates and atmospheric pressure, as well as the air temperature, mean radiant temperature and humidity catered for by the SET. (Hegger et al., 2008)

4.6.4 The Adaptive approach

The hypothesis of adaptive thermal comfort predicts that contextual factors and past thermal history modify the occupant's thermal expectations and preferences. (ASHREA,2009). The concept of a thermal adaptive principle is founded on the basis that if discomfort occurs, people react in different ways to restore their comfort, either by changing their clothing, activity or place. These adaptive actions are physiological, behavioural and the use of personal environmental controls, (Nicol 1993),

Behavioural adaptations and adjustments involve all the conscious or unconscious modifications a person would make to adjust his or her body thermal balance. This can include adjusting clothes and activity, or technological adjustment, in addition to changing living spaces in the house. (Glaser, 1966).

Moreover, it is important to note that thermal comfort is an example of a "complex adaptive system"– a multitude of interacting nonlinear variables such as; demographics (gender, age, economic status), context (building design, building function, season, climate, semantics, social conditioning), and cognition (attitude, preference, and expectations) (McIntyre 1982, Baker 1993, Baker and Standeven 1994, Oseland 1994, Griffiths et al 1988). This leads to a continuous change in comfort temperature, and the rate at which these changes occur is an important consideration if the conditions for comfort are to be properly specified (Crichton and Nicol, 2012).

On the basis of the majority of experimental evidence published to date, the prime contextual variable is the climate, the second major context of nearly all comfort surveys has been a building including the nature of the building and its services, and the third context is time, since human activity and responses take place in a time frame, (de Dear and Brager, 1998a) (Humphreys et al., 1995). The context, culture, buildings and climate are unique to any particular place; therefore investigating the thermal comfort in our towns and regions is essential in order to underline the complexities of the comfort system we inhabit.

4.7 Field studies

Researchers acknowledge that field studies are most reliable way to observe and investigate human thermal comfort, particularly studying human responses to the thermal environment. In order to predict thermal comfort, a database was created upon which to build a robust empirical model of human thermal response, using a large number of field studies published from a wide range of climates and countries. The adaptive approach was proposed to link the field studies through an adaptive principle. Therefore the results from individual studies can build into a model through meta-analyses such as those of Humphreys (1976, 1978) and de Dear & Brager (1998). In other wards, its results may be regarded as phenomena to be explained by theoretical models of thermal comfort.

Field study methods are based on the subjects continuing their normal occupations in their normal surroundings, with free control of the environment However, the environmental conditions can be controlled and modified, especially when studying the responses of people in air- conditioned buildings.

A rating scale method is used to estimate the human thermal responses; the most common rating scales of warmth are the Bedford and ASHRAE. The scales are arranged symmetrically about the 'comfortable' or neutral 'category' as shown in the table below:

ASHRAE		Bedford	(*)
Hot	+3	Much too warm	7
Warm	+2	Too warm	6
Slightly warm	+1	Comfortably warm	5
Neutral	0	Comfortable neither warm nor cool	4
Slightly cool	-1	Comfortably cool	3
Cool	-2	Too cool	2
Cold	-3	Much too cool	1

Table (4. 5) Scale of warmth in the Bedford and ASHRAE scale.

***Numbers used in the questionnaire.**

The subjects are asked to rate their feelings on a descriptive scale; this assessment is generally known as a ‘comfort Vote’ or AMV (Actual mean vote). Then the PMV (predicted mean vote) could therefore be calculated and compared to the votes of actual occupants. In some cases excellent agreement was found, in other studies small or large deviations were observed. To make a fair comparison, it is essential that all four environmental factors are properly measured and that a careful estimation is made of the activity and clothing levels, Humphreys (1981).

In afield study, the design of the survey and its analysis is the roots of the matter. Measurement of the thermal comfort variables is essential in the field study; the simplest way is to measure the air temperature, while the complete measurement is to measure all other environment variables (MRT, air velocity, RH). In addition, recording the clothing and metabolic heat generation (activity) are important factors contributing to the human response. The complexity of the survey depends on time and budget and what you want to find out and how accurate the result needs to be, (Nicol et al., 2012)

To analyse field study data, there are many methods such as “analysis into proportions” which aims to find the proportions of the assessments that are in several response categories, over the range of environments encountered during the study. Another method is the “analysis of mean response” method, which aims to analyse data by linear regression and correlation; the method is commonly used to examine the mean response over the range of temperatures encountered The method can be extended to include more than one environmental variable by the use of multiple correlation and regressions.

In field surveys the predictor (the horizontal axis) and the meaning of thermal comfort (the vertical axis) in the graph of the adaptive chart arouses a great number of questions. As Fanger argues, “the problem with the adaptive chart is ‘the vertical axis and the horizontal axis”. In the vertical axis, the meaning of comfort temperature depends on the nature of the thermal environments; the use of the operative temperature as predictor for comfort temperature is applied in indoor environment, when the difference between the mean radiant temperature and air temperature is minor and the air movement is slight and the humidity is moderate. However, if the air movement is high and the humidity is more than 50%, adjustments to the comfort temperature for air movement and humidity are important.

Humphreys compared the effect of five various metrics of outdoor temperature on the correlation of comfort temperature, and found that the running mean with $\propto = 0.8$ is decisively superior to the historic monthly mean from meteorological tables or to a running mean with $\propto = 0.96$, as predictor of comfort temperature. (Humphreys, 2010).

4.8 Examples of previous field studies in thermal comfort

Field studies provide practical data, and can give an accurate estimate of the thermal environment liked by particular people in a particular building at a particular time. Humphreys (1981). In 1975 Humphrey examined 36 thermal comfort field studies from various global climatic regimes, analyzing data from more than 200,000 observations. It has been found that in naturally ventilated buildings, there is a remarkable relationship between preferred temperature and average monthly outdoor temperature. People seem to be reasonably thermally neutral over a large range of indoor mean temperatures. Obviously people have altered their clothing and perhaps their activity, to maintain reasonable thermal neutrality even at quite high or low temperatures.

Humphreys found two equations to predict thermal comfort, one for natural ventilated building (free running mode) and another for air-conditioned buildings (heating and cooling mode). In a free running mode building the correlation between the neutral temperature and the outdoor monthly mean temperature is linear and strong (r=0.97). The variation about the line had a standard deviation of 1.0K. In Humphreys' paper presented at Windsor 2010, he found that in a naturally ventilated building comfort temperature (T_n) can be predicted from outdoor monthly mean temperature (T_0) using the following equation:

$$\boldsymbol{T_n = 11.9 + 0.534T_0}$$

However, for the heating and cooling mode the relation was curvilinear rather than linear and less strong (r=0.72), the variation about the curve having a standard deviation of 1.5K. The comfort temperature (T_n) can be predicted from the outdoor monthly mean temperature (T_0) using the following equation;

$$T_n = 23.9 + 0.295\ (T_o - 22).\exp(-[T_o - 22)/(24\sqrt{2}]^2)$$

Humphreys also suggested in his paper, that the highest correlation between neutral temperature and climate for natural ventilated building (free mode) were found when using the daily maximum and daily minimum temperature as the predictor variables.

Subsequently, Auliciems tried to re-analyse Humphreys's data by removing some incompatible information, including the results of more recent field studies, and combining data for buildings with active and passive climate control. The absence of thermal discomfort is predicted by simple equation in terms of mean indoor (T_i) and outdoor monthly temperature (T_o): this has been taken as statistical expression of the adaptive model of human thermal perception.

$$T_c = 0.48T_i + 0.I4\ T_o + 9.22 \qquad (r = 0.97)$$

Where T_c and T_i are in ℃

The above equation can be used to calculate the neutral temperature of the subject. Auliciems also proposed a single line for all buildings, which covered the naturally ventilated buildings and air conditioned buildings (de Dear and Brager, 1998b)

$$T_c = 0.31T_o + 17.6$$

Moreover, Nicol (1973) presented data suggesting that the mean comfort vote changed less with indoor temperature from climate to climate than might be expected. However, in his survey in Pakistan Nicol established a similar a results between comfort temperature and outdoor temperature given by

$$T_c = 0.38T_o + 17.0$$

The above Thermal comfort temperature equation shows that the comfort temperature is related to the outdoor temperature and therefore the climate It indicates that the temperature considered comfortable by the subjects changes with climate and season. Moreover it means that there is no universal comfort temperature. However, work is needed to explore the application of different equations in other seasons and cities, Nicole notes that "whichever equation is used, indoor comfort is related to the temperature outdoors".

4.9 Thermal comfort study in North Africa and Middle East (NAME)

Several studies on thermal comfort have been conducted in the Arab world and North Africa to indicate the people's thermal comfort temperature in their real environment. In Tunisia Bouden and Ghrab, 2001, carried out a similar field study and found that the Tunisian population has a large potential for adaptation to climate and seasons. Also, in Algeria, as part of a study conducted by El-Khier Belayat (2005), a thermal comfort survey was administered among 160 persons in 4 towns of Algeria representing four different climatic regions. The survey was carried out in two different types of buildings: domestic buildings and office buildings. The study concluded that people have different comfort conditions depending on the climate they live in. The study also shows that occupants of naturally ventilated buildings show higher thermal comfort levels compared to what PMV has predicted. It is believed that adaptive actions such as drinking more water, changing clothes and taking a bath more frequently have contributed in some positive ways to the higher level of thermal comfort. Many field studies have been conducted in Egypt such as the "Amgad Farghal and Andreas Wagner" study, which examined the Adaptive Comfort Model a Case Study in a Hot Dry Climate, Cairo, Egypt. The study focused on naturally ventilated buildings that are the basis of the Adaptive Comfort Model. In addition to many other researchers (Amr Sayed, Y. Hiroshi, T.Goto, N. Enteria, M.M.Radwan, and M.abdelsamei.Eid 2013) are investigating the indoor and outdoor thermal comfort.

However, Libya has a limited number of researchers in this field. In 1997 M. A. Ealiwa investigated thermal comfort in the summer season of Ghadames, Libya The study included two type of buildings, vernacular buildings and contemporary buildings and examined the responses of 237 residents to the environmental conditions. Data was collected from 51 buildings comprising 24 vernacular houses with natural ventilation system and 27 with air conditioning. In addition the environmental parameters were measured in 11 buildings (5 old, 6 new). The survey has shown that measurements of predicted mean vote (PMV) in new air-conditioned buildings provide satisfactory comfort conditions according to ISO 7730 and the occupants agree by indicating a satisfactory actual mean vote (AMV). The equivalent measurements and survey results in old traditional buildings indicated that although the PMV, based on measurements and ISO 7730, implied discomfort (hot), the occupants expressed their thermal satisfaction with the indoor comfort conditions. The field study also investigated occupants' overall impression of the indoor thermal environments.

4.10 The Comparison between the Static and the Adaptive approaches

Studies found that the predicted thermal comfort using a static model such as the PMV method is different from the thermal comfort obtained by field study of the actual votes. This led researchers to examine the validity of the static approach as used in the PMV. Humphreys states that the problems with the static approach is that it can be misleading when used to predict the mean comfort votes of groups of people in everyday conditions in buildings, particularly in warm environments. Nicol noted that the errors are of two kinds: formulation errors and measurement errors. However Fanger suggests that the difference in results arise from poor data input. (Fanger, 1970) Studies prove that different people in different part of the world will experience comfort at different temperature as a result of the effect of other factors on the thermal comfort condition, such as human behavior, expectation and adaptation. Oseland argues that the differences could be due to a genuine context effect because of differences in measurement or statistical technique (Oseland, 1994).

In the field study the lack of control over the participants and their environment results in more accurate data for predicting comfort temperature: the respondents being asked in their normal environment to continue their normal activity in their normal clothing. In contrast, in studies that use climate chambers, participants are asked survey questions in a room which they are unfamiliar with and usually lack any ability to control the environmental conditions. Therefore comfort temperature predicted by using PMV is found to be more accurate in air-conditioned building than in naturallyventilated buildings.

The measurements of clothing insulation and metabolic rate are difficult to assess accurately and these affect the result from the PMV. In addition some environmental parameters can be hard to measure, such as the air speed that varies through different time and different places. To arrive at a decision, it seems some points from both methods should be considered; as pointed out by Humphreys "it is interesting to compare results from both approaches".

4.11 Conclusion

This chapter has reviewed the theory of thermal comfort, proving that thermal sensation is one of humanity's major preoccupations and requirement for shelter. Studying thermal comfort requires an understanding of different factors such as the physiological, psychological and physical factors and their impact on predicting the thermal comfort temperature, n addition to an understanding the indexes and standards that have been developed to predict thermal comfort. The literature also comprises the two thermal comfort schools of thought, the classic theory of heat transfer between human body and its surroundings, and adaptive approach (field studies), were broadly reviewed and compared.

During the last decades very little thermal comfort research has been conducted in Libya (Akair and Bánhidi, 2007; Alzubaidi,, 2002; Ealiwa et al., 2001). Number of respondents in most of the thermal comfort investigation in Libya did not give a good estimation for the population responses. Therefore more studies on the field are required. Thermal comfort standards are not defined in Libyan Code, therefore more thermal comfort field survey will enrich the field of thermal comfort in Libya and north Africa and help to establish guidelines and legislation for the indoor environment. In addition to establishing an indoor temperature standard that would encourage the use of naturally ventilated building and reduce the energy consumption in air- conditioned building

This study will apply both methods of 'static' and 'adaptive' to predict comfort temperature. Both methods have proven to be accurate in special conditions. Finding the right thermal comfort temperature for population requires field survey, as Humphreys points out "if we want to know how people feel in a particular situation there is no better way to find out than to go and ask them". Therefore conducting a field survey is a vital approach to predict thermal comfort condition. Knowledge of how to conduct, analyse, interpret and report on field survey is considered essential.

5 Chapter five: Thermal Comfort in Libya

5.1 Thermal comfort in Libya

Buildings in Libya are responsible for more than 40% of the overall energy budget, according to the Libyan General Electric Company "GECOL". This is due to the use of more mechanical systems such as air conditioning, which makes the comfort aim increasingly costly in terms of energy use in buildings (GECOL).

This statistc indicates that setting a thermal comfort temperature is the key issue to decreasing the energy usage in the houses and therefore the emission of CO_2. This chapter reviews the thermal comfort studies that have been conducted in the three cities Tripoli, Ghadames and Gheryan. The chapter also presents the researcher study on thermal insulation values for traditional Libyan clothing. In addition, it aims to describe a new thermal comfort field survey conducted in the study. The results obtained from the survey are analysed and the findings are compared with other studies, in order to set a thermal comfort temperature and its equation.

5.2 Libyan thermal comfort field studies

During the last years a few number of thermal comfort studies were conducted in Libya. In 1997 M. A. Ealiwa and A. H. Taki investigated thermal comfort in the summer season of Ghadames, Libya, (Ealiwa et al. 2001). Questionnaires were collected from the residents of 51 buildings: 24 traditional vernacular houses that employ natural ventilation systems with courtyards and 27 new (contemporary) houses with natural ventilation systems. In addition the environmental parameters were measured in 11 buildings (5 old, 6 new) representing 50 subjects, to calculate the predicted mean vote value of the subject using Fangers model as presented in the ISO 7730 standard 1995.

The results from this study suggest that, to assess thermal comfort in such environments, the adaptive model is valid for predicting the thermal comfort, while ISO 7730 is less successful, without modification. The temperature that the subjects found comfortable was different from the one that was predicted by ISO7730 especially when it concerns naturally ventilated buildings.

The second study was conducted by Akair, this field study includes only two climatic regions in Libya, the study includes only free running buildings, where 200 persons have been asked to complete questionnaires in their houses and working places, once each month during one year. The study found that the Libyan population uses lighter clothes than the western standard, and has a higher physiological potential of adaptation to changes. It's also shows, a good agreement with Humphreys findings for air-conditioned buildings.

The results that were obtained from the past surveys laid the foundation for future work, as they cannot be considered sufficient in themselves for the setting of Temperature Standards. Therefore more studies are needed to establish a Libyan Temperature Standards, which include all Libyan climatic zones. (Akair and Bánhidi 2007)

5.3 Investigating thermal comfort in Libya

This chapter describes the investigation in to thermal comfort and indicates thermal comfort temperature for Libya. In order to achieve this aim two fields studies were conducted by the researcher. Firstly, an experimental test using a thermal manikin to evaluate the thermal insulation of Libyan traditional clothing was carried out in collaboration with the Environmental Ergonomics Research Center - Loughborough Design School. Secondly a thermal comfort field survey was conducted in the three Libyan cities of Tripoli, Ghadames and Gheryan.

5.4 Evaluating the thermal insolation of Libyan traditional clothing.

Clothing is one of the main parameters that effect the people's thermal sensation; therefore evaluating the clothing thermal insulation of subject is important. In order to estimate the clothing insulation for the western clothing the study uses ASHRAE tables, (ASHRAE, 1992; ISO, 1994, 1995). These have been developed from clothing insulation studies conducted in laboratory studies, mainly for western clothing. However, the data from the field survey conducted in Tripoli, Ghadames and Gheryan shows that a number of subjects included in the survey were wearing traditional Libyan clothing, therefore finding the thermal insulation value for the traditional Libyan clothing is important to study the thermal sensation and comfort temperature in Libya.

Recently, ASHRAE extended the western clothing table to include non-western clothing, in the 1504-TRP, "Extension of the Clothing Insulation Database for Standard 55 and

ISO 7730." The data also includes the effect of posture on air movement. Nevertheless Libyan traditional clothing is not included in the tables. This led the researcher to conduct an experiment to evaluate the thermal insulation properties of traditional Libyan clothing in the climate chamber in the Environmental Ergonomics Research Centre (University of Loughborough), the result will be added to ASHRAE as part of ASHRAE clothing insulation values of non-western clothing.

5.4.1 The description of Libyan traditional clothing

Traditional Libyan clothes are unique in their components and ensemble, as they are products of the Mediterranean civilizations influence on the Libyan tradition.

5.4.2 Male traditional clothing

The Libyan traditional Male clothes changes according to seasons (figure 5-1). It consists of two parts the internal and external clothing, the internal clothing include the Serwal, a loose light trousers made of cotton, Suriya is a short loosely fitting gown that covers the body to the knees, and Farmela, a cotton vest is worn in summer; however in winter a long sleeve Farmela replaces the vest or worn over the vest.

Figure (5. 1) Libyan traditional clothing for male

The external clothing part (Al Ja'red) a garment that is similar to the Ancient Roman (toga). A white cloth of 4-meter long and 1meter width is wrapped around the body in special way. It is worn over the internal clothing. The weight of the Ja'red changes according to the season. In winter it is made of heavy wool and it made of light wool in summer, although wearing Al Ja'red in summer is not common anymore.

The male clothing ensemble changes according to seasons. In summer, a man usually wears the Serwal and Suriya only without the vest inside the house. However wearing Al Jared in winter is most common in older generation.

5.4.3 Female traditional clothing

The female traditional clothing consists of two part the internal clothing and external clothing. The internal clothing includes; Serwal, a light loose trousers made of cotton, Eqmeja a short loosely fitting long sleeve dress, usually made of light material in summer and heavy material in winter. Al Re'da is the external part worn by female in everyday. It is a coloured cloth of 4-meter long and 1 meter width, usually made of cotton and sometimes wool and silk, but cotton is the most common material for everyday wear. It is wrapped around the body over the dress and trousers. The material of the Re'da changes according to seasons, in summer, they are made of cotton material while in winter they are made of wool (figure 5-2). Wearing headscarf is part of the Libyan female traditional clothing; usually it is made of the same material of the Re'da. These days female wear Re'da over their western clothing mainly over a dress. However culturally, the eternal part of the clothing cannot be worn by it self the Re'da have to worn all the time.

Figure (5. 2) Libyan traditional clothing for female

5.4.4 The specifications of the thermal manikin and Climatic Chambers

Thermal insulation is the clothing resistance to the sensible heat transfer between the human body and the environment by convection, radiation and conduction, therefore to measure the clothing thermal insulation a thermal manikin is a valuable tool. The manikin is used due to their unique advantage, namely the simplicity and repeatability of the experimental procedures and the precision of the results. (K. Soltynski, M Konarska 2000).

Since 1941 Manikins have been developed as more sophisticated models were manufactured. For this study Newton thermal manikins are used to evaluate the thermal insulation of the traditional Libyan clothing. The Newton is based on an advanced CAD digital modeling, and built in accordance with ASTM and ISO standards. It is made of thermally conductive copper filled carbon-epoxy shell with embedded heating wire elements (max output 800 W/m2) and distributed wire sensors in 34 microprocessor controlled heating zones, the temperature of each zone is controlled independently. Moreover the way the model is jointed allows any possible body pose, with flexible motion at the joints: shoulders, elbow, hips, knees and ankles. (Holmér 2004)

The measurements were carried out in climatic chamber to control the environment. The clothing test room has temperature and humidity co§ntrol in the range of +10ºC to +30ºC, 30 % RH to 70% RH, and air speed controllable 0.1 to 0.5 m/s.

5.4.5 Experiment and method

The physical parameters of the environment in the test chamber were measured under ISO 7726 requirements. With air speed less than 0.15 m/s, air temperature and mean radiant temperature 21℃, relative humidity of 40% and mean skin temperature of the manikin 34℃.

The method to measure clothing thermal insulation value includes, first heating the nude manikin to thermal equilibrium, then add clothing and measured the total heat loss from the manikin at known and fixed skin temperature and environmental condition.

The most referred methods for the calculation of clothing insulation are the serial and parallel methods; these methods make of use the skin temperature and the heat flux from each segment to calculate the local resistances, which are then summed according to parallel mode. (A. V. M. Oliveira, 2008). The Parallel method for thermal insulation is as follows: $\frac{1}{I_T} = \sum f_i \times \left(\frac{Q_{s,i}}{\bar{T}_{sk,i} - T_o}\right) = \sum f_i \times \frac{1}{I_{T,i}}$

Where $I_T = \frac{\bar{T}_{sk} - T_o}{\overline{Q_s}}$, where the$\bar{T}_{sk}$ °C and $\overline{Q_s}\left[{}^{W}/_{m^2}\right]$ are the main skin temperature and sensible heat flux of the manikin obtained by area weighting and $T_o$is the operative temperature°C, and f_i represents the relationship between the surface area of segment *(i) of the manikin,* A_i, and the total surface area of the manikin

$$A\left(f = {}^{A_i}/_{A}\right).$$

5.4.6 Evaluating the thermal insulation of the Traditional Libyan clothing

The Libyan traditional clothing for women and men were tested using the most common ensemble, and the everyday clothing.

Figure (5. 3) the traditional Libyan cloth for female and male worn on the thermal manikin Newton

The test of the thermal insulation for winter and summer traditional Libyan clothing for male and female are listed in the following table.

Female-summer clothing	Clo	$m^2.°C/W$	Male summer clothing	CLO	$m^2.°C/W$
Long sleeve light shirt-Eqmeja	0.22	0.0341	Shirt (Suriya)	0.22	0.034
Trousers (Serwal)	0.26	0.04	Trousers (Serwal)	0.26	0.040
External material (Ra' da)	0.69	0.107	Vest (Farmela)	0.15	0.023
Total for summer	1.176	0.182	Total for Summer	0.63	0.098
Head scarf	0.062	0.01	Hat (Al Shana)- wool hat	0.17	0.026

Table (5. 1) the thermal insulation value for the female and male traditional Libyan clothing in summer

In winter season the traditional Libyan clothes for women are usually heavier than summer as they wear a heavy Cardigan. On the other hand the men traditional clothing for winter are even heavier as they wear (Al Jared), wrapping it around the body over the internal clothing (long sleeve shirt and trousers and heavy vest or jacket) as illustrated in figure (5-2).

Female – winter clothing	Clo	$m^2.^oC/W$	Male – winter clothing	CLO	$m^2.^oC/W$
Long-sleeve shirt (Eqmeja)	0.29	0.045	Shirt (Suriya)	0.22	0.034
Heavy long-sleeve sweater	0.37	0.058	Trousers (Serwal)	0.26	0.04
Trousers (Serwal)	0.26	0.045	Heavy jacket– (Farmela)	0.49	0.076
External material (Ra' da)	0.69	0.107	External material (Al-Jared)	0.98	0.155
Total for winter	1.61	0.25	Total for winter	1.95	0.35
Head scarf	0.062	0.01	Hat (Al Shana)- wool hat	0.17	0.026

Table (5. 2) thermal insulation value for female and male traditional Libyan clothing in winter

The above tables shows that the thermal insulation for the women traditional Libyan clothing are heavier then men in summer and lighter in winter. This can be related to cultural factor, as wearing Re'da is obligatory for women in many families especially in extended families houses and in most of the older generation. Men's clothing varies from light clothing with low insulation value 0.63 clo to higher thermal insulation value in winter with 1.952 clo by wearing a heavy jacket, 0.49clo, and Al Jared with 0.982 clo.

Data obtained from the manikin experiment were used in the study to calculate thermal comfort temperature in Tripoli, Gheryan and Ghadames, Although in Ghadames the traditional clothing for men may differ than, women clothing are mainly the same.

5.5 Field study survey

The environment and thermal comfort field survey was carried out in 39 domestic building across the three cities from three climatic zones in Libya, the survey aimed to investigate thermal comfort level in Libya, nearly 160 persons were included in this survey. They have been interviewed in their houses under their normal living conditions during the hottest (Summer), the coldest (Winter) and the moderate (Spring) periods of the year.

The survey include both subjective (collecting data from the subjects), and objective (measuring the environment variables).

5.5.1 The Questionnaire

The subjects were asked to complete a questionnaire, which was divided into two parts Personal questions (Gender, and Age) and thermal comfort questions; which referred to their thermal sensation, the air movement, humidity and their preferences. In addition they have been asked about their clothing and activities during the last hour. (See appendix B)

The subject marks their answer in a seven steps scale according to ASHRAE scale, and the environmental variables air temperature and RH, air flow and Air quality were measured.

5.5.2 The Instruments

In this study two types of instruments are used; long term temperature reading were installed in only two houses in each climatic zone, for 10 days during summer, spring and winter season, using the iButton (described in chapter 6). In addition to on spot readings to measure air temperature, RH, air flow and CO2 leves, by using the following instruments; testo 625,testo 425,testo 535.

testo 625, Wet and dry bulb temperature meter

testo 425, Air movement (anemometer

testo 535, Carbon dioxide meter.

Figure (5. 4) Instruments

5.5.3 Survey Data

From the three cities nearly 160 individuals have been interviewed in their own houses, 16 houses in Tripoli, 12 houses in Ghadames and 11 houses in Gheryan, during the hot period of the year. The buildings were selected from natural ventilated buildings with variation from vernacular traditional houses to new houses in the three climatic zones. However, In Ghadames and Gheryan most of the data was conducted from new houses, since most of the traditional vernacular houses were deserted.

Data collected from the survey can be divided into two parts, personal data and environmental data. The personal data include the age, gender, clothing and activity, and the environmental data include the objects responses to - air temperature, relative humidity and air movement.

5.5.3.1 Personal data

The personal data includes age, gender, clothing, and activity.

5.5.3.1.1 Age and gender:

The subjects concerned in the survey were from both genders with age ranging from 18 to over 80 years old. The study covered three seasons summer 2010 and winter 2010 and spring 2012. The distribution of votes by age and gender is shown in figure (5- 5) Most of the subject age was between 20 years to 40 years with average of 45% of the subjects. Next people aged from 40 years to 60 years with average of 39%, and 10% are over 60 years old 6% are between 10 to 20 years.

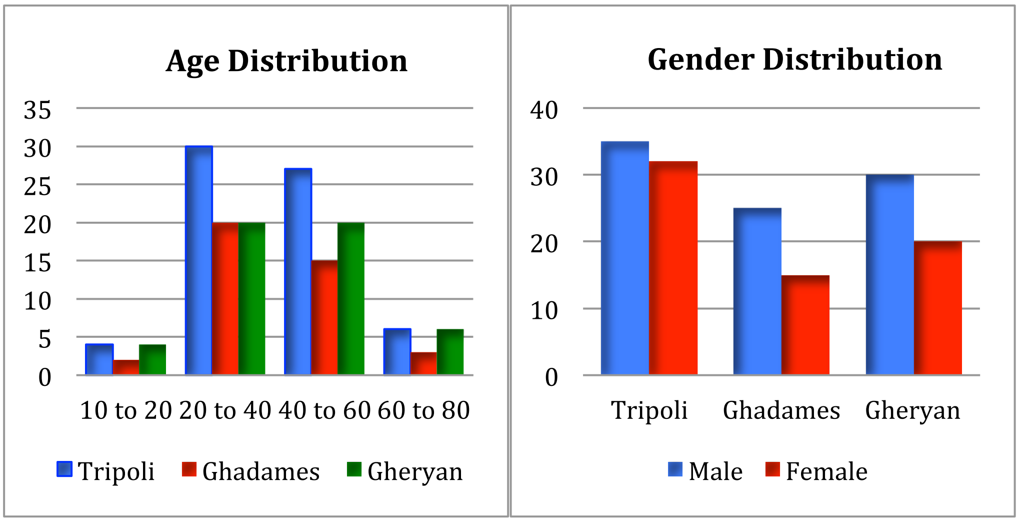


Figure (5. 5) Age and gender distribution.

According to the chart illustrated in Figure (5.5), the gender distribution was 43% percentage of the votes for female and 57% male.

5.5.3.1.2 Clothing Insulation:

The variation of clothing is subject of climate and culture, in terms of climatic aspect; from the survey the subject were recorded to wear less than 0.5clo if the operative temperature is higher than 25°C and they wear heavier cloths when temperature is low. The clothing as an indicator of behavioural adaptation to the climate is illustrated in figure (5.6).

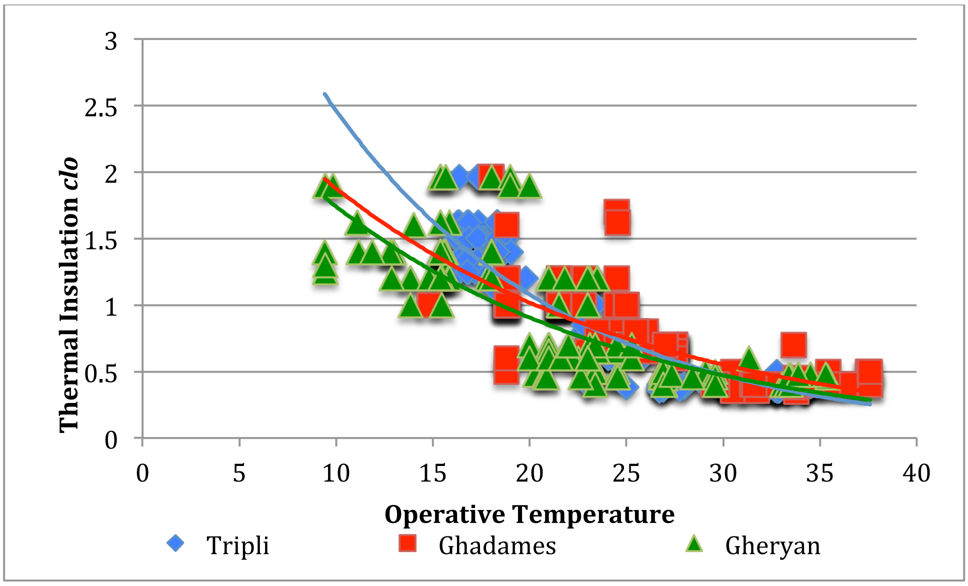


Figure (5. 6) the average clothing insulation worn in the three cities

In Libya the cultural factor had great influences on clothing type, the clothing preferences of the Libyan people have been categorise into two categories western clothing and traditional clothing. Furthermore, women's clothing differs according to the family social structure, women in a single-family house wear less than women in a multifamily house. This is related to the cultural factor, as most of the Libyan families are very conservative, and as an Islamic society, women tend to wear Islamic clothing in the presence of their extended families such as Brothers in law.

5.5.3.1.3 Activity (Metabolic Rate)

The subjects were asked about their activity over the last two hours before the interview, and this information is used to develop a met estimate for each participant. Using the Metabolic Rate table, ANSI/ASHRAE Standard 55-1992R (Activity levels – Metabolic Rates for Typical Tasks).

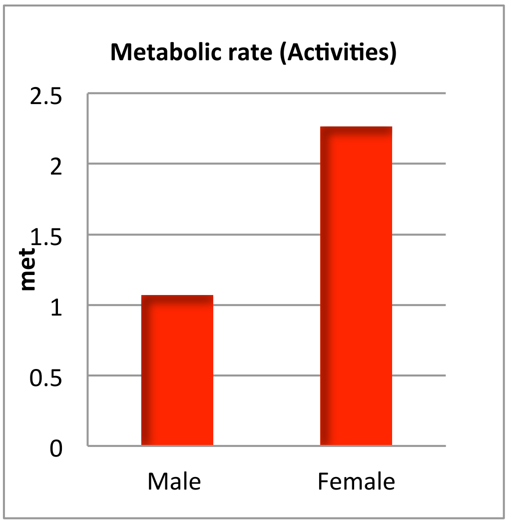


Figure (5. 7) The average metabolic rate for male and female

According to ANSI/ASHRAE Standard 55-1992R (Activity levels – Metabolic Rates for Typical Tasks) most of the activities are ranged between standing or sedentary work with 1.2 met (70W/m^2), to medium light work with 2 met (116 W/m^2). This shows that women tend to record more activity than men; this is mainly as a cultural factor in the country where only women are responsible for housework.

However, the standard table has been calculated based on the western life style, there is many factors determined the metabolic rate such as the meaning of the activity description can be vary according to culture, using 2.0 met as an estimate for housekeeping in the ANSI/ASHRAE Standard 55-1992R cannot be applied on the Libyan women were housecleaning includes heavy work such as cleaning carpet or courtyards.

5.5.3.2 Environmental variables data

The environmental variables (Air temperature, MRT mean Radiant temperature, RH Relative Humidity, Air velocity and Air Quality), the measurements were taken during the interview.

5.5.3.2.1 Indoor air temperature

Indoor temperature differs according to outdoor temperature, type of building and the location. The following table shows the mean indoor temperature recorded in the survey.

Tripoli's summer indoor temperature fluctuates from 27°C to 36°C and in winter it ranges from 16 °Cto 20°C. During the moderate season indoor temperature usually recorded a value nearly equal to the outdoor which around 24 °C.

Ghadames summer indoor temperature varies from 32°C- 38°C and in winter it ranges from 17°C to 24°C. In spring it is average to 25°C.

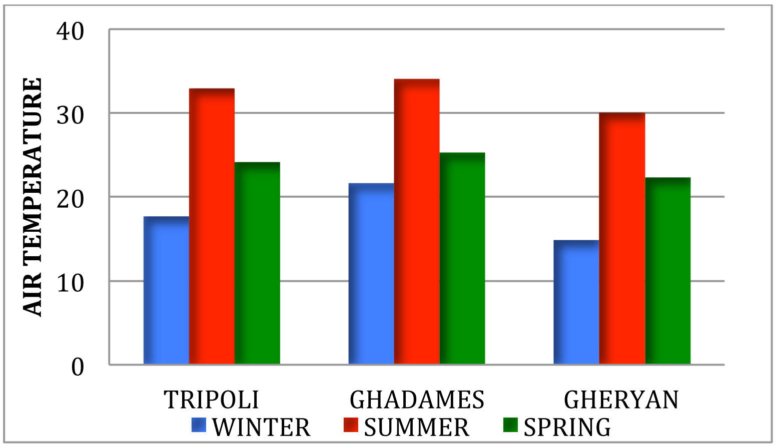


Figure (5. 8) mean indoor temperature in the three cities

In Gheryan summer indoor temperature varies from 19 °C- 35°C, in winter the indoor temperature ranges from 10 °Cto 18°C, finally indoor temperature in spring recorded an average of 22°C

The variation in indoor temperature related to the building construction, and the different between indoor temperature and outdoor temperature. As recorded by the survey in summer the indoor temperature in the traditional vernacular houses (earth sheltered) is as low as 19°C as illustrated in chapter 4, while it recorded as high as 35°C in some contemporary houses of the same area.

5.5.3.2.2 Relative humidity RH

Relative humidity varies according to the season, type of building and location. The chart figure (5.9) shows the mean relative humidity recorded in the houses in the three cities.

Tripoli as a coastal city has a high external RH averaging 60% to 70%, and can rise up to 80% in extreme conditions. In winter the humidity is relatively low, ranging 43% to 55%, and can drop down to 40%, however the indoor RH recorded in the houses ranges from 55% in the contemporary houses up to 66% in the vernacular houses. While in Ghadames and Gheryan RH is relatively lower than Tripoli, in Ghadames it ranges between 30% to 35% in winter and 10% to 15% in summer. In Gheryan it is between 55% to 60% in winter and 25% to 30% in summer.

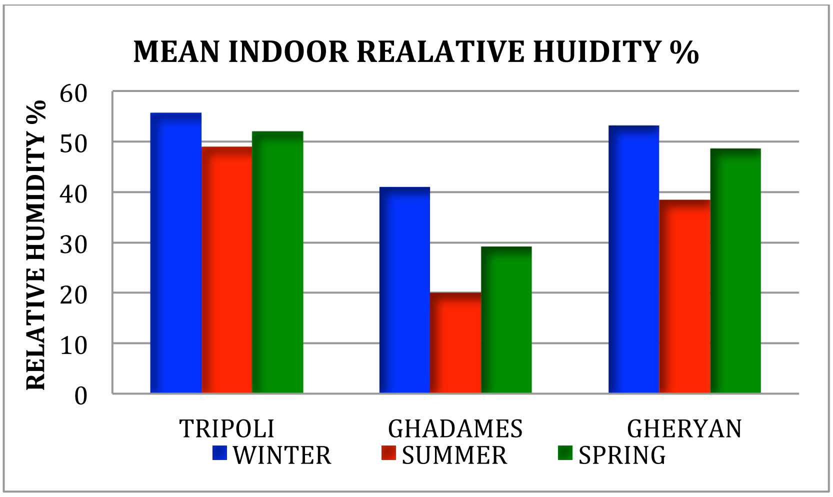


Figure (5. 9) mean relative humidity in the houses at the time of the survey

5.5.3.2.3 Air movement

It is known that within buildings the air speed is generally less than 0.2m/s, which is almost unnoticeable this is true within a close layout building; however it differs according to the type of building. During the summer survey in Tripoli, air velocity recorded with a speed range from 0.1 m/s to 0.2 m/s, and from 0.2m/s to 0.3 m/s in winter. While in Ghadames the air velocity within the house depends on the wind and stack effect, the air velocity ranges between 0.2 and 0.4 m/s.

5.5.3.2.4 Mean Radiant temperature

To measure mean radiant temperature required costly equipment and requires complex analysis. However in most previous studies the mean radiant temperature was estimated from the mean globe temperature, air temperature and air speed. In this survey the globe temperature was measured using a 40mm black painted (Ping-Pong) ball on the *testo 625* a compact instrument, then estimating the MRT using the following formula, $T_r = \frac{T_g - \Theta T_a}{(1-\Theta)}$, where Θ found from a monogram provided by ISO 7726, figure (5.10)

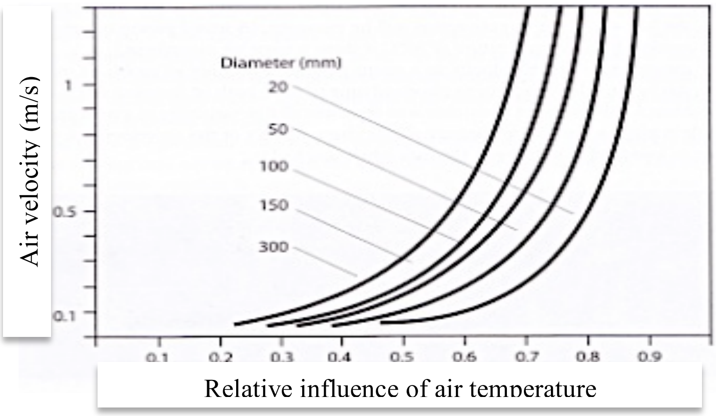


Figure (5. 10) relative influence of air temperature and mean radiant temperature on the globe temperature for difference air velocity and globe diameters. source BS ISO 7726

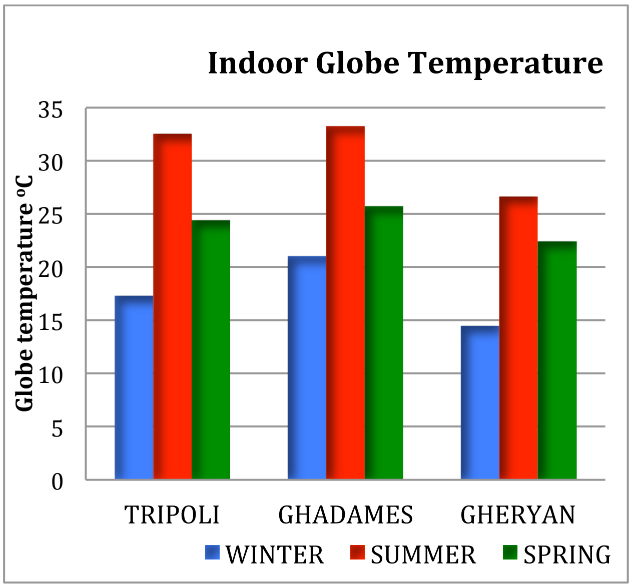


Figure (5. 11) Indoor Globe temperature in the three cities

The average reading of the T_g varies according to type of building and the location. Tripoli's summer T_g fluctuates from 28°C- 35°C and in winter it ranges from 16°C to 18°C and from 23°C to 25°C in spring. Ghadames summer T_g varies from 29°C- 37°C, in winter it ranges from 18.5°C to 24.5°C. In Gheryan summer T_g varies from 18°C- 34°C and in winter it ranges from 9°C to 18°C.

The MRT was calculated using the above equation, with in door air velocity ranges between o.1 m/s and 0.4 m/s and 40mm sphere the result is illustrated in figure (5.12).

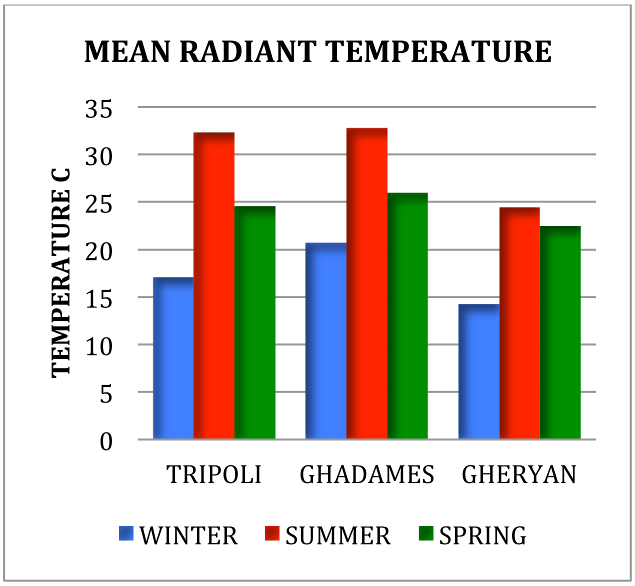


Figure (5. 12) Indoor MRT in houses in the three cities

5.5.3.2.5 Indoor air temperature and indoor operative temperature

The operative temperature is subject of air temperature, globe temperature and air velocity. As noted in the BS EN 7730 that if air velocity is less than 0.2m/s and the difference between the air temperature and the mean radiant temperature is less than 4K, the operative temperature can be calculated as the mean value between air temperatures and mean radiant temperature.

$$T_{OP} = \frac{T_i + T_r}{2}$$

Therefore, a comparison has been done between the indoor air temperature and the mean radiant temperature found in the field survey, and the result was illustrated in figure (5.13). From the chart it is clear that the differences between the air temperature and the mean radiant temperature is less than 4K, therefore the above equation can be applied to calculate the operative temperature.

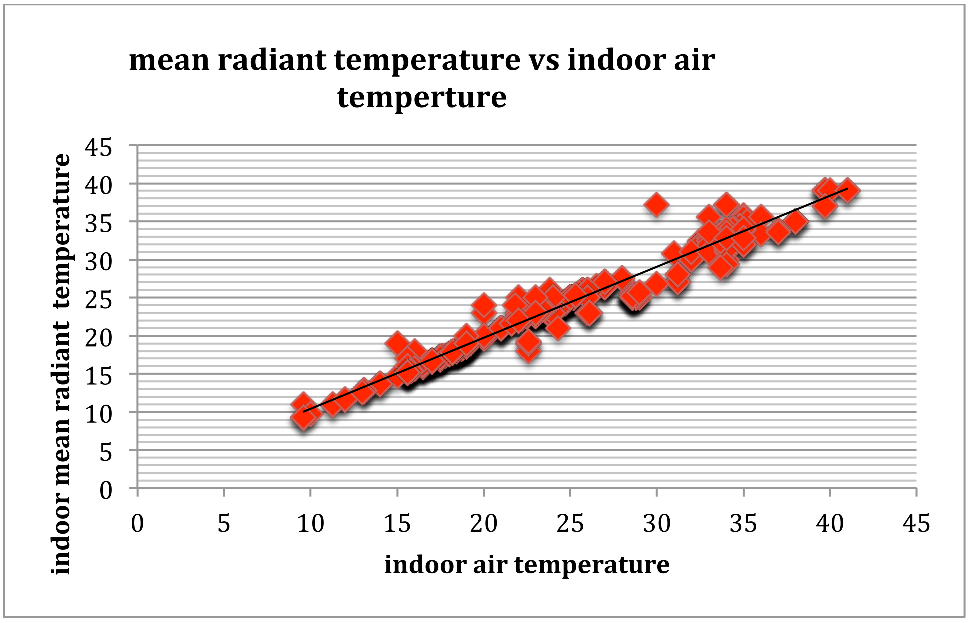


Figure (5. 13) Mean Radiant temperature VS air temperature in the three cities

5.5.4 Data Analysis

Organising a comfort survey is costly in both time and effort, using a scatter- gun approach to the analysis can increase the like hood of a spurious or trivial result (Fergus Nicol, Humphreys, and Roaf 2012). The result obtained from the survey, are used to indicate the comfort temperature for Tripoli, Ghadames and Gheryan.

First the Actual Mean Vote AMV was compared to the Predicted Mean Vote, in order to test the accuracy of the method when applied to the Libyan conditions.

Then Linear regression analysis using the least square method have calculated between the thermal sensation as depended variable and the indoor operative temperature, from the results the thermal comfort temperature was calculated using Griffiths method.

Finally, the linear regression analysis was used to predict the thermal comfort temperature using mean outdoor temperature as independent variable (predictor to comfort temperature). Then by using the running mean outdoor temperature as predictor.

5.5.4.1 Actual Mean Vote (AMV) and Predicted mean vote (PMV)

The ASHRAE 7 Point scale was used for thermal sensation and a subjective measurement were made. Subjects in three cities were asked to record their thermal sensation using the ASHRAE 7 Point scale. The mean votes for the three cities were plotted on a chart to compare the AMV in the three cities. From the chart illustrated in figure (6.14), it is clear that the Actual Mean Vote (AMV) is higher in summer in Tripoli the mean vote is 5 and Ghadames 4.2 in Gheryan the vote is 4.6. Moreover the AMV Actual Mean Vote is low in winter in the three cities 2.5, 3.3, 2.3 respectively in Tripoli, Ghadames and Gheryan. However, subjects voted in average 4 in the three cities during spring season.

The actual mean vote recorded by the object was compared with the predicted mean vote in order to examine and test its accuracy when applied to the Libyan conditions. Predicted Mean Vote was calculated using Excel spread sheet that calculate the PMV value (Predicted Mean Vote) based on the input of the physical parameters using the comfort equation.

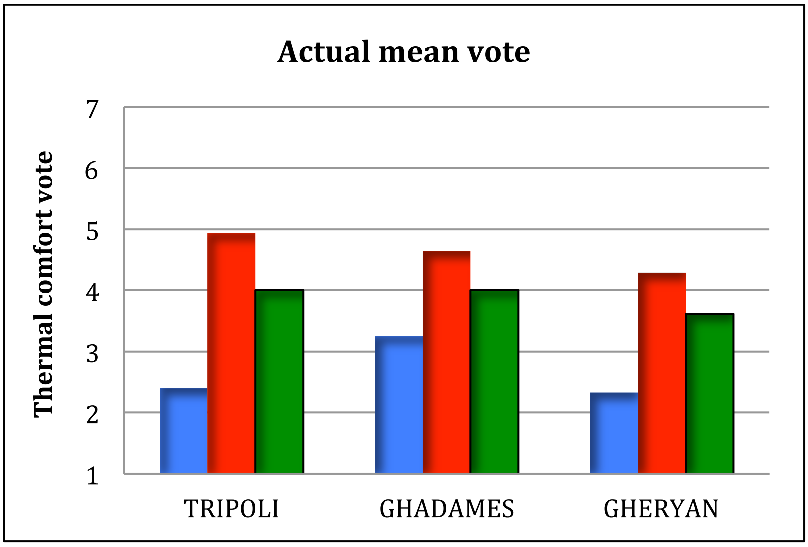


Figure (5. 14) summer, winter and spring Actual Mean Vote of the subjects in the three cities

According to the chart the PMV differ according to the location and season. In Tripoli the PMV varied from 4.1 in the winter to 6 in summer. In Ghadames the PMV is higher in summer with 7 and 4 in the winter. While in Gheryan the PMV is lower in winter 4 and 5.4 in summer. However in the moderate season the PMV in the three cities averages to nearly 4.

The predicted mean vote was compared to the actual mean vote as described by the subjects, the comparison shows that the PMV in the three cities is higher than the AMV, according to the chart illustrated in figure (5-15) the analysis shows that PMV overestimated the mean thermal sensation by approximately 1.7, 2.4, and 1.16 of scale unit respectively in Tripoli, Ghadames and Gheryan in summer, and in winter, it overestimated by 2, 1.8 and 2.2 of scale unit. This concludes that PMV values from ISO7730 still show disagreement with AMV values reported by the subject in this study. Furthermore, the results emphasis the hitherto thermal comfort studies in the region which indicates that Fanger's model is invalid for predicting the thermal comfort in such environments; it is possible that this can be related to the adaptation effect. As described in chapter five the validity of the ISO 7730 can be considered in terms of to whom it applies and over what range of environmental conditions (Olesen and Parsons 2002). The standard notes that deviations in the PMV /PPD index may occur due to age, ethnic, national-geographic deviations and for people who are sick or disabled.

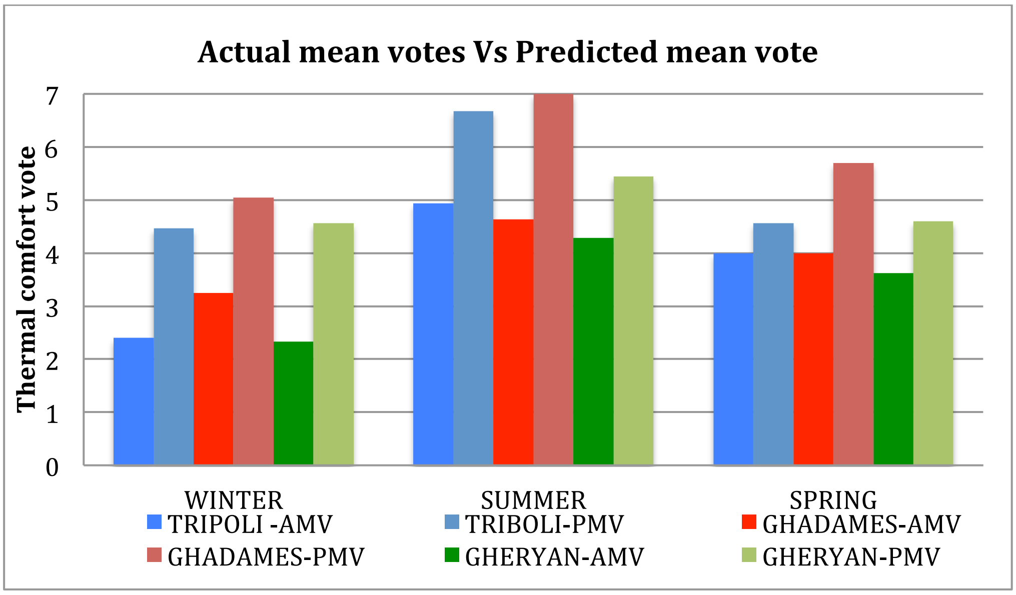


Figure (5. 15) comparison between PMV and the AMV

5.5.4.2 Neutral temperature based on Actual mean vote

The response of the subjects to the thermal environment (Actual Mean Vote) is plotted against the indoor operative temperature. The linear regression of the relation between the thermal sensation and the operative temperature in the three cities in summer, winter and spring shows that the respondents were thermally comfortable in a wide range of indoor operative temperature. As illustrated previously the air movement below 0.5m/s and with average relative humidity 50%, the operative temperature is sufficient thermal index to define the neutral temperature.

The relationship between the AMV and the operative indoor temperature for the three cities are shown in Figures (5-15).

According to Tripoli chart, in summer the subjects voted neutral when the temperature ranged between 26°C to 34 °C with over all average of 28°C for all votes. In the cold season the subjects voted neutral in a lower temperature ranged between 17°C to18 °C with average of 22°C.

Ghadames chart shows higher votes in the three seasons than Tripoli, in summer the subjects voted neutral when the temperature ranged between 29.5°C to35.5 °C with over all average of 30.8°C for all votes. In the cold season the subjects voted neutral in a lower temperature ranged between 18°C to23 °C with average of 25.5°C.

Gheryan recorded the lowest comfort temperature, the actual mean vote was plotted against the operative temperature, According to Gheryan chart, in summer the subjects voted neutral when the temperature ranged from 21.5°C to 35°C with over all average of 26°C for all votes. In the cold season the subjects voted neutral in a lower temperature ranged from 15°C to 21 °C with average vote of 21°C.

However, during the moderate season the three cities voted neutral when the temperature 24°C, 26°C, and 23.5°C in Tripoli, Ghadames and Gheryan. The variation in temperature can be related to the city location, topography and environmental variables. The following table illustrates the neutral temperature for the three cities during the three seasons according to the linear regression analysis.

	Winter	Summer	Spring
Tripoli	22	28	24
Ghadames	25.49	30.88	26.28
Gheryan	20.5	26.25	23.55

Table (5. 3) the neutral temperature for the three cities

The three seasons of the three cities were plotted in the chart illustrated in figure (5-15) in order to calculate the comfort temperature.

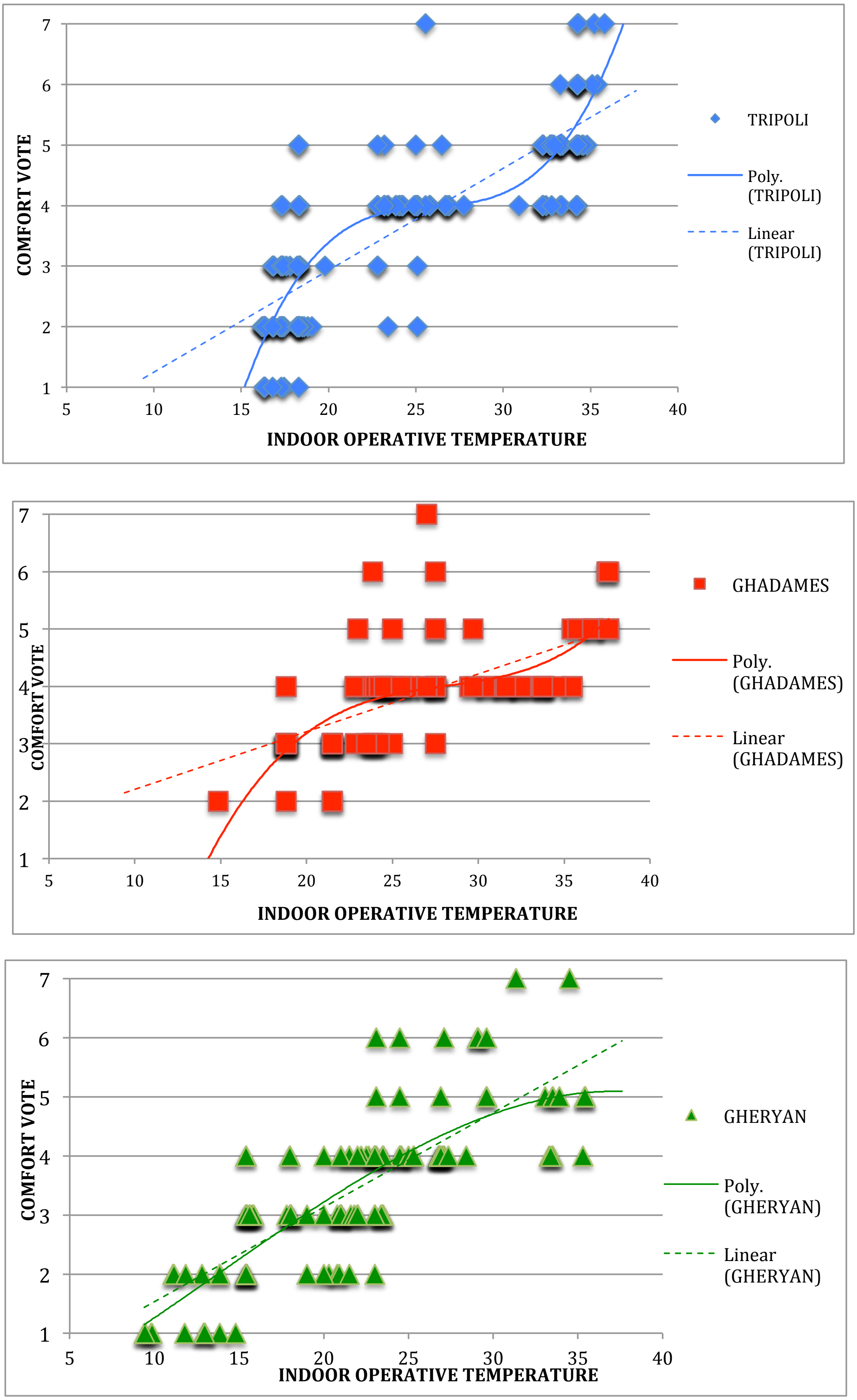


Figure (5. 16) Poly. and Linear regressions of AMV on indoor air Temperature for objects in the three cities during the three seasons.

According to the polynomial trend line illustrated in the graphs figure (6.15), in the three cities people voted comfort in wide range of operative temperature; in the city of Tripoli the people voted comfort in operative temperature ranges from 20°C to 32°C, and in Ghadames they vote comfort in operative temperature ranges from 20°C to 35°C, while in Gheryan people vote comfort when the operative temperature in between 20°C and 30°C. This shows that in Libya people tend to adapt to wide range of temperature.

Moreover a linear regression analysis shows that the desert (Ghadames) is higher than the coastal zone (Tripoli) and the mountain zone (Gheryan), indicate that people in Ghadames tolerate higher temperature than Tripoli and Gheryan.

The neutral temperature can be found from the linear regression equations illustrated in Figure (5.15). Table (5-4) Shows the results of linear regression in the form: $\mathbf{C = aT_i + b}$

Location	Number of votes	Values for *a*	Values for *b*	Correlation coefficient r^2
Tripoli	201	0.1684	-0.4368	0.69
Ghadames	120	0.1005	1.2014	0.4
Gheryan	150	0.1599	-0.0664	0.63

Table (5. 4) thermal comfort vote and the linear regression results

Tripoli $C = 0.1684\, T_i - 0.4368$ (r^2= 0.69) (5-1)

Ghadames $C = 0.1005\, T_i + 1.2014$ *(r^2= 0. 4)* *(5-2)*

Gheryan $C = 0.1599 T_i - 0.0664$ (r^2= 0.63) (5-3)

In other word to calculate the comfort temperature (T_n) for the summer and winter, in Tripoli subjects voted neutral (C=4) when the temperature is 26.3°C, In Ghadames the subjects voted neutral in a higher temperature 27.8°C. While in Gheryan the subjects voted neutral in a lower temperature 25.4°C. It is also shows that the Minimum thermal sensation vote in Tripoli and Gheryan is (1-cool) in the cold period and the highest is (7-hot) in the hot period, in Ghadames the minimum thermal sensation vote is (2-cold) in winter, and the highest is (7- warm) in the hot period. It also indicate that subjects in Ghadames tolerate a higher range of temperature than subjects in Tripoli and Gheryan, as in Ghadames when indoor temperature is T=37°C, subjects voted (5 slightly warm) while in Tripoli and Gheryan they voted (6 -warm). It is noted that the determination coefficient was low in the three charts; this is mainly due to the low number of subjects in the survey for each city (nearly 50 per season). The influence of the psychological aspect in this study is noticeable, as the subject stat of mind control the thermal sensation.

Moreover, taking the comfort temperature value from the people who voted neutral reduces the data by neglecting the other votes and therefore an unreliable comfort temperature.

5.5.4.3 Thermal comfort votes versus the environmental variables.

Using the Multiple regressions to include more environmental variables such air velocity and relative humidity can give an idea of their relative importance in deciding the value of C and their statistical significances can indicate which variable are most important.

$$\boldsymbol{C = a + bT_{op} + cV + dRH}$$

For Tripoli, Ghadames and Gheryan the equations are as follow

$$\boldsymbol{C} = (\boldsymbol{-0.949741}) + (\boldsymbol{0.174895})\boldsymbol{T_{op}} + (\boldsymbol{-1.176})\boldsymbol{V} + (\boldsymbol{0.009525})\ \boldsymbol{RH}$$

$$\boldsymbol{C} = ((\boldsymbol{-0.06229}) + (\boldsymbol{0.126127})\mathbf{T_{op}} + (\boldsymbol{-0.273610})\mathbf{V} + (\boldsymbol{0.020708})\ \boldsymbol{RH}$$

$$\boldsymbol{C} = (\boldsymbol{-1.507}) + (\boldsymbol{0.191376})\boldsymbol{T_{op}} + (\boldsymbol{0.48176})\mathbf{V} + (\boldsymbol{0.013471})\ \boldsymbol{RH}$$

The above equation shows that indoor operative temperature and the relative Air Velocity are the most important environmental variable that affects thermal comfort vote.

5.5.5 Calculating comfort temperature.

As noted by Nicol "If, for any block of data, the mean operative temperature and the mean thermal sensation are known it is simple to calculate the thermal comfort temperature" this also known as Griffiths method, (Fergus Nicol, Humphreys, and Roaf 2012 -P16). Moreover for a small group of subjects using the Griffiths method is more reliable for evaluating the mean comfort, by assuming the increase in temperature for each thermal sensation scale point using the Griffiths slope G (K^{-1}), this is equivalent to the regression coefficient between the comfort vote and operative temperature.

In this study the regression coefficient between the comfort vote and operative temperature was found from the scatter chart illustrated in figures (6-18), (6-19) and (6-20). Statically, the correlation coefficients for comfort temperature in the three cities are low; there are two reasons for this result; first this is expected for any field studies that attempt to predict human psychology and respond toward thermal comfort. Secondly, the low number of subjects in the survey for each city (nearly 50 per season) and measurement error can result this low regression. In order to correct small data Griffiths used G slop where the value of G is 0.3 K^{-1} is nearly 3K. However, this value have been found from large number of thermal comfort study based on climate chamber studies, it neglected the measurement error and assumed there is no adaptation to temperature changes took place. Humphrey founded that the most likely value for Griffith slop is G= 0.5 K^{-1}whish is 2K, a value founded from a large number of data based on a day survey, this have been assumed to overcome the problem of both, the measurement error and adaptation to temperature. (Nicol, Humphreys, and Roaf 2012, 148). Therefore in this study the comfort temperature for the three cities were calculated using the following equation

$$\mathrm{T_{comf}} = \mathrm{T_{op}} - {}^{\mathrm{TS}}\!/_{\mathrm{G}}$$

Where $\mathrm{T_{comf}}$ is the comfort temperature, $\mathrm{T_{op}}$ is the mean operative temperature, and TS is the mean thermal sensation. The value of G was found from the field survey for each city and during each season $\left(G = a = \frac{1}{\Delta T}\right)$, and comfort equation for the three cities was as follows

$$\boldsymbol{T_{comf} = a\,T_{op} + b}$$

This study adopted Humphrey's assumption for the G value where the increase in temperature for each thermal sensation scale point is 2K. And the correlation between the comfort vote and operative temperature was found from the chart illustrated in figure (5.16), the comfort temperature was calculated for each vote. According to research questionnaire for example at operative temperature 30 ℃ a person voted (5 slightly warm) on the thermal sensation scale, therefore to feel comfort (4) we need to reduce the operative temperature 2K which is equivalent to one thermal sensation, and his comfort temperature will be 30-2K= 28°C. Moreover if at the same operative temperature person voted (7 Hot) on the thermal sensation scale, in order to feel comfort (4) we need to reduce the operative temperature 3×2K which is equivalent to three thermal sensation, and his comfort temperature will be 30-6K= 24°C.

The thermal comfort temperature equations for the three cities have been calculated as follows

$$T_{comf} = 0.6631T_{op} + 8.8735 \qquad R^2 = 0.90 \text{(Tripoli)} \qquad (5\text{-}4)$$

$$T_{comf} = 0.799\, T_{op} + 5.5972 \qquad R^2 = 0.91 \text{ (Ghadames)} \qquad (5\text{-}5)$$

$$T_{comf} = 0.6803\, T_{op} + 8.1283 \qquad R^2 = 0.89 \text{(Gheryan)} \qquad (5\text{-}6)$$

From the above equation it is clear that subject in Ghadames tolerate higher temperature than Tripoli and Gheryan. For example for the indoor operative temperature 30°C, Ghadames comfort temperature is nearly 29.5°C, while in Tripoli and Gheryan it is 28.5°C.

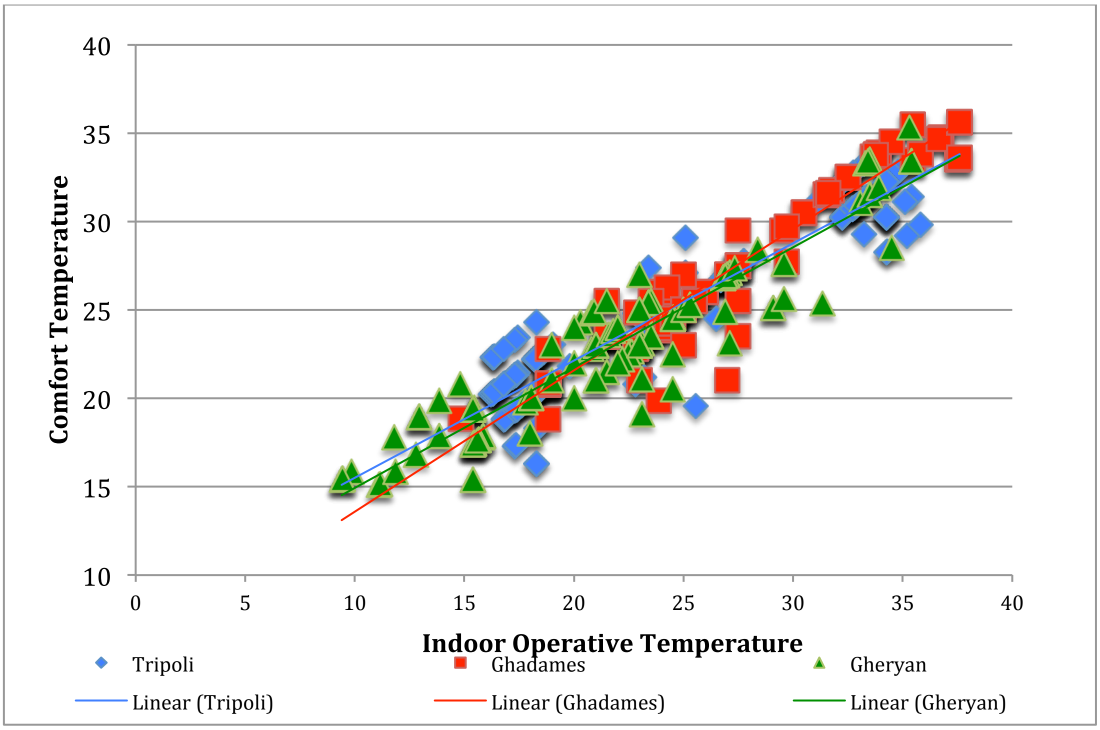


Figure (5. 17) comfort temperature predicted from indoor operative temperature founded on the base of G = 0.5

5.5.5.1 The comfort temperature versus out-door temperature.

Many studies have used the mean out door temperature as predictor of comfort temperature, since the indoor temperature is dependent on out-door temperature, particularly in a natural free running building. Therefore a linear regression analysis done between the comfort temperature and the out door, a scatter chart has been used for the mean daily out door temperature as indicator of comfort temperature in the three cities.

From the chart illustrated in figure (5-17) we can conclude the equations for comfort temperature as subject of outdoor temperature; the equations for Tripoli, Ghadames and Gheryan are as follows

$$\boldsymbol{T_{comf} = 0.558\, T_o + 11.67} \qquad (R^2=0.8) \qquad (5\text{-}7)$$

$$\boldsymbol{T_{comf} = 0.5848\, T_o + 10.682} \qquad (R^2=0.78) \qquad (5\text{-}8)$$

$$\boldsymbol{T_{comf} = 0.6081\, T_o + 10.134} \qquad (R^2=0.8) \qquad (5\text{-}9)$$

The mean daily outdoor temperature was taken from the site at the time of the survey.

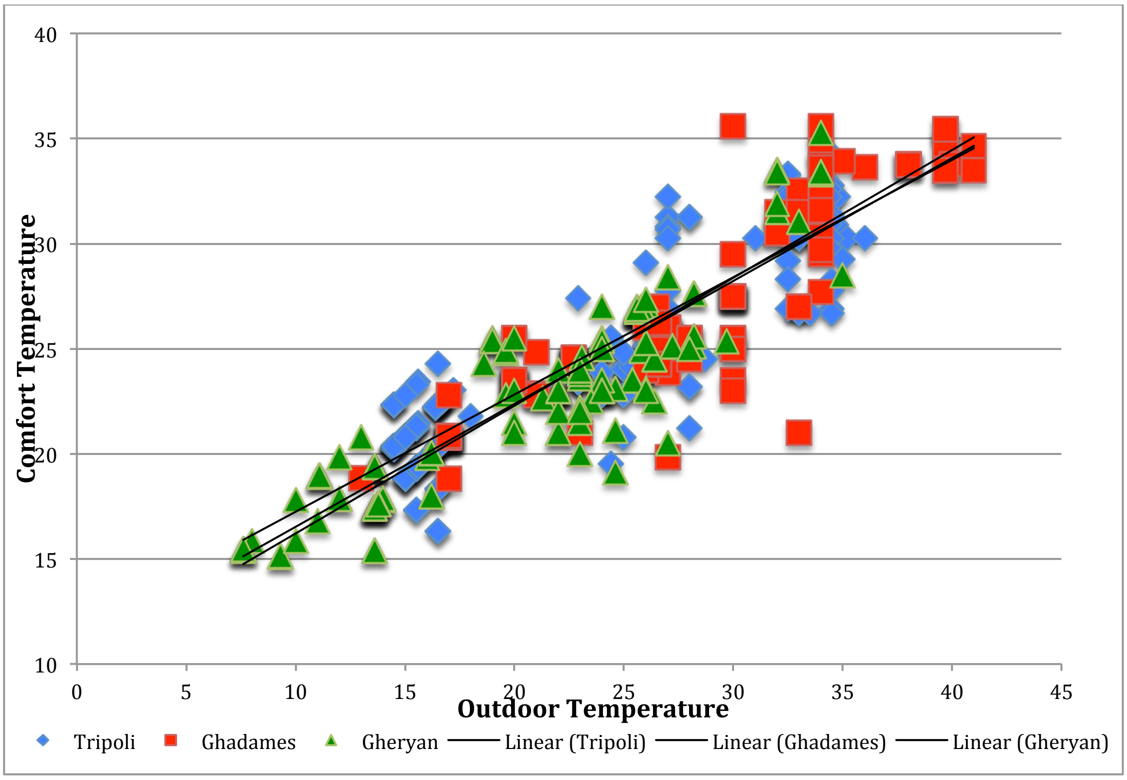


Figure (5. 18) mean out door temperature versus comfort temperature

5.5.5.2 The comfort temperature versus running mean outdoor temperature

According to Adaptive theory, predicting thermal comfort temperature is dependent on indoor environment and out door temperature. However, the relationship between indoor and outdoor temperature may vary, based on the extent to which the indoor environment is connected to natural seasonal swings in outdoor climate (Olesen and Brager 2004). Moreover Humphrey points out that "the correlation coefficient indicate that the running mean with $\propto = 0.8$ is decisively superior to the historic monthly mean from meteorological tables, or to a running mean with $\propto = 0.96$, as predictor of the comfort temperature". (Humphreys, 2010)

Therefore calculating comfort temperature using the running mean outdoor temperature is crucial. In this study the running mean outdoor temperature was selected as predictor of the comfort temperature with $\propto = 0.8$ using the following equation (Humphrey, 2010);

$$T_{rm(tomorrw)} = \propto \times T_{rm(yesterday)} + (1 - \propto) \times T_{m(today)}$$

The running mean outdoor temperature was taken from the data collected from the three cities using a long term temperature reading computer chip (iButtom) installed outside the houses for 10 days during summer, spring and winter seasons, using the courtyard temperature data in Tripoli and Gheryan, and the roof temperature in Ghadames. However, for missing data, it has been estimated with respect to the weather data collected from meteorological stations. Chart illustrated in figure (6.20) shows the correlation between the running mean outdoor temperature and the comfort temperature for the three cities.

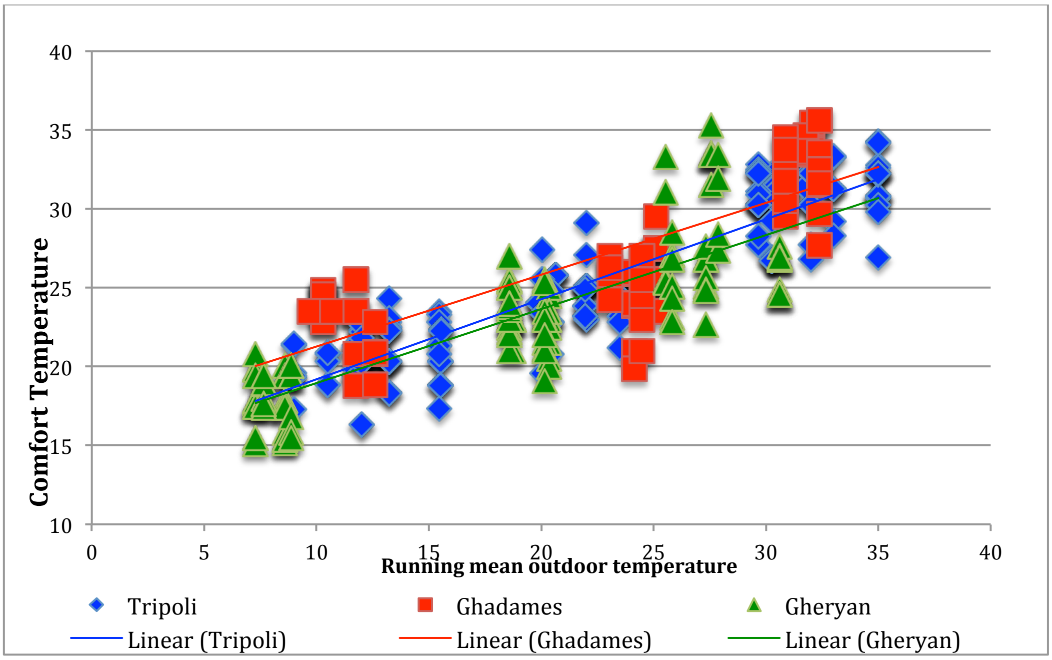


Figure (5. 19) comfort temperature Versus Running mean outdoor temperature

Comfort temperature for the three cities can be found from the above chart as follows:

$$\boldsymbol{T_{comf} = 0.51T_{rm} + 14.12} \qquad R^2=0.85 \qquad (5\text{-}10)$$

$$\boldsymbol{T_{comf} = 0.46T_{rm} + 16.72} \qquad R^2=0.7 \qquad (5\text{-}11)$$

$$\boldsymbol{T_{comf} = 0.47T_{rm} + 14.26} \qquad R^2=0.7 \qquad (5\text{-}12)$$

To indicate the limits of the comfort zones for the three cities it can be assumed that subjects can be comfortable in a range from 3 to 5 on the thermal sensation scale, 3 for slightly cool and 5 for slightly warm. The correlation coefficient indicates that the running mean outdoor temperature as predictor varies according to the location.

5.5.6 Comparing the study with previous studies.

Studies use different environmental variable such as indoor operative temperature, mean daily outdoor temperature or monthly mean outdoor temperature in order to predict comfort temperature and set what is the most reliable environmental variable to predict the comfort temperature.

5.5.6.1 Indoor temperature as predictor of comfort temperature

Comparing the study with models using the indoor operative temperature as predictor to the comfort temperature, Humphreys (1976) uses the indoor temperature to develop a linear regression to predict the neutral temperature from his field study in Asia, Europe and Australia, where neutral temperature is;

$$\mathbf{T_n = 0.831T_i + 2.56 \qquad (5\text{-}13)}$$

Followed by Auliciems and de Dear study (1986), by using Humphreys data with an additional data the developed another equation

$$\mathbf{T_n = 0.73\ T_i + 5.41 \qquad (5\text{-}14)}$$

Finally, in this study the neutral temperature has been calculated using the indoor operative temperature as predictor from the following equations (6-10), (6-11) and (6-12) for the three cities during three seasons. Table (6.5) shows that people in the three cities tend to accept higher temperature in both winter and spring comparing it to Humphreys and Auliciems and de Dear. This can be related to the Adaptive variables as noted by Nicol "Adaptive variables are extremely important in free running buildings (Nicol, 2008). Fanger points out that indoor temperature, as felt by the occupant is a function of mean outdoor temperature; this is affected by the location and season on comfort temperature.

	Humphreys (5-13)			Auliciems & de Dear *(5-14)*			Current study (4,5,6)		
	Winter	Summer	Spring	Winter	Summer	Spring	Winter	Summer	Spring
Tripoli	17.25	29.9	22.62	18.32	29.44	23.04	20.5	30.5	25
Ghadames	20.5	30.83	23.56	21.17	30.25	23.86	22.6	32.5	26
Gheryan	14.9	27.5	21.11	16.25	27.33	21.7	18	28	23.3

Table (5. 5) comparative study between the current study comfort temperature and other studies

5.5.6.2 Outdoor temperature as predictor of comfort temperature

Predicting the indoor thermal comfort by the outdoor temperature founded on the base that the indoor air temperature is the function of the outdoor temperature.

In his paper (1978), Humphreys shows that in natural ventilated building comfort temperature can be predicted from outdoor mean temperature T_o using the equation;

$$T_c = 11.9 + 0.534T_o \qquad (5\text{-}15)$$

Auliciems and de Dear developed another equation derived from RP884 ASHRAE database, that proposed a single line for the naturally ventilated and air-conditioned buildings;

$$T_c = 17.8 + 0.3T_o \qquad (5\text{-}16)$$

Furthermore, a new regression for different climatic condition found by Nicol in his study in Pakistan;

$$T_c = 18.5 + 0.36T_o \qquad (5\text{-}17)$$

Finally in 1990 Griffths presented equation to calculate the neutral temperature;

$$T_c = 0.49T_o + 12.16 \qquad (5\text{-}18)$$

A comparison is made between the previous studies of Humphreys, de Dear, Nicole and Griffiths, for predicting comfort temperature using the equations (6-15), (6-16),(6-17),(6-18) respectively, and with the comfort temperature for each of the three cities found from the equations (6-7), (6-8) and (6-9) in current Field study.

Models	Tripoli			Ghadames			Gheryan		
	Winter	Summer	Spring	Winter	Summer	Spring	Winter	Summer	Spring
Humphreys (5-15)	20.3	29.5	25	22.4	30.9	27	18.8	26.1	24.5
de Dear (5-16)	23	27.4	25.5	24	28	26.3	22.2	25.8	25
Nicol (5-17)	23	29.5	26.6	24.4	30.6	27.8	21.9	27.1	26
Griffiths (5-18)	19.8	28.3	24.6	21.8	29.7	26.	18.5	25.2	23.7
Current study (T_o) (6-7,8,9)	22.9	27.5	25.4	22.1	31.5	27.3	20.5	26	24

Table (5. 6) a comparison between previous study and the current study, using outdoor temperature as predictor of comfort temperature.

With reference to Table (5-6) it shows that most of the studies predicted quit close to the current study results the Humphreys and Griffiths with less than ($\Delta < \pm 2$ K). However, the other two models de Dear, Nicole models shows high differences with (Δ> ± 3-5K). From the table the Humphrey model has the closest results when compared to the current study natural temperature for Tripoli with less than ± 0.5K difference.

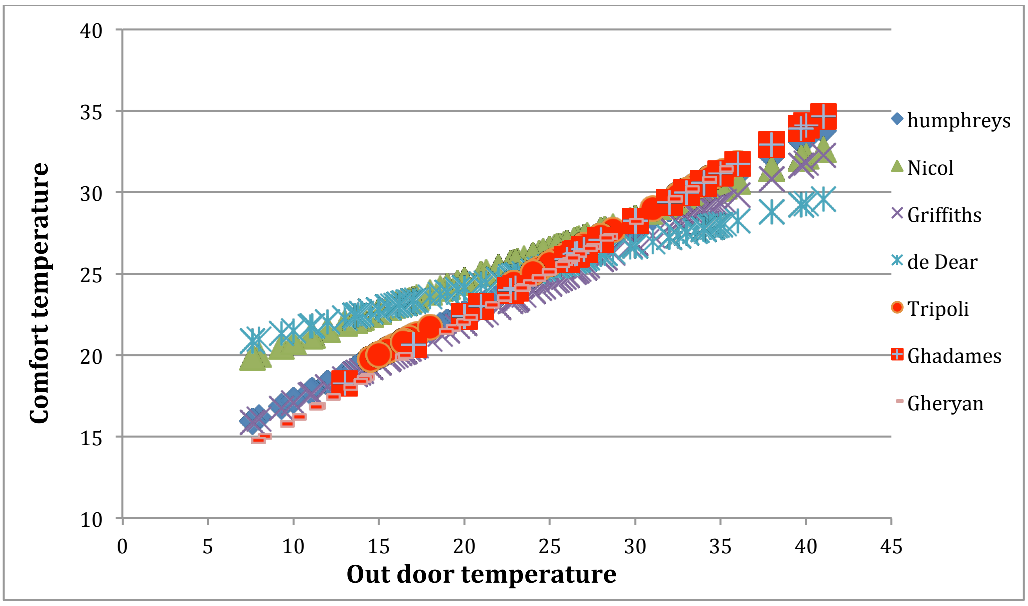


Figure (5. 20) compression between the previous studies and the current temperature.

5.5.6.3 Running mean Outdoor temperature as predictor of comfort temperature

The European standard EN15251 uses the exponentially weighted running mean outdoor temperature (T_{rm}) with the value of α = 0.8 as predictor of comfort temperature. Using the following equation for free running building with margin of ±2K.

$$\boldsymbol{T_{comf} = 0.33T_{rm} + 18.8} \quad (5\text{-}19)$$

The above equation for optimum comfort temperature was developed from the SCATs project for free running building.

Models	Tripoli			Ghadames			Gheryan		
	Winter	Summer	Spring	Winter	Summer	Spring	Winter	Summer	Spring
EN15251 (5-19)	24	29	25.72	23.49	29.94	27.47	22.12	28.6	25.88
Current study	21	30	24.7	23	32	28	19	28	24

Table (5. 7) comparison between the EN15251 study and the current study using running mean outdoor temperature as predictor of thermal comfort

Table (5-7) Compare the field study with EN15251 research, using running mean outdoor temperature (T_{rm}) as predictor of comfort temperature. From the table EN15251 predicted higher temperature in winter for Tripoli and Gheryan with deference less than (3K). While in Ghadames it is lower with less than (1K). In summer the result shows that the EN15251 predicted lower than found by the study in Tripoli and Gheryan. However in general the comfort temperature predict by the study in Tripoli Gheryan and Ghadames are close to the EN15251 prediction.

5.6 Conclusion

The chapter analysis the outcome of two studies, first, is the finding from investigating the thermal insulation of Libyan clothing; where in the summer, females in Libya usually wear heavier clothes than the male clothing, while in winter men were recorded to wear heavier clothes than women. Thermal insulation of the traditional Libyan clothing was tested in a climatic chamber and the results show that male traditional clothing is 0.63clo in summer and 1.95clo in winter. While female traditional clothing is 1.17clo in summer and 1.6clo in winter.

The research shows that, older generations tend to wear heavier clothing than younger generation, and wearing traditional Libyan clothes is more common in older generation.

Secondly, a thermal comfort investigation in the three cities is conducted to calculate comfort temperature in Libya. By studying the six parameters that affect thermal comfort, the study correlates the comfort temperature with the indoor operative temperature and the running mean outdoor temperature to define comfort temperature.

The study also shows that occupants staying in naturally ventilated houses demonstrate higher thermal comfort level as compared to what PMV has predicted. This is related to the adaptive actions, which contributed in positive way to a higher level of thermal comfort. Thermal comfort is influenced by non-physiological factors in addition to the six physical factors. Occupants' adoptive adjustments have a great influence in setting the thermal comfort temperature in the three cities. The study shows that female tends to record more activity than male; this is mainly as a cultural factor in the society where only women are responsible for housework. Furthermore, using the ANSI/ASHRAE Standard 55-1992R to estimate the metabolic rate is unreliable, because it is designed for western societies, where the meaning of the activity description is different culturally as described in the chapter.

The study investigates and assigns the thermal comfort temperature in three climatic zones in Libya, and three equations were concluded from the study, using the running mean outdoor temperature as predictor of the thermal comfort, that can indicate the limits of the comfort zones for the three cities.

The equations found from the survey will be used to indicate the thermal comfort temperature in the energy simulation models in the next two chapters, the conclusion from both chapter will have been used to then calculate energy requirement for heating and cooling in houses in three climatic zones by setting the comfort temperature in the three cities as base temperature

There is limited thermal comfort research in Libya conducted by just a few studies (Ealiwa et al. 2001; Alzubaidi, 2002; Akair and Bánhidi 2007), thus, thermal comfort standards are not defined in Libyan Codes yet. The small numbers of respondents in most of the thermal comfort investigations in Libya do not give a good estimation for population responses. Therefore more studies in the field are required. The data in this research can be part of a broader study to set a thermal standard for the North African Countries 'Al-Maghreb Al-Arabie' includes (Libya, Tunisia, Algeria Mauritania and Morocco).

6. Chapter Six: The Environmental Analysis of The Case Studies

6.1 The environmental factors

The role of the climate in the creation of built form is significant. The importance of environmental factors in shaping our built environment was first pointed out by Vitruvian in his book Ten Books on Architecture, emphasises the fundamental relationships between climate, comfort and the role of architecture in his ‘Tri-partite model of the environment’. Victor Olgyay’s model of the environmental process extends the Vitruvian model to include the ‘technology’ factor. He points out that the way to achieve environmental control is through working with the climate rather than against it. He explains that this can be achieved through his ‘schematic bioclimatic index’, an analytical system by which the relationship of climate to comfort may be clearly established for any given conditions and his taxonomy of building types related to climate, (Olgyay 1992).

On the other hand, Oke argues that there is no universally optimum geometry, “there are an almost infinite combination of different climatic contexts, urban geometries, climate variables and design objectives” (Oke 1981). Therefore this chapter discusses the effect of the environment variables on the thermal performance of the three tradition vernacular houses in the three regions of Libya, in other words studying the force of the climate in forming the traditional vernacular houses.

The thermal performance of a building is determined by a large number of factors. They can be summarised as firstly weather data including solar radiation, air temperature, wind speed and relative humidity, secondly, design variables and geometrical dimensions of a building including the building envelope, orientation, shading devices, and urban context. Further, the thermo-physical properties of building materials include density, specific heat, thermal conductivity and transmissivity and finally, the internal heat gains due to occupants, lighting and equipment.

In this study the influences of these factors are measured and analysed in order to understand the thermal performance of the vernacular houses. Accordingly an empirical study is conducted in this chapter to determine the thermal performance of the three case studies under the different external climatic conditions of different seasons, by monitoring the indoor air temperature using a computer chip (iButton), In addition to measuring the mean radiant temperatures, internal and external relative humidity, and air quality and speed were measured using the following instruments; thermo hygrometer (testo625), anemometer (testo 425), and CO_2 meter (testo 535).

6.2 The climate in Libya

The effect of climate as modifier forces that shapes the houses in Libya, and the thermal performance of these houses is vital in order to design a low energy. As pointed out in chapter two the climate of Libya is categorised into five different climatic zones, this study will focus on three main climatic zones in Libya represented by

- Semi-Mediterranean on the coastal area (Hot-humid) case study Tripoli.
- Mediterranean climate- on the mountains (cold zone) case study Gheryan.
- Desert (hot-arid) case study Ghadames.

Since this study is concerned with the thermal performance of the building, the focus will be on the effect of the four major components of mesoclimate and their importance in this respect: Air Temperature, Relative Humidity and Precipitation, Solar radiation and Air movement and speed. Within these different climates in Libya, three different traditional vernacular houses were built to cope with and modify these climates in order to achieve thermal comfort required by the inhabit: courtyard house in the coastal region, compact house in the desert and an earth sheltered houses in the mountain region.

6.3 Thermal performance of buildings

Herbert A Simon points out that "An artifact can be thought of as a meeting point, an "interface" in today's terms, between an "inner" environment and "outer" environment"(Asselin, Lamoureux, and Ross 2008). The thermal performance of a house is determined by many factors including the house location, form, orientation, and the house envelope.

6.3.1 The house location, form and orientation

Solar radiation and air movement are the two major criteria of the local climate that guide the form and orientation of buildings to achieve 'the optimum shape'. This is the shape of building that has minimum heat gain in summer and minimum heat loss in winter. (Olgyay, 1976). These two factors may lead to contradictory orientation requirements; however by adjusting the design of the house the effect of the orientation can be modified.

6.3.2 The House Envelope

The heat transfer through the building envelop by conduction, radiation and convection is controlled by the thickness and the thermo-physical properties of the materials; conductivity, thermal capacity and absorptivity. There are five thermal measures or indicators which are useful to describe the way in which the envelope will modify internal thermal conditions; U-Value (thermal transmittance coefficient), Admittance Y value, Time Lag, and decrement factor.

The envelope's material affects the heat exchange from the external environment to the internal environment. The external envelop of the building is examined in this study as two related components; the walls (vertical surfaces) and the roof (horizontal surface).

6.3.3 Opening orientation and shading devices

The effect of opening properties, size and orientation, on the indoor temperatures is vital; this can be largely determined by the ventilation conditions and the degree and efficiency of the window shading and shutters. However, the thermal effect of a glazed area section is dependent on the shading provided and the spectral properties of the glass.

6.3.4 Passive or active cooling- heating systems

The use of passive or active cooling heating systems depends on many factors; climate, material and economy, "In most dwelling of the world climate modifiers must be installed. The buildings were designed in order to modify the climate, where every type of dwelling serves the function of assisting us in adjusting to one or many aspects of climate". (Oliver, 1990). In a hot dry climate a passive cooling system is one of the main protections against solar radiation, starting with orientation, minimizing the wall area exposed to the external environment, use of materials that reduce the heat gain and form of the building.

Modifying climate has been the one of the main factors in the creation of the traditional vernacular house; Rapoport highlights that as '….a tool which frees man for other activities by creating an environment which suits him, protecting him from the undesirable effect of his surroundings' (Rapoport, 1969.).

Therefore, in this study three type of traditional vernacular dwelling have been analyzed in order to examine their thermal performance and outline the vernacular passive cooling technique each dwelling adopts to modify its different climate in order to create a comfortable environment which suit the occupants.

6.4 Tripoli Micro Climate - Building surrounding

The city terrain is almost flat, although there is a gradual slope from the sea towards the south near the Nafusa Mountains, rising up to 200m to the south Jefarra Plain, which extends for 100km in width south of the city. The distance from the city and the height of the mountain renders its influence negligible. Most of the Mediterranean vegetation grows in the city where the soil (fertile and consisting of a high amount of organic materials, and clay) encourages growth. This in turn encourages Libyans to use vegetation to modify their climate. (El Dars and S. Zaki 1972). The urban fabric of the old city of Tripoli is compact, as the buildings share two or three walls with neighbouring buildings. Thus the exposed surface is minimised. In addition to the narrow streets that provides shading almost all day and protect the buildings' vertical wall surfaces from the direct solar radiation Most of the main street runs from the Northwest to Southeast and Northeast to Southwest. This protects the city from the undesirable south wind in the summer (Ghibli), and causes it to be oriented towards the desirable sea winds.

6.4.1 Physical component of the courtyard house in Tripoli

The location, form and orientation affect the indoor climate in two respects by its regulation of the influence of two distinct climatic factors; solar radiation and ventilation (GIVONI, 1976). However the urban fabric of the city restricts the forms of traditional vernacular houses in the old city of Tripoli. Most courtyard houses have a nearly square courtyard, which creates a maximum volume to surface ratio that reduces the exposed surface area.

The old city houses have a height range from one to three floors, however two floor houses are the most popular houses. Studying the structure, building material and the thermal performance of these types of houses as discussed in chapter three is the key point to understanding and learning from the traditional vernacular houses in Tripoli.

Structurally, the case study house consists of two floors built with a load-bearing system. The building will be analysed into its three components: exterior walls, roof and floor. First the exterior walls in the case study house are adjacent and shared by the attached houses, the only exterior wall is the southeast exterior wall that faces a narrow covered street. However in these types of houses the courtyards' walls can be considered as exterior walls. The walls have different thickness and different dimensions according to their height and position The thickness of the first floor walls range from 50 to 90 cm, however on the second floor it is reduced to 40-60 cm. Walls were built with irregular limestone blocks with mortar made from lime and sand, which is very common in the old city houses.

Secondly the roof; two different methods were employed for roof construction; using the first method, flat roofs were made of ordinary pine timber; joints are covered with timber boards and a layer of ordinary clay about 6cm thick, the main beams are made of cast iron, the balks are of wood as are the floorboards. The second method is the vault; two types of vaults can be identified, the parallel and cross-vaults, found in the entrances and the corner spaces in the ground floor, they are made of small stones and covered with plaster. Foundations are made of limestone blocks, they are shallow (often not deeper than 50 cm), and there is no intermediary layer between the stone and the earth, the floor is laid with colored tiles in geometrical shapes.

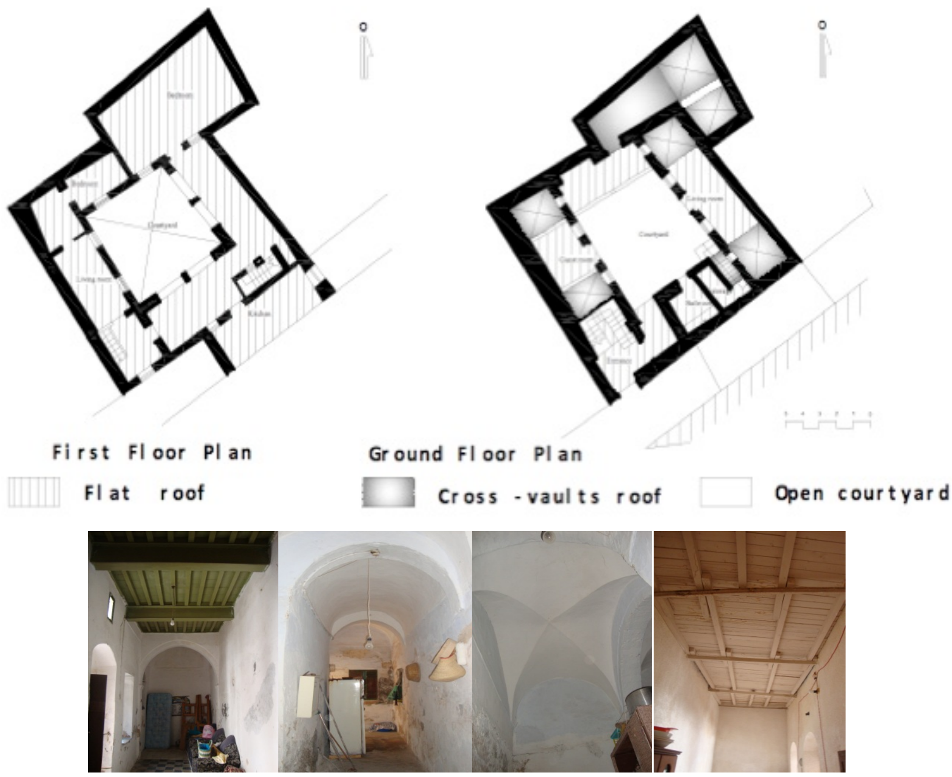


Figure (6. 1) Types of roof construction in the courtyard houses

6.4.2 Passive cooling and heating techniques in courtyard houses

The courtyard house was planned and built mainly to provide protection from the external environment. Therefore studying the passive heating and cooling techniques in vernacular house can provide a guideline to low energy house design.

6.4.2.1 Envelope thermal mass and surface

Heat flow through the walls depends on the wall's dimension and its material. Most of the rooms are roughly rectangular in shape, not governed by a strict geometric grid where the longer side overlooking the courtyard with dimensions ranging from 2 m to 4m wide and 3m to 6 m long. The relatively thick walls act as a thermal mass that delays temperature fluctuations, and a high thermal capacity and low U value as low as 1.5. Moreover, the higher the thermal capacity the greater the time-lag, this property of the material has a significant effect in hot climates, where the maximum heat load in the afternoon will be delayed until the cooler hours at night.

In terms of rendering, material and colour has had a significant impact on its thermal performance. Lime plaster is the most common wall coating; it is considered as a vital element in the masonry because it protects the stone and its absorbency allows the evacuation of the inner humidity of the walls. Because white lime wash proved to be an excellent solar reflector and emits long wave radiation to the night sky, and by reducing the absorptivity of the wall surfaces, minimises the quantity of solar radiation effective in heating the building and thus reduces both the maximum and minimum temperatures, (Givoni 1998). In addition, it helps to reflect light into the darker recesses of the house.

6.4.2.2 Air circulation

Air circulation has been enhanced by the opening locations and medium sized windows, being about 0.8m to 1m wide and about 1.6m high, a door with dimensions of approximately 1m by 2.2m, and a small widow found just above the door, by allowing to the cool air to replace the hot air. Each room has at least two windows, creating a loop of air circulation, in addition to the small opening above the door creating a passive stack effect, which depends on the difference between outside and inside temperature, the height between the outlet and the inlet, and their size. The window of the room that extends over the street, facing the north acts as wind trap creating an air circulation, reducing the house temperature.

6.4.2.3 Shading devices and glazed area

Shading devices include wooden shutters on the windows that reduce the heat flow rate through the glazed area. (The U value for glazed area = 5.7 W/m2K, while the U value for the timber shuttered area= 0.12 W/m2K). The wooden shading device on windows

Mashrabia Wooden shutters have been replaced by steel bars and wooden shutter for security and financial reasons.

Secondly, the arcade in the courtyard is used to provide shading to the south facing elevation, and extra shading to the courtyard.

Figure (6. 2) Type of opening - courtyard house

6.4.2.4 The courtyard

The courtyard is a climatically responsive urban form (Fathy 1986). The properties of courtyard spaces depend on their proportions. The height of the courtyard is usually bigger than its width and length, to assist shading and act as a sun protector (Edwards et al. 2005). In other word it is a closed area that acts as a sink where the cooler nocturnal air is trapped and flows into the rooms at low level, while the warm air is moved out of the rooms at a higher level.

Although most of the houses in the old city have a tree or two in the courtyard, the case study house had only a few pots with small plants that have no effect on the courtyard. This had a negative influence on the shading of the courtyard and the temperature of the surrounding rooms.

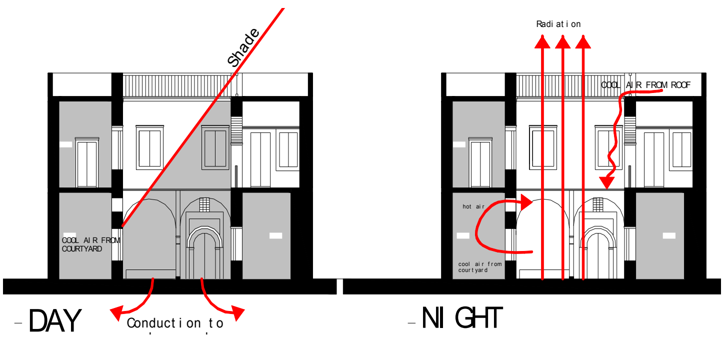


Figure (6. 3) Thermal performance of the courtyard, after Koenigsberger - Manual of topical housing and building

6.4.3 Casual Heat Gain:

In order to analysis the thermal performance of a house studying the casual heat gains is important. These include occupants, lights, and domestic equipment.

The current occupants are a Libyan family, one male 55 years old, one female- 46 years old, one female 16 year old and a female 13 years old. The father is a fisherman who works most of the day out of the house (from sunrise to sunset); the mother is a housewife and their two daughters are students. Concerning lights, each room has 2 fixtures at 100 lux, each with a heat emission of 40W. Lights for all zones are used between 18:00 -24:00. As to the equipment, there are two types of equipment, electrical plug loads (sensible heat gain only) and cooking equipment (sensible and latent heat gain) usually using a hooded gas burner unit. Finally heating or cooling devices: an electric heater is used in the winter period and an electric fan is used during the summer period.

6.4.4 Monitoring apparatus

Temperature can be defined as the thermal state of matter with reference to its tendency to communicate heat to matter in contact with it. With respect to air temperature, it is the rate of heating or cooling of the earth's surface, which determines the temperature of the air above (Goulding, 1992). The indoor temperature varies according to the thermal performance of the house. Moreover, the distribution of temperature may vary according to a number of factors such as the sun movement and location, state of the sky and air movement.

Figure (6. 4) iButton is a Computer chip

In this study two types of instruments are used; a long term temperature reading installed in the houses for 10 days during summer, spring and winter seasons using the iButton. In addition, spot readings were taken of temperature and relative humidity, air flow and air quality (CO_2) using the following instruments; testo 625,testo 425,testo 535.

The instrumentation which has been used to measure the long-term temperature consists of electrically self-sufficient 1-wire devices (i-Buttons) that measure the temperature and record the result in a protected memory section. A Thermochron i-Button stores up to 2048 temperature measurement and will take measurement at a user-specified rate. The iButton is a very small computer chip enclosed in a 16mm thick stainless steel can which can be mounted virtually anywhere because it is rugged enough to withstand harsh environments, indoors or outdoors. The Thermochrons have been chosen because of their ability to read and store data without the need of any external wire.

6.4.4.1 Courtyard house – Thermal monitoring

A number of iButtons were distributed around the traditional vernacular architecture houses to read and store the temperature of the houses for ten days each season, during the hottest period in summer (22 July - 2 August), and the coldest period in winter (22 December – 1 January). The following Figure illustrates the iButton distribution around the house according to the room's orientation. For data recorded by the iButtun see (appendix A)

Sketch plan showing room orientation and iButton locations

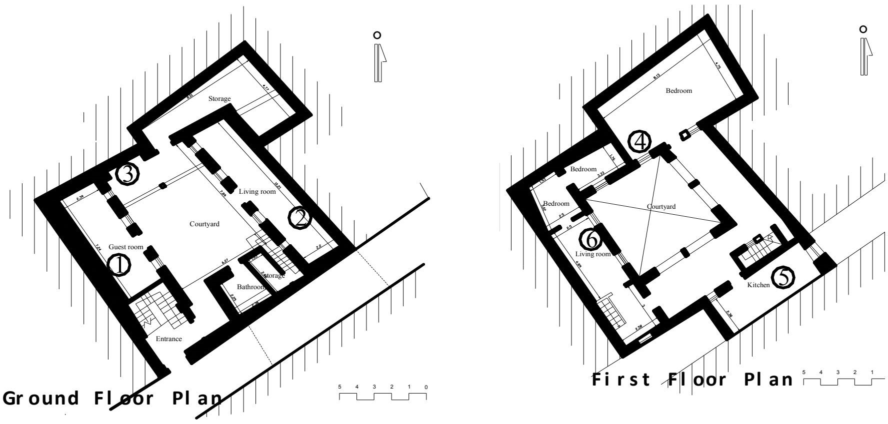


Figure (6. 5) Plan - iButton location

The iButtons were positioned near the external walls of each room as shown in figure (6.14), and the devices measures the temperature and record the result in a protected memory section. A temperature measurement is taken each 60 min for ten days.

The chart Figure (6.6) illustrates the temperature of the rooms over 24 hours through one week in summer, and winter The influence of orientation on external temperatures in turn affects the heat flow through the wall and the internal temperature.

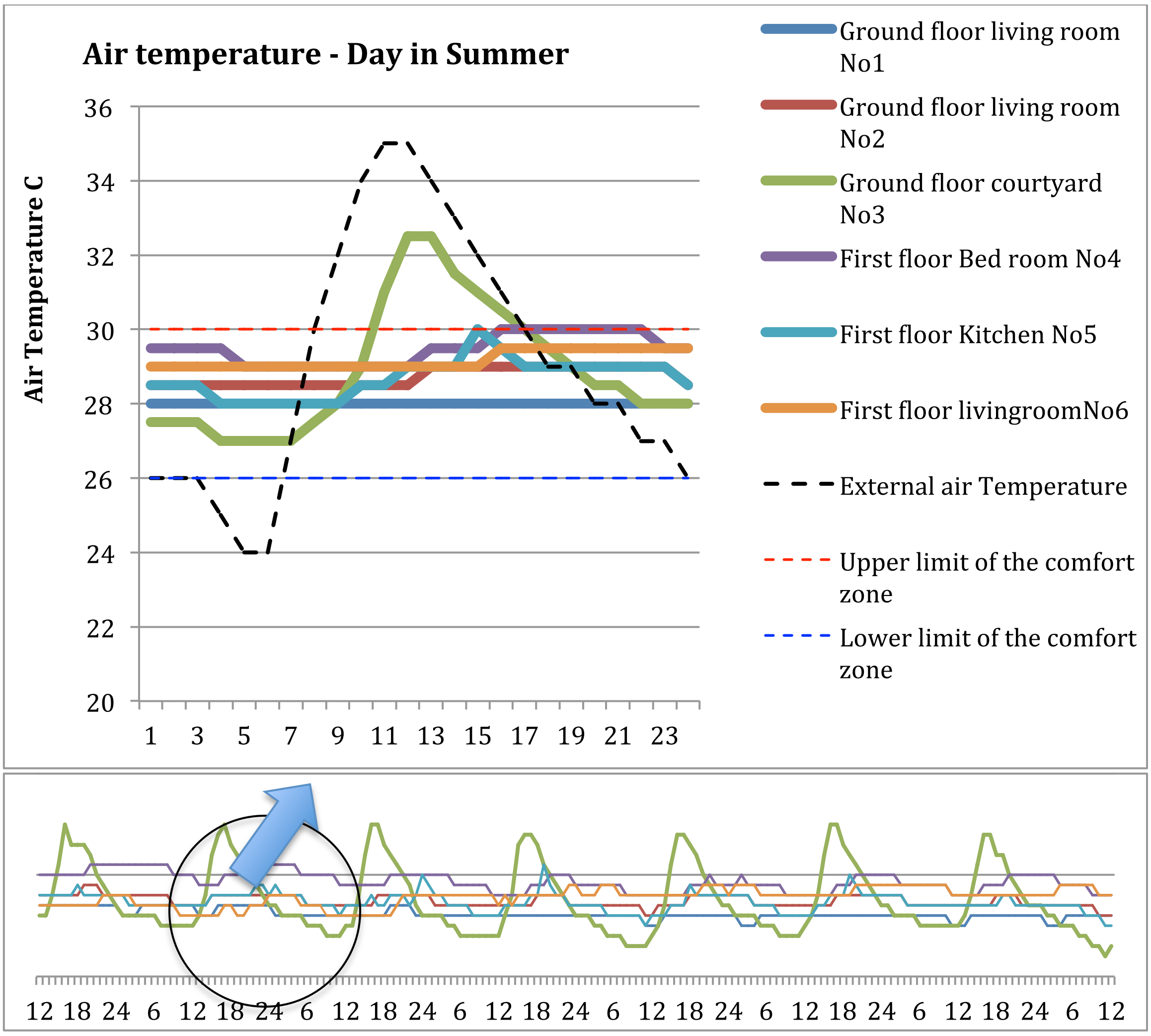


Figure (6. 6) Above indoors air temperature during a day, and during a ten day in summer

*External air Temperature found from Meteorological station at Mitiga international airport, Tripoli.

6.4.4.2 Data analysis

From studying and comparing the result of the thermal performance of the house during summer and winter many points can be highlighted.

- In summer the ground floor courtyard reading illustrates that the external temperature fluctuated above 32°C at 12:00 to 13:00 as a result of the sun altitude there are no shaded areas in the courtyard. However the temperature dropped gradually after 14:00, as the sun altitude decreased, to below 27°C at 4:00 to 6:00 in the morning. In winter the temperature dropped to 16°C at 15:00 and to below 13°C at 4:00.
- The indoor temperature rises to 30°C at 13:00 and is below 27.5°C at 4:00 in the morning, in winter the temperature drops to 19°C at 13:00 and below 15.5°C °C at 4:00 in the morning.

- In terms of location, the ground floor rooms have a lower temperature than the first floor rooms, in both summer and winter.
- Rooms with openings oriented towards the Northeast direction have the lowest temperature reading in summer and have the highest temperature in winter. The first floor room (No 4) has the highest indoor temperature reading in summer, as result of its orientation towards the Southeast.
- The kitchen has the advantage of a North oriented window positioned over the street, which act as a wind catcher, that catches the seas breeze from the street pathway, this acts in a negative way in winter causing the low temperature in this room. However the chart illustrates a sudden change at 14:00 indicating the activity in the kitchen.

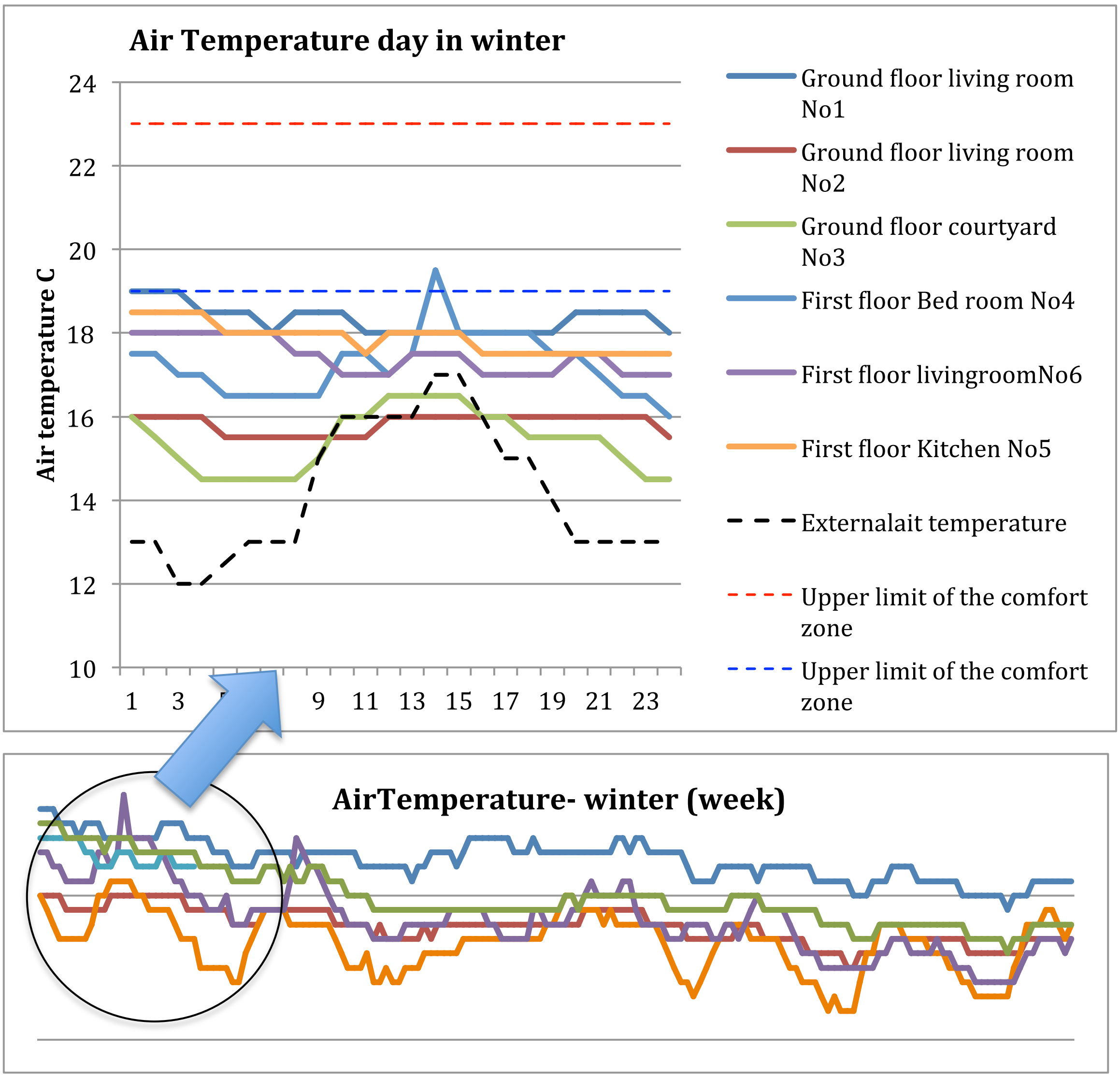


Figure (6. 7) Indoor air temperature-winter day and during ten days in winter

*External air Temperature found from Meteorological station at Mitiga international airport, Tripoli.

- The outdoor temperature (courtyard Temperature) reaches its peak and starts decreasing before the inner temperature reach its peak, this periodic change is known as the time lag of the rooms, which extended up to 6 hours, delaying the noon heat until the evening (B.GIVONI, 1976). The time lag ranges from 3- 4 hours according to the room's location. However the rate at which the wall transmits heat from its first external surface to the next surface depends on the thermo-physical properties of the building material.

Figure (6. 8) Indoors air temperature at 13:00 -summer

- The temperature readings throughout the winter and summer have uneven sudden changes, these can be related to internal change in temperature as result of user activity and the control pattern of the house (open or closing of windows). In addition, the sudden rise in temperature can also be related to the casual heat gains, ventilation and rate of infiltration. The casual heat gains result from activities such as using a coal pottery stove for heating the rooms in winter and warming traditional tea.

In conclusion the Courtyard house uses of various passive cooling strategies which may be summarized in main four strategies; orientation, thermal mass, shading devices and urban context. These four strategies have a remarkable effect on the thermal performance of the house.

- The external temperature found from Meteorological stations using the following website (https://weatherspark.com/#!dashboard;a=Libya/Tripoli), The station is located nearly 10 Km from the old city. The comparison between the external Temperature and the courtyard Temperature shoes the thermal performance of the courtyard, with 2K reduction in air temperature.

- The results were compared to the comfort temperature for Tripoli, using equations found in chapter five, that calculate the comfort zone for Tripoli:

$$T_{comf} = 0.5T_{rm} + 14.1 \pm 2$$

This sets the comfort zone for January (winter week) to 23°C as upper margin and 19 °C as lower margin. For July (summer week) it was set to 30°C as upper margin and 26°C as lower margin.

- The comparison shows that the indoor air temperature laid within the comfort zone during the monitored period, this prove that traditional vernacular houses has a good thermal performance.

6.5 Micro climate – Ghadames

The urban fabric of the old city of Ghadames is a compact built-up area that works as a single organism to produces a suitable micro- climate condition. The narrow covered streets provide shading almost all the day and protect the vertical building's wall surface from the direct solar radiation, and it protects the city from the undesirable desert storms (Ghibli). While the regularly spaced light wells provide natural lightening and ventilation, and create different pressure zones which, in turn, causes air movements from high-pressure zones to low pressure zones, where the hot air is replaced with cooler and humid air in the shaded passageways, and this is one of the most important planning solutions in desert cities (Al-zubaidi, 2001).

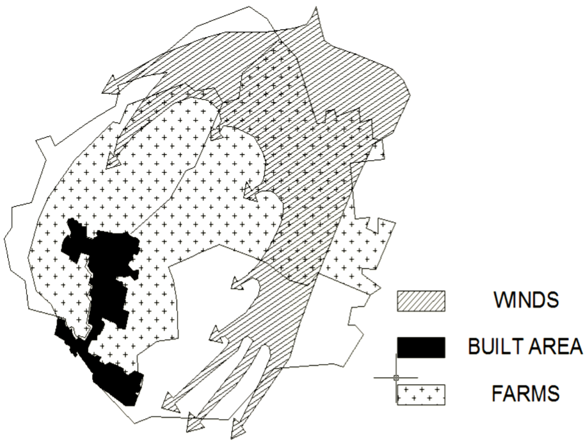


Figure (6. 9) Microclimate modifying the wind- Ghadames Source (Alzubaidi, 2006)

On the other hand, the surrounding farms of palm trees protect the built up area. These influence air movement by acting as a barrier to the unwanted and sandy winds also filtering and directing the wanted one towards the building.

6.5.1 Physical component of the compact house (case study)

Climate as a design constraint has a significant role in the development of a number of design principles in traditional vernacular architecture in Ghadames. The city deals with the harsh desert climate through protection from dense solar radiation, high temperatures and dusty winds. It does this through sensitive and conscious solutions and construction technologies and well-studied planning and design, using suitable available building materials of certain thermal properties that are appropriate to the ambient environment, in order to create a comfortable internal microclimate.

The old city of Ghadames has a compact urban fabric, covered streets, and narrow passageway forms in order to adapt to the extreme annual and diurnal variation and the severe ambient environment. Houses on three sides and a covered narrow passageway on the fourth side surround the case study house. The house has a rectangular multi floor plan with a compact design offering a better ratio of useable floor area to envelope surface area. The plot size is 65m^2 (13*5m) and, with height of 12m and multi-levels, the design minimize the roof area and provides less surface exposed to the external climate.

The external envelop of the building is examined in this study as two related components, the walls and the roof. The main elements in the external walls are highlighted here: The structural system and building material. The construction system is a load bearing wall system made of sun-dried clay bricks. The wall thickness reduces from bottom to top respectively (0.75m-0.60m-0.5m). The brick size is different according to wall location. It is (0.6m x 0.4m) in the ground floor to (0.5m x 0.4m) in the first floor, and (0.4m x 0.4m) in the second floor. The brick has a standard height of 0.12 m. The mud brick walls sit on stone foundations, and structural support and bracing is accomplished with palm trunks.

6.5.2 Passive cooling and heating techniques in the compact house

In the compact house four techniques are used to help to reduce the indoor temperature; the thermal mass, the air circulation, shading devices and glazed area and context and layout

6.5.2.1 Thermal mass and surface treatment

The walls are relatively thick with a high thermal capacity that acts as a thermal mass to delay temperature changes. This property of the material has significant effect in hot climates, where the maximum heat load at the afternoon will be delayed until the cooler hours at night. The walls are plastered inside with gypsum and whitewashed, while the exterior walls are the brownish and pale yellow colour of the sun-dried clay bricks with a whitewash coating on the top level. The emittance of a material refers to its ability to release absorbed heat; therefore they improve the thermal performance of the building envelope in extreme climate conditions.

Figure (6. 10) Day lighting distribution in Ghadames house.

The roof is constructed from the smoothed trunks of date palm trees used as beams and covered with date palm leaves and topped with a sun baked mud-sand slab. This technique produces a massive roof with a thickness of 0.3-0.4 m, which therefore has a great effect in resisting heat flow rate through the roof. Painting the roof with white wash gave it a high emissivity value.

6.5.2.2 Air circulation

The layout of the city of Ghadames was designed to enhance air movement through the city and into the houses. The narrow passageways of the city and the light wells provide natural ventilation, and create different pressure zones which causes air movements from high-pressure zones to low pressure zones, where the hot air is replaced with cooler and humid air in the shaded passageways. In house scale the opening is designed to create air movement from the street and the light well through small openings (0.3*0.3) on the external walls to the house. The openings in the living room floor and ceiling are located in certain positions in order to provide light and ventilation to the lower floor. Small openings on the external walls on the ground floor create a siphon effect, hot air inside the house rises through the roof opening and is replaced by cooler air from the covered street. the air movement from the streets into the house is illustrated in figure (4-20).

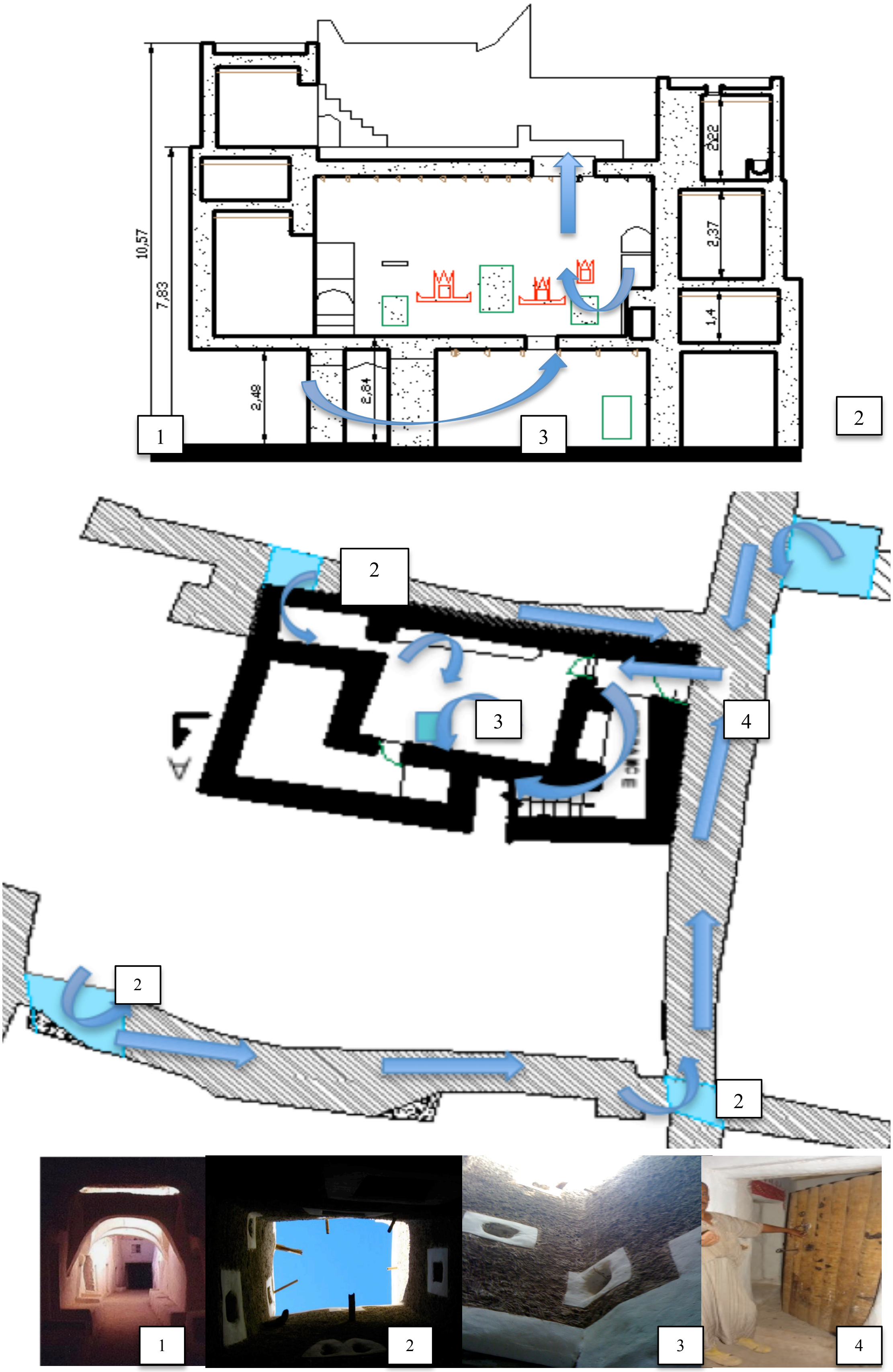


Figure (6. 11) air movement from the streets into the house

6.5.2.3 Shading devices and openings

Undoubtedly, with a maximum temperature as high as 50°C in the summer, limiting the number of external openings in the house is vital, therefore there is only a single aperture found on the living room ceiling, with dimension of (1.2*1.0), this minimizes the solar radiation and heat gain. In addition, as an effect of the high rate of solar radiation and degree of glare, this small opening is quite enough to light the house, and the natural light is enhanced in the bedrooms by mirrors and reflecting objects.

Moreover, shading the roof by high parapets and arcades reduces direct solar radiation. The strategy for roof shading is illustrated in figure (6.12)

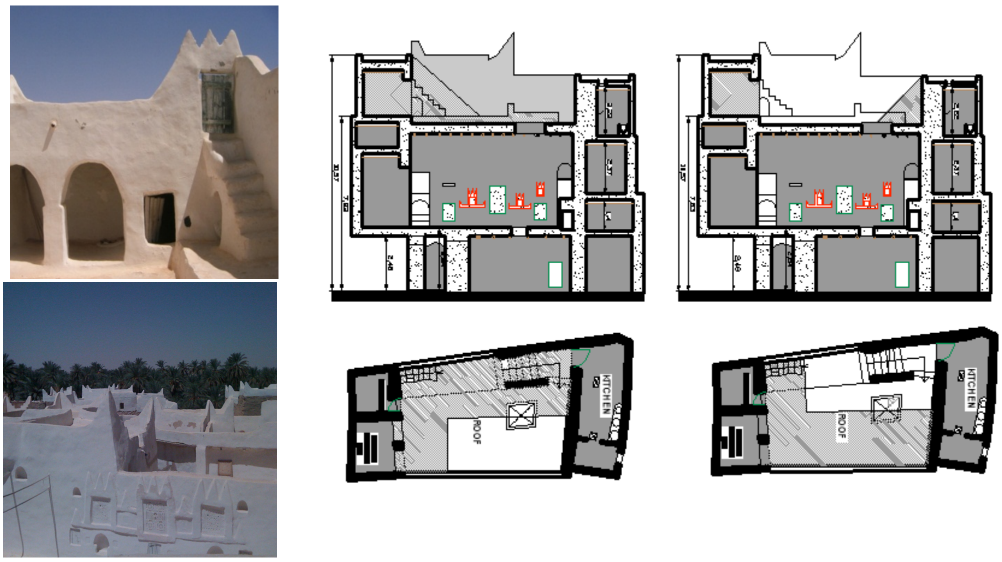


Figure (6. 12) Shade strategy -Ghadames

6.5.2.4 Layout context

In additional to the compact urban fabric in Ghadames the compact multi floor layout creates an ideal solution to the harsh external environment. Because all external walls in the house are adjacent to a neighboring house, the roof is the only element that is exposed to the external environment, therefore reducing the area of the roof is important to reducing the exposed surfaces. Another important aspect in the house layout is the location of the kitchen, taking into consideration that it is the major source of casual heat gains in the house, therefore it is segregated from the house and located on the roof reducing the effect of its heat gain on the house thermal performance.

6.5.3 Casual Heat Gain

The casual gains in the house have been studied. Firstly, the occupants; The current occupants are a Libyan family, one male 55 years old, one female 50 years old. The male is a farmer who works most of the day outside the house (from sunrise to sunset); the female is a housewife. A thermal comfort investigation was conducted and the result will be shown in chapter five. Secondly, the lighting; the living room and the ground floor rooms have 2 fixtures at 100 lux each, with heat emission of 40W. Lighting was used from 18 -24. Thirdly the equipment, there are two types of equipment, electrical plug loads (sensible heat gain only) and cooking equipment (sensible and latent heat gain) usually using a hooded gas burner unit. Finally the heating or cooling devices, this includes an electric fan.

6.5.4 Monitoring apparatus

A number of iButtons were distributed around the traditional vernacular architecture houses to read and store the temperature of the houses during the hottest period of the year (5 August –to 15 August) and during the coldest period of the year (22 December-1January). For data recorded by the iButtun see (appendix A).

6.5.4.1 Monitoring Plan

Temperature readings were taken using iButtons at 60 minutes intervals for ten days. The following diagram illustrates the distribution of the iButton devices in the compact house:

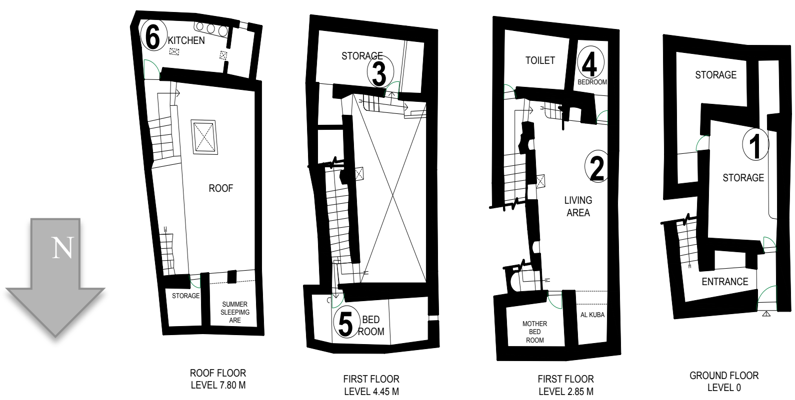
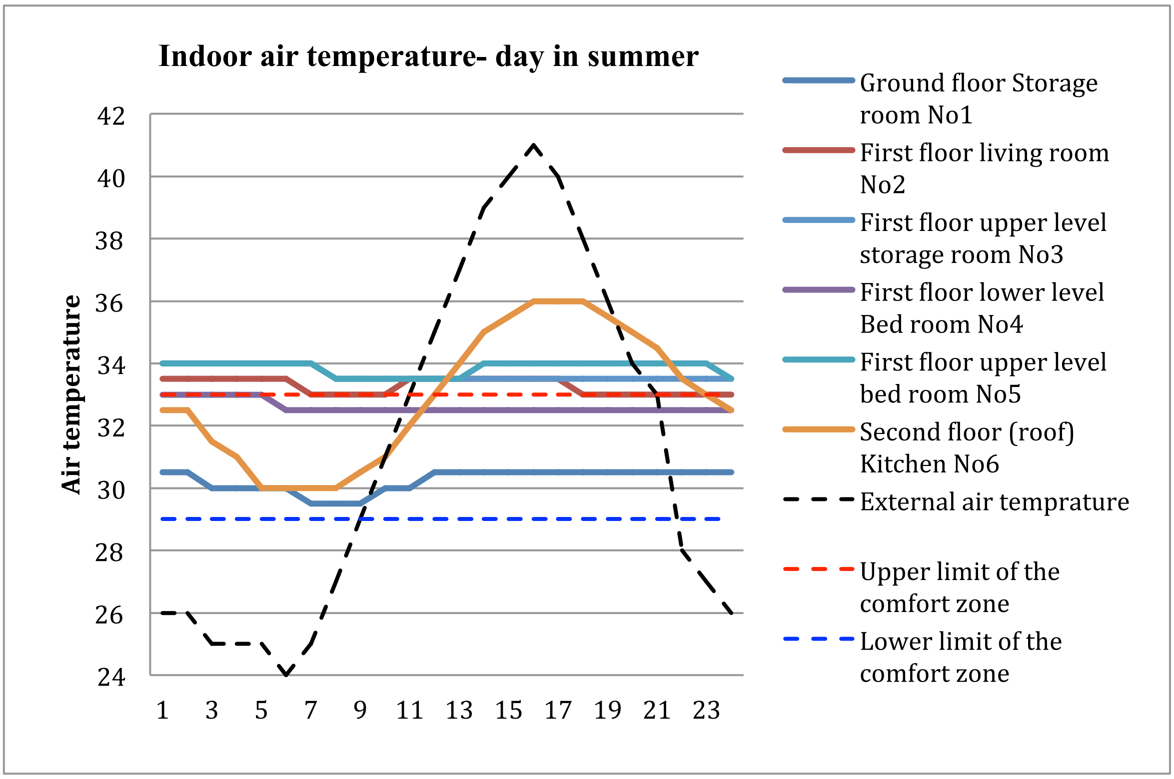


Figure (6. 13) iButton location -Plan



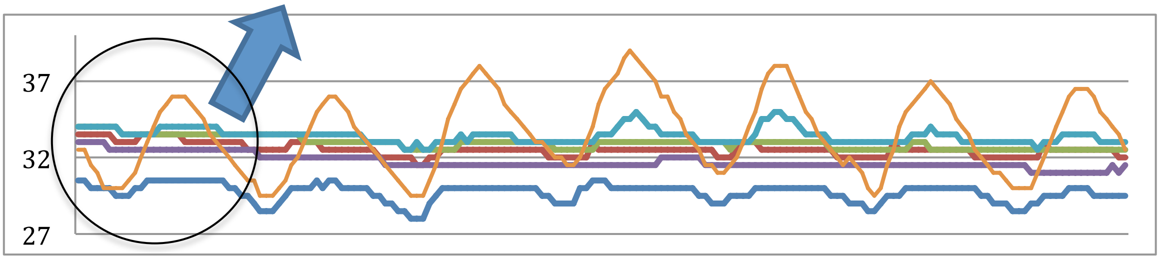


Figure (6. 14) Indoors air temperature -day in summer and week

***External air Temperature found from Meteorological station at Ghadames.**

6.5.4.2 Data Analysis

From studying the charts and comparing the thermal performance of the rooms, various points have been highlighted

- The roof floor reading illustrates that the external temperature shows a different fluctuation in summer and winter respectively as follows (above 36°C, 15°C at 16:30 in the afternoon and below 30°C, 10°C at 4:30 in the morning.
- In summer the indoor temperature fluctuated above 37°C at 4:00 afternoon and below 30°C at 4:00 in the morning, in winter the temperature drop to 14°C at 4:00 afternoon and below 10°C at 4:00, while in spring the temperature fluctuated above 31°C at 4:00 afternoon and below 21°C at 4:00 in the morning.

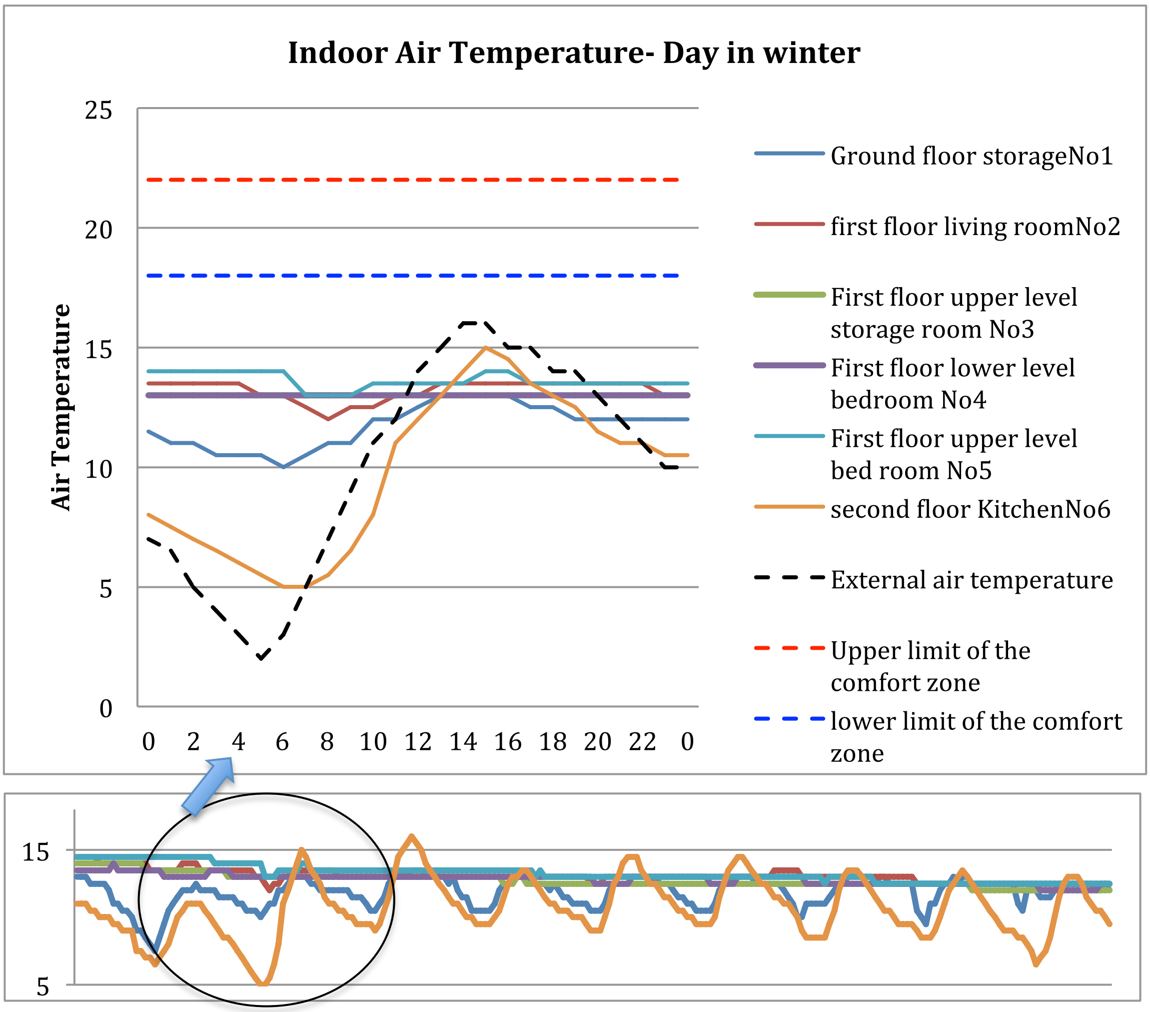


Figure (6. 15) indoors air temperature, day in winter and week

*External air Temperature found from Meteorological station at Ghadames.

- The ground floor storage has the lowest temperature in summer with a nearly flat line with only one degree different between day and night between 29°C to 30°C. Furthermore the temperature starts to increase from 12:00 as the solar radiation reaches the lower storage through the ground floor opening, illustrated in figure (6.14).
- Rooms on the higher floors have the highest temperature, as the only external element of the house envelope is the roof while the walls are shared with the adjacent houses.
- The shape of the house - a rectangle with the longer side oriented toward east west, and the high parapets on the roof allow perfect shading to the roof.
- The first floor lower bedroom No 4 has nearly flat fluctuation indoor temperature reading, as result of its location and has no connection to the external walls; in addition the room currently is not in use.

- The first floor upper level storage and lower level bedroom had the same fluctuation pattern with different temperatures; this is as result of their location and the position of the mirrors in the living room.
- The time lag for the homogeneous material subject to temperature fluctuation over a 24 hours cycle, as the outdoor temperature (roof temperature) will reach its peak and starts to decrease before the inner surface reaches its peak temperature, delaying the noon heat to the evening by up to 5 hours, thence from the graph the time delay of the heat to transmitted from one side of the construction to the other side throughout the house, figure (6.15).

Figure (6. 16) indoors air temperature 13:00, and the time lag.

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- The main living room is the room most affected by the external temperature as a result of its direct connection to the external envelope through its roof opening. Humidity in the house range between 20% in summer and 35 % in winter.
- The indoor air velocity in summer is 1m/s and in winter 1.3 m/s.
- The external temperature found from Meteorological stations using the following website (https://weatherspark.com/#!dashboard;a=Libya/Ghadames).
- The results were compared to the comfort temperature for Ghadames, using equations found in chapter five, that calculate the comfort zone for Ghadames:

$$T_{comf} = 0.46T_{rm} + 16.7 \pm 2$$

This sets the comfort zone for January (winter week) to 23°C as upper margin and 19 °C as lower margin. For July (summer week) it was set to 33°C as upper margin and 29°C as lower margin.

- The comparison shows that the indoor air temperature laid within the comfort zone during the summer period, this prove that traditional vernacular houses has a good thermal performance.

6.6 Micro climate –Gheryan

Gheryan is situated on the southern edge of a mountain (Jebal Nafusah), 300 meters above Jifarah Plain. On the west side of the city stretches the mountainous areas, south of the city lies an agricultural landscape covered with both orchards and crops, acting as barrier against the unwanted southern wind. However, the distribution and the nature of the earth shelter houses prevents the effect of surrounding buildings on the Micro-climate. (National Consulting Bureau 2009)

The earth sheltered houses are located according to the city topography, most of the houses being found on the higher level of the mountain, while a few are found on the lower levels. This can be related to the mountain slope and soil nature.

6.6.1 Physical component of the earth sheltered house

The traditional vernacular houses of Gheryan are distinguished by a minimal use of construction materials. The construction process of the earth-sheltered dwelling is a subtractive rather than additive one,(Oliver 2003). In other words they are the only houses that do not depend on any built structural elements. As more than 80 % of the house is excavated, while only 20% is built of local material, chiefly at the entrance area. As discussed in chapter three, Gheryan vernacular earth sheltered houses include two types of structural system in the dwelling: a load bearing wall system (over ground level) and excavation system (under ground level).

The first part is a small section built over ground that has a loadbearing wall construction system made of irregularly cut limestone plastered with lime plaster to protect the stone from exterior aggressions and humidity, the wall thickness is nearly 0.6m and its heights is 2.5m. The house has a flat roof constructed from treated olive branches, and covered with a layer of small stones mixed with clayed soil and lime.

The second part is the underground level; the courtyard is excavated into the ground. From studying the Gheryan geological levels, it is seen to consist of many layers: first a hard layer with a depth range from 1.80 to 2.40m, followed by a soft clay layer (National Consulting Bureau 2009). Therefore, the courtyard must be excavated to a depth of 10m in order to get to the soft layer. The size of the courtyard is 100 m^2 (10*10) allowing more space for the rooms to be excavated around the courtyard. The rooms are dug in nearly a trapezoidal shape, where the shortest dimension is at the entrance area, about 1.5m to 2m wide, then it becomes wider towards the inside, reaching a width of about 5.0m to 6.0m. The depths of the rooms are carefully chosen in order obtain a good air quality in the rooms, therefore it always less than 6m, while, as the kitchen has a shallow depth, the roof is curved into a nearly vaulted roof, with a height varying from 1.8 m near the entrance and rises to 2.5m in the middle and end of the room. The walls are coated with lime plaster, since its absorbency allows the evacuation of the inner humidity of the walls. Kitchens were excavated only on the south, east and north facing walls while the west facing wall is neglected as result of the west winter wind and rain. However, the kitchens have a shallow depth space with no doors; this allow more air circulation which is necessary for good air quality.

6.6.2 Passive cooling and heating techniques in courtyard houses

The thermal performance of the earth shelter house depends on many factors: house location and soil type, and the depth of the house. The soil is the key factor in earth sheltered dwellings Mike Edelhart points out that “soil is a complex, changeable, vital element of any earth sheltered design, one that should be examined carefully in conjunction with a professional engineer.” (Edelhart 1982)

6.6.2.1 Earth passive cooling and heating

Given the proper geology and hydrology Gheryan has the perfect aspects for earth sheltered house construction. The nature of the soil is an important aspect for the thermal performance of the earth shelter house. The soil temperature varies with the depth, type of the soil, time, and climate. The temperature of the soil is mainly affected by the thermo-physical properties of the material especially its conductivity and diffusivity (the ratio of the conductivity to the specific heat capacity) With higher diffusivity, heat is exchanged more easily between the surface and the layers below. The conductivity of the soil varies with the type of soil, and the moisture content. The conductivity of the soil with a high loam and clay content is higher than that of sandy soil, because it has higher water content. Therefore the diffusivity of loam and clay soil would be higher than that of a

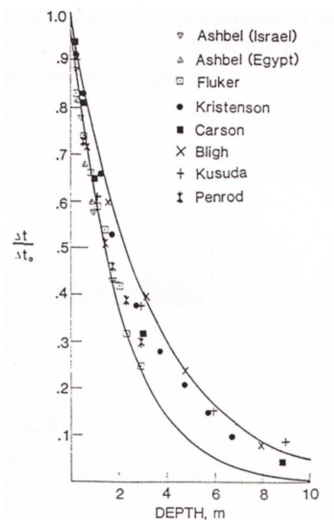


Figure (6. 17) Relative temperature range (dT/aTo) as function of depth various experiment studies (Givoni, 1994)

sandy soil, (Edelhart 1982). Below ground level, the temperature of the earth is remarkably even and remains close to the average yearly air temperature of the region. At greater depths, soil temperature responds only to seasonal changes, and the temperature change occurs after considerable delay, (Givoni 1994).

6.6.2.2 Openings orientation and shading strategies

In studying the construction process of the rooms excavation is essential in understanding the best orientation in the dwelling, as the first main rooms excavated on the East elevation taking advantage of the early sun radiation, the west facing elevation considered undesirable orientation, therefore it usually the last rooms to be excavated with their doors positioned nearly at the corners to avoid afternoon solar radiation.

The only opening in the room is through the entrance door; therefore the rooms have poor daylight, however the rooms have limited depth to obtain good quality air ventilation in the rooms.

6.6.2.3 Courtyard

The depth and dimensions of the courtyard create the core of the spatial arrangement of the house. It has a rectangular, nearly square, shape, with an area of 100 m2, with proportion of the wall to the dimension of the court width close to 1:1. This provides shade for the courtyard most of the day.

The courtyard wall was curved, creating a shading section to provide shade from sun and rain to the area near the rooms, Figure (6.18).

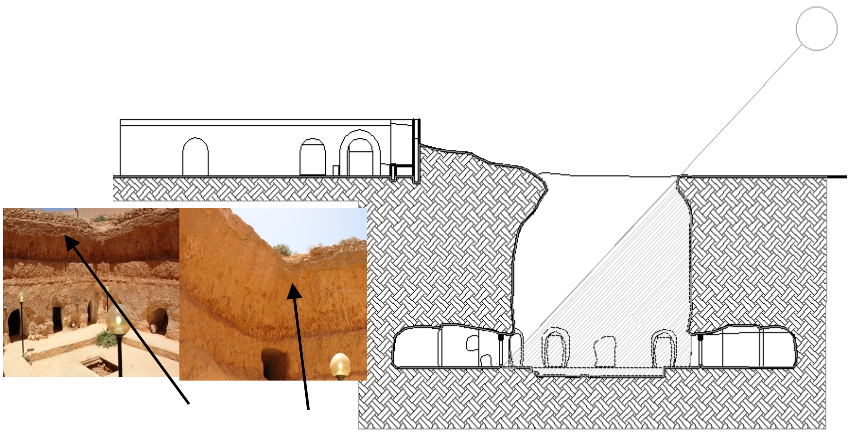


Figure (6. 18) shading strategy - Gheryan

6.6.3 Casual Heat Gain:

The casual gains includes occupants, lights and equipment; in the earth sheltered house the current occupants are a Libyan family, 55 years old male, female 50 years old, The male is retired; the female is a housewife. Secondly the lights, each room have 2 fixtures at 100 lux each, with heat emission of 40W. Lights for all zones are on most of the day, as result of poor daylight. Finally, equipment; there are two types of equipment: electrical plug loads (sensible heat gain only) and cooking equipment (sensible and latent heat gain) usually using a hooded gas burner unit. In addition, an electrical heater and an electrical fan are used in the living room on the ground floor.

6.6.4 Earth-sheltered house – Thermal monitoring

Nine iButton devices were distributed around the house, the devices positioned on the walls of each room. The following charts illustrate the room temperature through 24 hours for 7 days during 10 days in summer and 10 days in winter, from 24July to 6 August, and 21 December to the 3 January. Data recorded by the iButtun can be found at appendix A

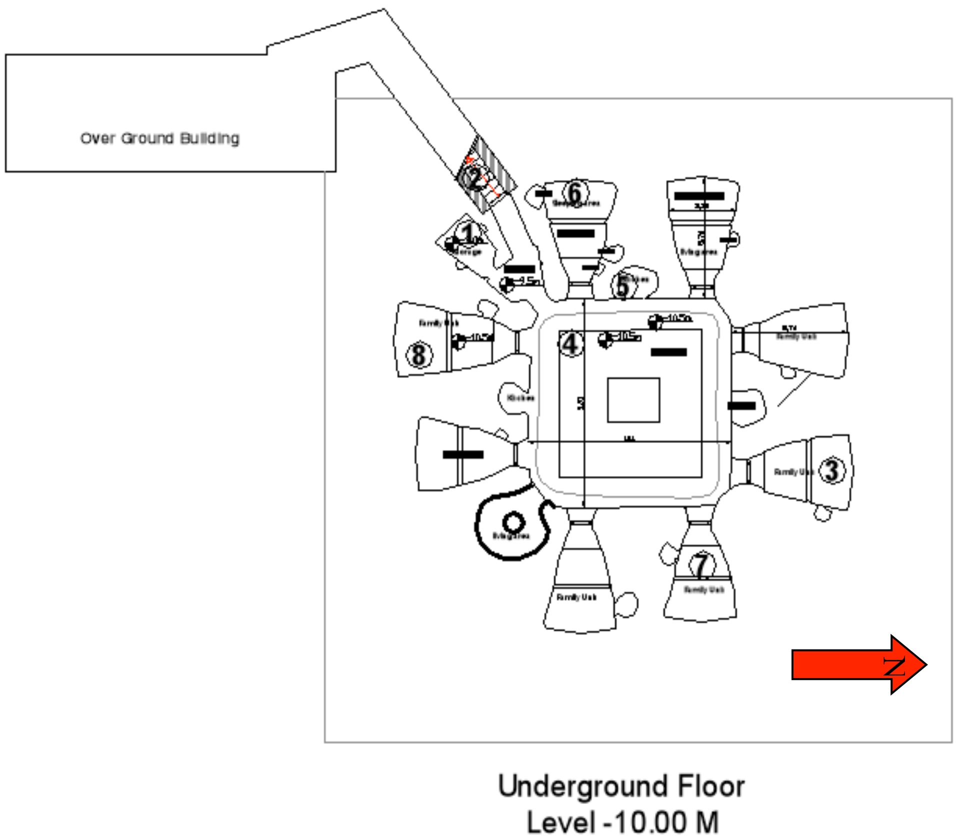


Figure (6. 19) iButton location in the house

6.6.4.1 Data Analysis

- The indoor temperature changes according to the seasonal earth temperature. In summer the indoor temperature is 20°C less than the external ambient temperature, and nearly 10°C above it in winter. In other word the room temperature is affected by the seasonal earth heat flows from the floor walls and roof; this changes according to the soil type, climate and the depth of the rooms. (GIVONI, 1976).
- The outdoor temperature (courtyard temperature) reaches its peak as illustrated in the external temperature readings. It is nearly 39°C at 15:00 and 23°C at 4:00, while in winter it drops to nearly 10°C at 14:00 and to nearly 6 °C at 4:00 while the solar radiation affects the room temperature only through the doors.

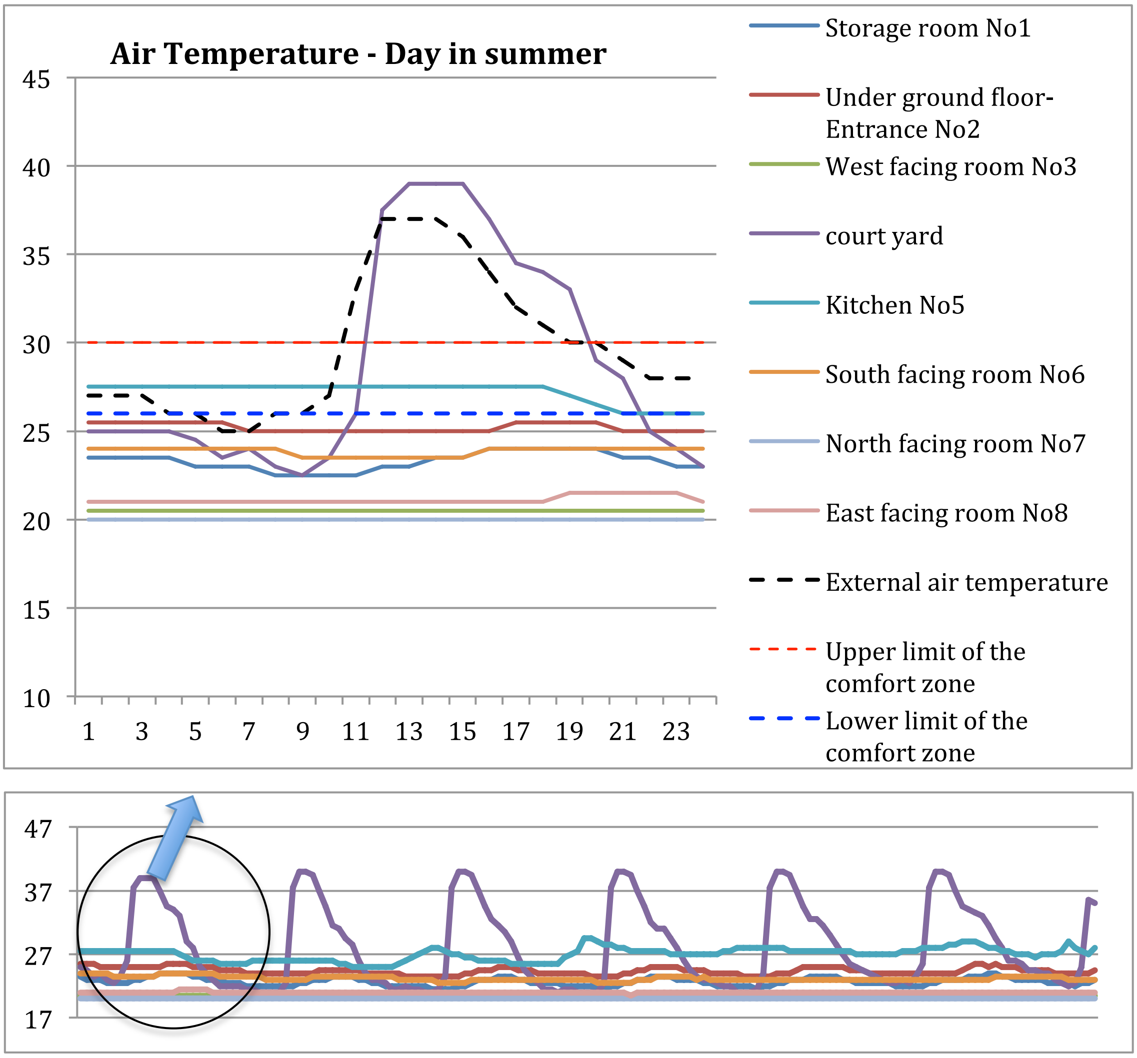


Figure (6. 20) indoors air temperature - day and a week in summer

*External air Temperature found from Meteorological station at Gheryan.

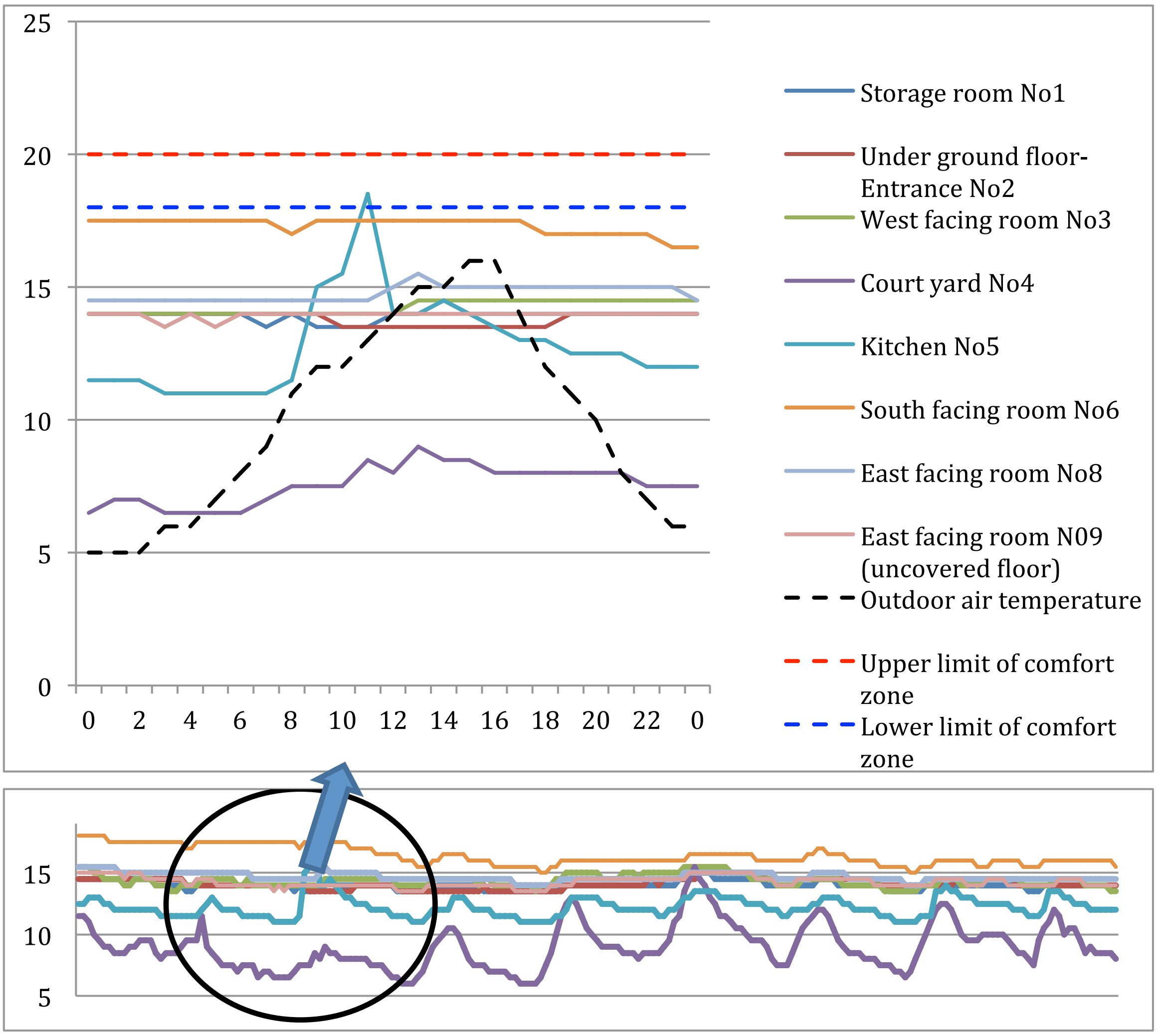


Figure (6. 21) indoors air temperatures - for a day and week in winter

***External air Temperature found from Meteorological station at Gheryan.**

- The room dimensions affect the indoor temperature. The deeper the room, the cooler it is. In addition there is a temperature variation within the room; the temperature near the door is affected by the external temperature and the air movement, while the deep end of the room is more effected by the earth temperature. With a shallow depth of nearly 1.8m, the kitchen (No 5) recorded the highest room temperature range, from above 27 °C to below 25 °C.
- East facing room No 6 has the highest temperature, with a flat reading at nearly 18C^{o}, as a result of the activity in the room.
- The heat losses and gains through the rooms envelope in remarkable, in summer the cold air flowed from the earth to the air near the wall and roof, rising as a result of actual gains and flowed through the doors to the courtyard. Therefore the shape and height of the room assists the heat exchange and improves the air quality of the room.

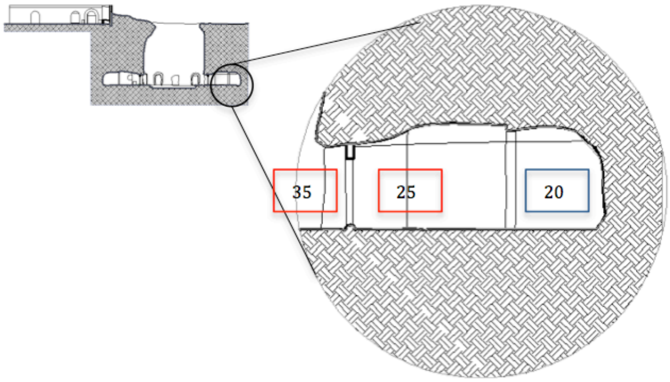


Figure (6. 22) variation in air temperature in the room (open door)

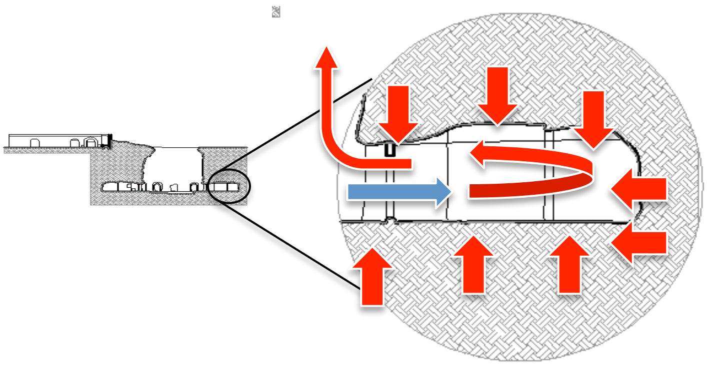


Figure (6. 23) heat flow from the earth to the rooms cool season

- There are indications of sudden changes in the readings of the kitchen temperature (as a result of cooking activity), however the sudden changes in the room temperature can be related to the change in the activity of the occupants.
- Rooms No 3, 6 and 7 recorded the lowest temperature reading, as result of the lack of ventilation (closed doors) and activity (abandoned rooms). With linear reading of nearly 20°C more or less the seasonal earth temperature.
- Relative humidity in the rooms ranges from 29% to 35% in winter and 20% to 30% in summer.
- The external temperature found from Meteorological stations using the following website (https://weatherspark.com/#!dashboard;a=Libya/Gharyan;a=Libya/Gharyan).
- The results were compared to the comfort temperature for Gheryan, using equations found in chapter five, that calculate the comfort zone for Gheryan:

$$T_{comf} = 0.47T_{rm} + 14.3 \pm 2$$

- This sets the comfort zone for January (winter week) to 22°C as upper margin and 18 °C as lower margin. For July (summer week) it was set to 30°C as upper margin and 26°C as lower margin.
- The comparison shows that the indoor air temperature laid within the comfort zone during the monitored period, this prove that traditional vernacular houses has a good thermal performance.

The indoor air velocity is very poor with only 0.1 m/s in both summer and winter.
From the results it can be conclude that earth cooling and heating technique can be considered the key factor in the traditional vernacular houses in Gheryan, in additional to other passive heating and cooling strategies such as orientation, opening and shading strategies.

6.7 Conclusion

In the three traditional vernacular houses the modification to the climate is the main aspect in the house construction. It is clear that the three houses have a respectable thermal performace, through their climate modification techniques which can be reused in the new houses in order to reduce the energy consumption.
The climate as main modifier of the house form can be illustrated in the position of the courtyard as everyday living space in the three traditional vernacular houses. The courtyard in the coastal region was positioned on the ground, while the courtyard was elevated on the roof in the desert region (to reduce the indoor heat gain), in the mountain region the courtyard was dropped to the underground level, (to benefit from the earth seasonal temperature).

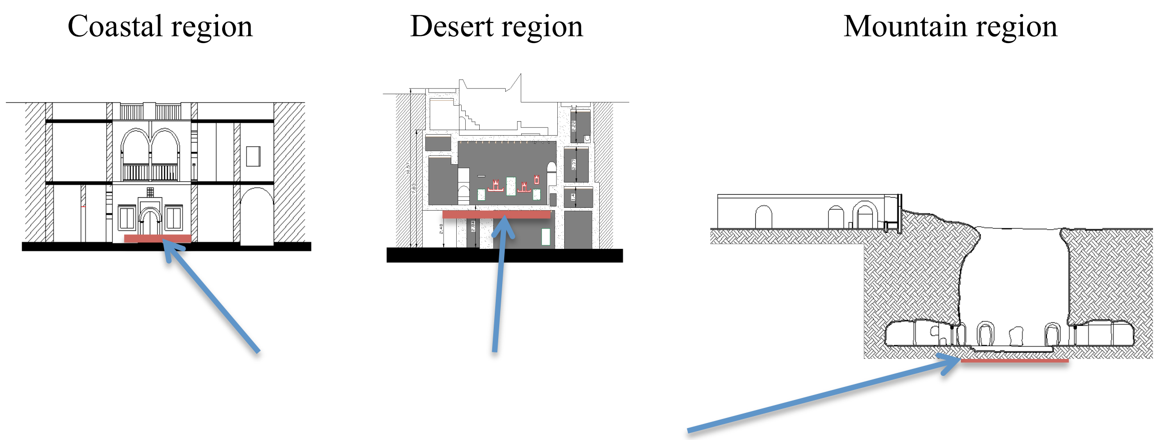


Figure (6. 24) courtyard modified by the climate in the three regions

Paul Oliver pointed out "If access to a wide range of materials is available the most suitable can be selected". The construction of the three house types depended on the materials available in the region, modified to cope with the climate in order to achieve the ultimate thermal comfort. Analysis of the thermal performance of the courtyard house in the coastal region demonstrates a noticeable reduction in both summer and winter heat ranges from 4-5K , the rooms on the ground floor have the best thermal performance. In the desert region, the thermal performance of the compact house displays a reduction in summer heat from 3 -7K. The rooms on the ground floor have the lowest temperature, and in winter it ranges from 5-10K. Finally in mountain region, the thermal performance of the earth shelter house displays a reduction of summer heat of 11- 20K and it ranges from 5-8K in winter, changing according to the rooms depth, and seasonal soil temperature.

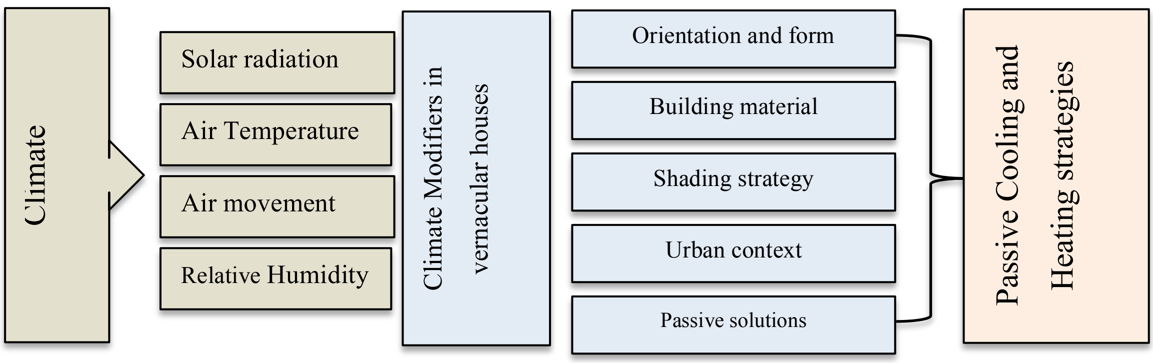


Figure (6. 25) Passive heating and cooling strategies.

The main conclusion of this chapter is that the traditional vernacular dwellings have a remarkable thermal performance. The climate factors such as solar radiation, air temperature, air movement and relative humidity have been modified by the passive cooling and heating strategies in the houses.

7. Chapter Seven: Energy Simulation –ESP-r

7.1. Application of the Energy Simulation

In this chapter a house model has been developed and analyzed using a computer programme to examine the thermal performance of the building in three climatic zones of Libya. The layouts for the house were modified according to the environmental and cultural requirement in the three cities of Tripoli, Gheryan and Ghadames. The energy simulation results were analyzed to achieve the lowest energy consumption within the comfort zone of the region.

7.2. Energy Simulation Methods and Tools.

During the last decades many energy-modeling tools have been developed, such as Energy Plus, PSVyst, TRNSTS, IES-VE and ESP-r. Crawley's report (Crawley, 2014), "Constructing the capabilities of building energy performance simulation programs", compared 20 major energy simulation programs where the comparison is based on various criteria such as internal loads, daylighting, insulation, thermal mass, infiltration, ventilation, HVAC system and renewable system. From his report, it can be concluded that (ESP-r) is one of the top programmes that can provide the most comprehensive set of capabilities. In addition, ESP-r is available for academic research and offers flexibility and support for research purpose, and it is also open for developers to enhance and upgrade the performance. Therefore, this study has adopted the (ESP-r) program, to be used for the analysis of the thermal performance and energy consumption of the model in the three climatic zones of Libya.

7.3. Energy Simulation Procedure

The procedure was done in three phases: firstly establishing the input data for the three models, secondly the simulation and finally the result recovery and analysis. From the basic database folder, three databases were modified according to the environmental requirements for each city; the climatic database, the material database and the construction database were developed for each city as illustrated in figure (7-1).

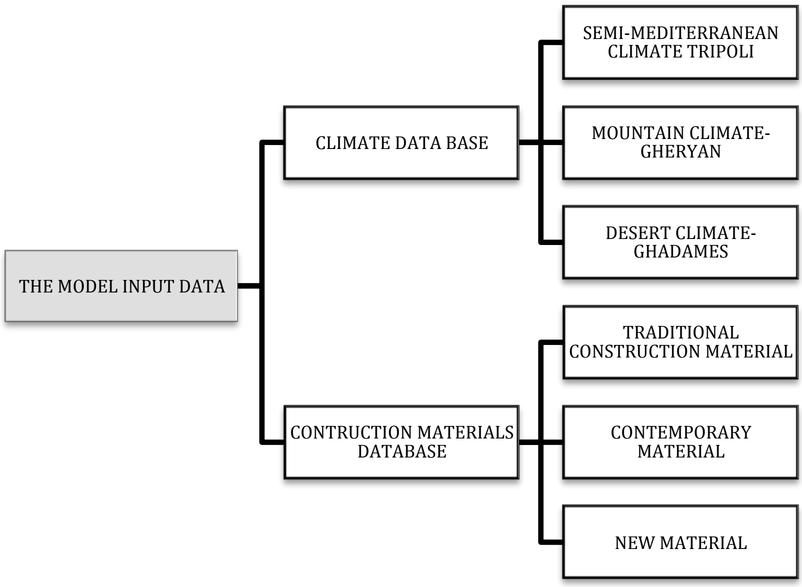


Figure (7. 1) Database input for the models

7.3.1. Climate Database

A climate database for the three cities has been obtained from METEONORM Software as EPW files and converted to an (ESP-r) binary climate file. Climate database sets of hourly values of Diffuse horizontal solar intensity (W/m^2), Dry bulb temperature (tenth of a degree), Direct normal or global horizon, solar intensity (W/m^2), Wind speed (tenths of m/s), Wind direction (degree from North, clockwise) and Relative humidity (percent), for one year from 1 January to 31 December. The climate parameters for the three cities were presented earlier in Chapter 4.

7.3.2. The material databases

Energy demand in building can be significantly reduced by the use of the right building materials. The thermophysical properties of the material determine its thermal performance: therefore studying its thermal properties is the key point to achieving the optimum building shell.

For the purpose of the study, new materials were added to the database to include local materials such as sun dried sand blocks and date palm wood insulation. Moreover, the thermophysical properties of these materials were added to the database as illustrated in Figure (7.2).

Material details
a Name: Sundry sand block
b Note: Sand
c Conductivity (W/(m-K) : 1.830
d Density (kg/m**3) : 2200.00
e Specific Heat (J/(kg-K): 712.00
f Emissivity out (-) : 0.900
g Emissivity in (-) : 0.900
h Absorptivity out (-) : 0.600
i Absorptivity in (-) : 0.600
j Vapour res (MNs g^-1m^-1): 29.00
k Default thickness (mm) : 200.00
l type >>legacy opaque

Material details
a Name: date palm mix
b Note: Date palm insulation
c Conductivity (W/(m-K) : 0.080
d Density (kg/m**3) : 979.00
e Specific Heat (J/(kg-K): 1800.00
f Emissivity out (-) : 0.900
g Emissivity in (-) : 0.900
h Absorptivity out (-) : 0.500
i Absorptivity in (-) : 0.500
j Vapour res (MNs g^-1m^-1): 3.00
k Default thickness (mm) : 100.00
l type >>legacy opaque

Figure (7. 2) the thermo physical properties of the new material

One of the main techniques for reducing the U value of the building envelope is to apply insulation in walls and roof, (Panyakaew and Fotios 2011).The selection of insulation material plays a critical role in preventing loss of heat; the most widely used categories of the insulation material are inorganic fibres such as glass wool and stone wool. The following figure (7.3) illustrates the classification of thermal insulation materials used in buildings.

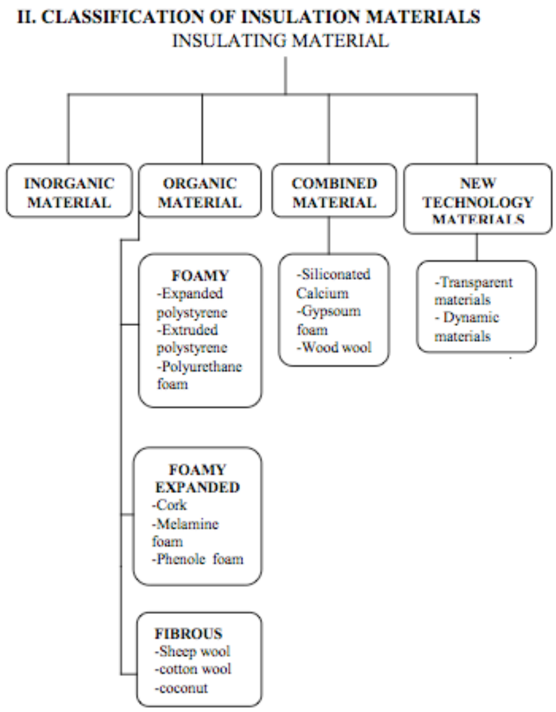


Figure (7. 3) Classification chart of the most used Insulation materials, Source (Papadopoulos and Giama, 2007a)

Due to environmental and sustainability issues, the natural fibre material was widely investigated as an alternative green material, because of its availability and cost. Satta Panyakaew (2008) points out that not just the thermophysical material should be of concern but also its environmental sustainability and health impact, considering that the current popular insulation materials have negative side effects from the production stage until the end of their useful lifetime (Papadopoulos and Giama 2007a). Insulation has been examined by researchers in terms of the use of renewable raw material resources originating from agricultural waste such as jute, flax, rice-hulls, coconut, corn cob, oil palm leaves and date palm as an alternative insulation material. (Al-Homoud 2005; Papadopoulos and Giama 2007b; Al-Maadeed et al. 2012; Satta Panyakaew; Alami 2013; Boudjemaa Agoudjil 2011).

Researchers have been studying the date palm tree as a building material, mainly for thermal insulation, and most of the studies concluded that date palm wood is a renewable biodegradable building and insulation material that can give a net reduction in CO_2 emissions over its life cycle (M. A. AlMaadeed 2014; AlMaadeed et al. 2012; Alami 2013; Amirou Siham 2013; Boudjemaa Agoudjil 2011). An experimental study in Algeria (Amirou Siham 2013) shows that the thermophysical properties of date palm wood differ according to the type of palm. The study tests three varieties of date palm wood (phoenix dactylifera) in order to use it in the manufacture of thermal insulation for buildings. The study also compared the results with other natural building insulation materials such as hemp, cork, sisal and banana wood, and found that except for cork, the date palm wood exhibits lower thermal conductivity, as shown in figure (7.4). Thus, it can be concluded that the date palm wood is a good candidate for the development of efficient and safe insulation material, with conductivity ranges from 0.03 W/mK (Boudjemaa Agoudjil 2011) to 0.083 W/mK (Amirou Siham 2013), depending on the mixture and source, as the thermal conductivity for the samples decreases by increasing the palm fibre content. (M. A. AlMaadeed 2014).

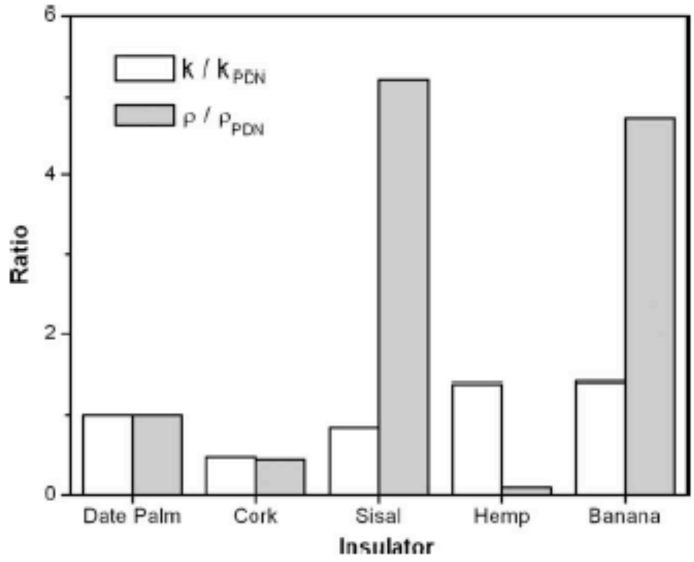


Figure (7. 4) Comparison between thermal conductivity and density of some natural fiber base insulation materials, Source (Amirou Siham 2013)

Therefore, this research is considering the date palm insulation, and using it as one of the alternative insulation materials for the model for two reasons: its thermal properties as discussed above, and the wide availability of the date palm in Libya. It has been recorded by ACSAD (Arab Center for Studies for Arid zones and Dry land) study (ACSAD, 2011) that the date palm is one of the most cultivated palms in the arid and semi-arid regions of the world, It is spread all over the western Arab region from Morocco to Libya and, according to the ACSAD study, Libya has more than 7 million date palm trees and it is considered the most cultivated tree in the region,.

The two types of insulation material proposed in this study are cork and the new insulation material date palm wood. The thickness of the insulation depends on the required U value required for the component. For the wall construction using 50 mm of the thermal insulation (local material) palm tree fiber set in the cavity between a hollow concrete block and breeze block can result in a U value of 0.891 W/m^2K. Moreover the U value can be reduced to 0.58 W/m^2K by increasing the thickness of insulation material from 50 mm to 100mm. The U value for a limestone block wall is calculated at 0.895 W/m^2K. This U value can be reduced to 0.57 W/m^2K by increasing the insulation material thickness from 50 mm to 100mm. The U values for all the opaque elements are similarly treated.

7.3.3. Multi Construction database

In order to calculate the heat flow through the building envelope, the U value must be calculated; the U-value is the overall heat transfer co-efficient through the building envelope components, in other words it is a measure of heat loss or gain through the building components. Therefore, a lower U value for the component indicates that the construction has better thermal performance. In this study, the input data for the envelope constructions have been categorized into three categories; local, contemporary and new constructions.

Setting the right value for the U-value input data depends on the thermophysical properties of the material and the thickness of the construction (Givoni 1994). Usually these data can be found in the building regulations of the country. Referring to the first chapter of this study, Libyan building regulations do not include an energy section that sets the minimum energy performance requirements for buildings. Therefore it is useful to give an overview of the regulated U value required for dwellings in UK and the EU as shown in Table (7.1).

	Roofs	Outer walls	Ground floors	Windows
Austria	0.2–0.3	0.3–0.4	0.4–0.5	1.0–1.5
Belgium (Flanders)	0.4–0.5	0.5–0.6	0.6–0.6	1.5–2.5
Denmark	0.1–0.2	0.2–0.3	0.1–0.2	1.5–2.5
Finland	0.1–0.2	0.2–0.3	0.2–0.3	1.5–2.0
France	0.2–0.3	0.4–0.5	0.3–0.4	1.5–2.5
Germany	0.2–0.3	0.5–0.6	0.4–0.5	1.0–1.5
Greece	0,4–0,5	0,5–0,7	0,7–1,9	2,5–3,5
Ireland	0.1–0.2	0.2–0.3	0.2–0.3	1.5–2.5
Italy	0.3–0.4	0.4–0.5	0.4–0.5	2.5–3.5
Lithuania	0.1–0.2	0.2–0.3	0.2–0.3	1.5–2.5
Norway	0.1–0.2	0.2–0.3	0.1–0.2	1.0–1.5
Portugal	0.6–0.6	0.6–0.6	0.6–0.6	2.0–3.0
Russian Federation	0.1–0.4	0.1–0.2	0.1–0.4	1.5–3.5
Spain	0.6–0.6	0.6–0.6	0.6–0.6	2.5–3.5
Sweden	0.1–0.2	0.1–0.2	0.1–0.2	1.0–1.5
Switzerland	0.3–0.4	0.3–0.4	0.6–0.6	1.0–1.5
UK	0.1–0.2	0.3–0.4	0.2–0.3	1.5–2.5
The Netherlands	0.2–0.3	0.2–0.4	0.2–0.3	1.5–2.5

Table (7. 1) Typical U-value for the building envelope of presently built residential building in various European countries. Source (Papadopoulos and Giama, 2007,a)

In European countries the U value ranges from 0.1 to 0.6 for roofs, and outer walls, and ranges from 0.1 to 1.9 for ground floors. The window U value is higher with 1 to 3.5. For the purpose of this research, the study adopted the highest U value set by the European countries, especially the Mediterranean countries such as Greece and Spain.

Therefore the U value for the model will be set to less than 0.6 for walls, 0.6 for roofs, 0.6 for ground floors and 2.5 for windows.

Studying the available materials and construction methods is essential to the low energy building process therefore, the building material has been analysed in order to select the right material for the model that is locally available and has best thermal performance.

7.3.3.1 Construction using local materials (Traditional vernacular)

In the three regions of Libya, people used to construct their houses using the material available in the region. In Tripoli and Gheryan limestone was used as the main material for the construction of walls, and date palm wood as the main element for the construction of roofs. In Ghadames sun dried sand blocks were considered to be the main material for wall construction. The following tables (7-2, 7-3, 7-4) illustrate the thermal transmittance value of the construction materials used in the three traditional vernacular houses; first material used for walls in Tripoli and Gheryan houses (for Gheryan the material of the over ground construction).

Ext	Material description	Thickness mm	Conductivity W/m deg. C	Density kg/m**3	Specific heat J/(kg deg. C)
1	Lime plaster	20	0.7	1400	920
2	Lime stone	600	1.5	2180	720
3	Lime plaster	20	0.7	1400	920
In	U-value	1.5 W/m^2K			

Table (7. 2) Traditional vernacular construction material for walls used in Tripoli and Gheryan

Ext	Material description	Thickness mm	Conductivity W/m deg. C	Density kg/m**3	Specific heat J/(kg deg. C)
1	White dry render	30	0.5	1300	1000
2	Sand dry block	600	1.83	2200	712
3	White dry render	30	0.5	1300	1000
In	U value	1.618 W/m^2K			

Table (7. 3) Traditional vernacular construction material for walls used in Ghadames.

Ext	Material description	Thickness mm	Conductivity W/m deg. C	Density kg/m**3	Specific heat J/(kg deg. C)
1	Sand stone mixture	150	1.83	2200	712
2	Palm tree leaves (mat)	30	0.083	1800	180
3	Palm tree wood	150	0.08	600	2000
In	U value	0.402 W/m^2K			

Table (7. 4) Traditional vernacular contracture materials for roofs used in Tripoli and Ghadames

7.3.3.2 Contemporary building material thermal analysis

Contemporary houses located in the three cities are built with reinforced concrete frameworks, consisting of reinforced concrete roofs and columns and using hollow concrete blocks, limestone blocks or breeze blocks for wall construction in single layers. The following tables (7-5, 7-6, 7-7) illustrate the U-values for the building construction materials for external, internal walls and roofs, firstly using concrete blocks for walls secondly using limestone blocks.

Ext	Material description	Thickness mm	Conductivity W/m deg. C	Density kg/m**3	Specific heat J/(kg deg. C)
1	Light plaster	3	0.16	600	1000
2	Cement screed	20	1.4	2100	650
3	Hollow concrete block	150	1.06	1950	650
4	Cement screed	20	1.4	2100	650
5	Light plaster	3	0.16	600	1000
In	U value	2.648 W/m²K			

Table (7. 5) Contemporary construction materials for concrete walls

Ext	Material description	Thickness mm	Conductivity W/m deg. C	Density kg/m**3	Specific heat J/(kg deg. C)
1	Light plaster	3	0.16	600	1000
2	Cement screed	20	1.4	2100	650
3	Lime stone block	200	1.5	2180	720
4	Cement screed	20	1.4	2100	650
5	Light plaster	3	0.16	600	1000
In	U value	2.707 W/m²K			

Table (7. 6) Contemporary construction materials for limestone walls

Ext	Material description	Thickness mm	Conductivity W/m deg. C	Density kg/m**3	Specific heat J/(kg deg. C)
1	Floor tiles	10	0.6	500	750
2	Cement mortar	20	1.4	2100	650
3	Bitumen felt	6	0.5	1700	1000
4	Heavy mix	100	1.4	2100	653
5	Hollow brick	100	0.44	1500	650
6	Cement screed	20	1.4	2100	650
In	U value	2.016 W/m²K			

Table (7. 7) Contemporary construction materials for roofs used in the three cities

Ext	Material description	Thickness mm	Conductivity W/m deg. C	Density kg/m**3	Specific heat J/(kg deg. C)
1	Common Earth	400	1.2	1460	879
2	Gravel based	400	0.5	2050	184
3	Light mix concrete	50	0.38	1200	653
4	Bitumen felt	6	0.5	1700	1000
5	Heavy mix concrete	100	1.4	2100	653
6	Cement mortar	10	0.8	1800	1120
7	Floor tiles	6	0.6	500	750
In	U value	0.654			

Table (7. 8) Contemporary construction materials for ground floor

7.3.3.3 New construction for walls and roof

From chapter four of this study and the data above, it is clear that vernacular traditional houses have proven to be better in thermal performance than contemporary houses, therefore studying the local building material is key to improving the thermal performance of modern houses. The study aims to use the materials available in Libya to set a new construction composition for walls and roofs in order to minimize the energy performance requirement for new houses. By combining the new building technology with the design concepts of traditional vernacular houses, energy efficient houses can be achieved.

The main ambition of the study is to encourage the use of locally available construction materials in each city for building houses, in order to reduce energy consumption and to improve the thermal performance of the houses. Currently in Libya, three main materials are used in the construction industry; hollow concrete blocks, limestone blocks and breeze blocks, the first two being the most commonly used in domestic construction. However, sand block material was introduced to the Libyan market in 2012. A sand block plant was built in the south of Libya using naturally available materials. In this study the use of the three materials mentioned above as a wall was subject to their availability in the city. The following tables (7-9, 7-10, 7-11) illustrate the thermal performances of the three walls, firstly using a cavity wall made of sand block and breeze block with insulation in the cavity, secondly replacing the sand block with limestone, and finally replacing the limestone with concrete block.

Ext	Material description	Thickness mm	Conductivity W/m deg.C	Density kg/m**3	Specific heat J/(kg deg.C)
1	Light Plaster	3	0.16	600	1000
2	Cement screed	20	1.4	2100	650
3	Sand Block	100	1.8	1800	712
5	Date palm insulation	100	0.08	600	2000
5	Breeze block	100	0.44	1500	650
6	Cement screed	20	1.4	2100	650
7	Light plaster	3	0.16	600	1000
In	U value	0.578W/m²K			

Table (7.9). New construction material for external wall using sand block and date palm thermal insulation material.

Ext	Material description	Thickness mm	Conductivity W/m deg. C	Density kg/m**3	Specific heat J/(kg deg. C)
1	Light Plaster	3	0.16	600	1000
2	Cement screed	20	1.4	2100	650
3	Lime stone block	100	1.5	2180	720
5	Date palm insulation	100	0.08	979	1800
5	Breeze block	100	0.44	1500	650
6	Cement screed	20	1.4	2100	650
7	Light plaster	3	0.16	600	1000
In	U value	0.574 W/m²K			

Table (7.10). New construction material for external wall using lime stone and date palm thermal insulation

Ext	Material	Thickness	Conductivity W/m	Density	Specific
1	Light Plaster	3	0.16	600	1000
2	Cement screed	20	1.4	2100	650
3	Hollow concrete	100	1.06	1950	650
5	Date palm insulation	100	0.08	600	2000
5	Breeze block	100	0.44	1500	650
6	Cement screed	20	1.4	2100	650
7	Light plaster	3	0.16	600	1000
In	U value	0.580 W/m²K			

Table (7.11). New construction material for external walls using hollow concrete block and date palm thermal insulation.

However using 100 mm of cork as insulation material will change the U value in the sand block wall, limestone block wall and hollow concrete wall down to 0.336, 0.334 and 0.331 W/m^{2}K respectively. Moreover, the cavity wall components were tested for condensation using the Cymap programme (Slab) during winter season, when the temperature outside drops to 10 ^{o}C and the inside comfort temperature is 22 ^{o}C, and RH is 80% outside and 60% inside the house, the result shows that by using the breeze block as the second layer, no condensation in the above wall construction would occur.

The new combined roof materials from the vernacular and contemporary in addition to 50 mm of date palm insulation are shown in table (7-12). New building construction material for roofs using date palm insulation reduces the U value of the roof from 2.016 W/m^{2}K to 0.563 W/m^{2}K. Alternatively, U values of 0.53 W/m2K may be achieved by using cork as an insulation material.

Ext	Material description	Thickness	Conductivity	Density	Specific heat
1	Floor tiles	10	0.6	500	750
2	Cement screed	20	1.4	2100	650
3	Bitumen felt	6	0.5	1700	1000
4	Date palm insulation	50	0.08	979	1800
5	Heavy mix concrete	100	1.4	2100	653
6	Hollow brick	100	0.44	1500	650
7	Cement screed	20	1.4	2100	650
In	U value	0.563 W/m^{2}K			

Table (7. 12) New construction material for the roof adding Date palm thermal insulation

7.3.4. The model layout

The layout of the models is based on a contemporary house design as described in chapter two of this research. The study adopts the courtyard terrace house, figure (7-5), as the model for the contemporary house for many reasons; firstly, the house is considered to be the most popular houses in Libyan cities. Secondly, the house form is very widespread in Libya for low and middle income classes of the society, this indicates a noticeable percentage of housing in the urban fabric of most of Libyan cities. Finally, the compact layout of the house offers a respectable volume to surface ratio, and reduces the exposed surface area. The layout was modified according to the climate differences in each city; these differences are represented in the layout, orientation and context.

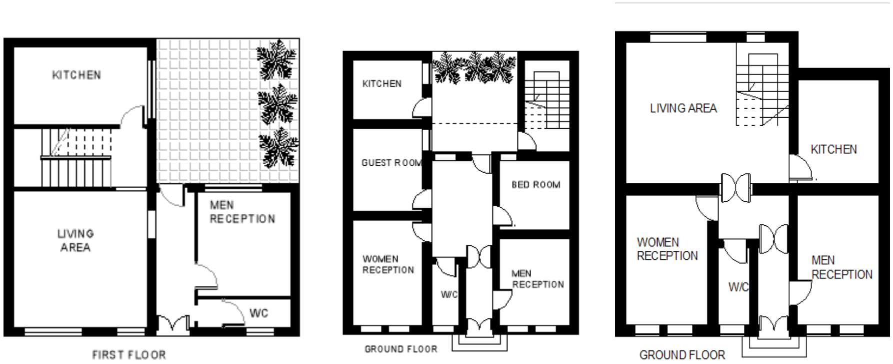


Figure (7. 5) Different layout options for the contemporary courtyard house

7.3.5. Casual heat gains

This section deals with the internal gains inside the space: in this study an average Libyan family with 6 to 8 persons has been added as occupants and the actual heat gain inside the house was calculated with respect to their cultural and social behaviour. Therefore, each zone in the model has a different occupant heat load related to the number of people in the zone and their activity. According to CIBSE, one person doing light work produces in total 115 W, divided into sensible and latent according to the room temperature. At a room temperature of 24°C, a person produces 75W of sensible heat and 40 W of latent heat with 0.2 radiant and 0.8 convective. However in an air temperature of 26 °C they would produce 65W of sensible heat and 50 W of latent with 0.2 radiant and 0.8 convective.

Zones	Casual gain	Period	Sensible	Latent	Radiant	Convection
Guest room	Occupancy	16- 24	70	70	0.5	0.5
	Lights	18- 24	2×40	-	0.6	0.4
	Equipment	-	-	-	-	-
Kitchen	Occupancy	13-15	90	175	0.5	0.5
	Lights	18- 24	2×40	-	0.6	0.4
	Equipment	8 – 20	570	1344	0.32	0.68
Living room	Occupancy	14- 24	6×65	6×50	0.5	0.5
	Lights	18- 24	2×40	-	0.6	0.4
	Equipment	14 – 24	140	-	0.2	0.8
Bed rooms	Occupancy	0- 8, 14-24	2×95	2×45	0.5	0.5
	Lights	18-24	2×40	-	0.6	0.4
	Equipment	-	-	-	-	-

Table (7. 13) the internal heat gain for each zone

Lighting for all zones is ‘on’ from 18.00 to 24.00, with only sensible heat gains, using 2 fixtures at 100 lux each, with heat emission of 40W/m^2 of the floor area.

There are two types of equipment: electrical plug loads (sensible heat gain only) and cooking equipment (sensible and latent heat gain) usually employing a hooded gas burner unit. Table (7-13) shows the internal heat gain for each zone.

The figures (7-6), (7-7) and (7-8) illustrate the casual gains for the kitchen, living room and the bedrooms, in the operation model in ESP-r. In the kitchen the total heat gains were recorded at over 1600W during the peak use of the space from 13:00 to 14:00, this related to the heat gains from the cooking equipment.

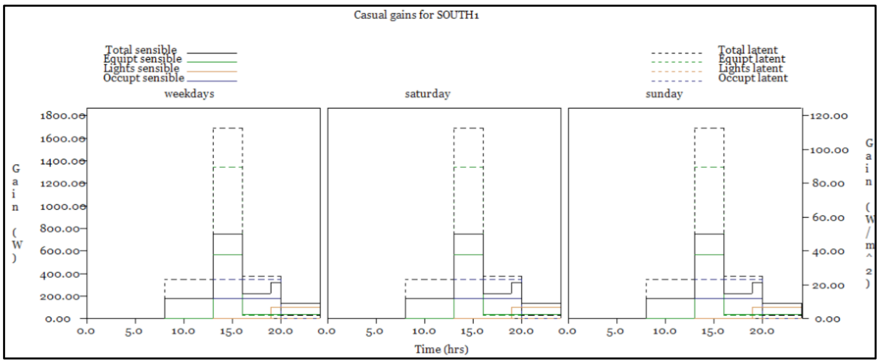


Figure (7. 6) Casual heat gains for the Kitchen zone

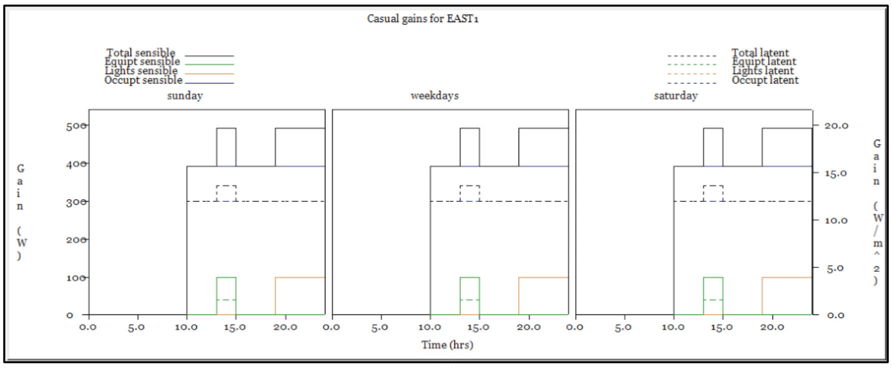


Figure (7. 7) Casual gains for the Living room zone

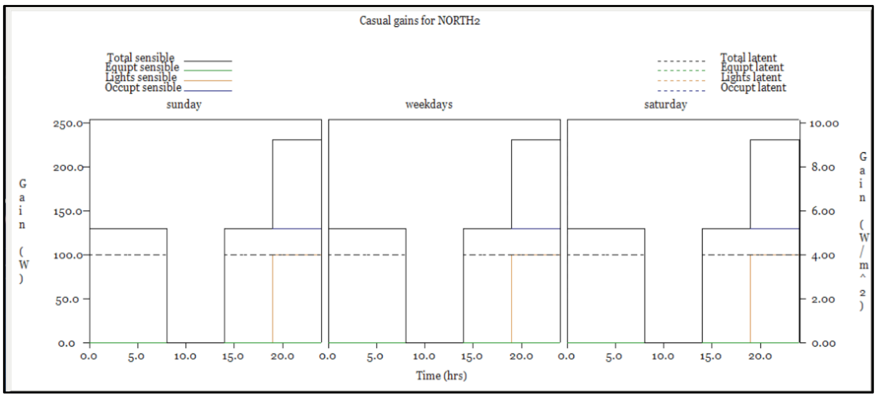


Figure (7. 8) casual heat gains for the bedroom zone

7.3.6. Ventilation and infiltration

The ventilation and infiltration was defined as constant air change where an infiltration rate with 0.5 ac/h was assumed for the zones. The air leakage distribution is in form of air leaks through cracks around windows, openings and doors from the external environment this infiltration is governed by flow network airflow. The flow network consists of several types of nodes assigned for the internal zones and the external environment; these are connected by components (openings, cracks, windows and doors); the type and description of the components was defined between the internal and external. The windows were defined to be open for passive ventilation during summer, therefore the programme will calculate with open windows if the temperature in the zone is above a certain limit. The airflow is controlled by a control loop that is set for certain periods and temperatures and connected to a sensor in a defined zone. In total 14 nodes, 6 components and 21 connections have been defined for the airflow network.

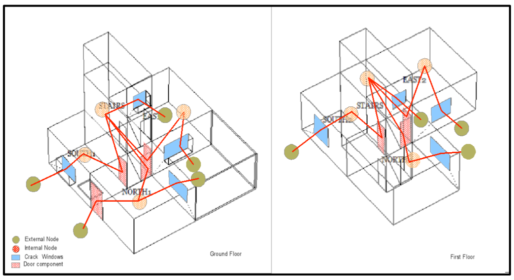


Figure (7. 9) Air flow diagram of the ground and first floors

7.4. Methodology and structure of the simulation strategy

Energy simulations for the model were made for the three climatic regions as naturally ventilated buildings using the same construction material but different climatic databases. The simulation was done in three steps: firstly the design strategy, as base case for Tripoli layout and then the model was modified according to the climate requirement with respect to the vernacular houses in the region. Secondly the orientation strategy: a four-zone model has been simulated to test the best orientation and best location for the courtyard. Thirdly, the model established for the region has been simulated with different passive cooling and heating strategies, first as base model and then with different strategies. Each strategy was tested and was compared with the base case, which includes insulation, shading strategy, glazing strategy, and context layout. Finally a combined strategy is simulated using the best results from the individual strategies. The following figures illustrate the simulation strategies.

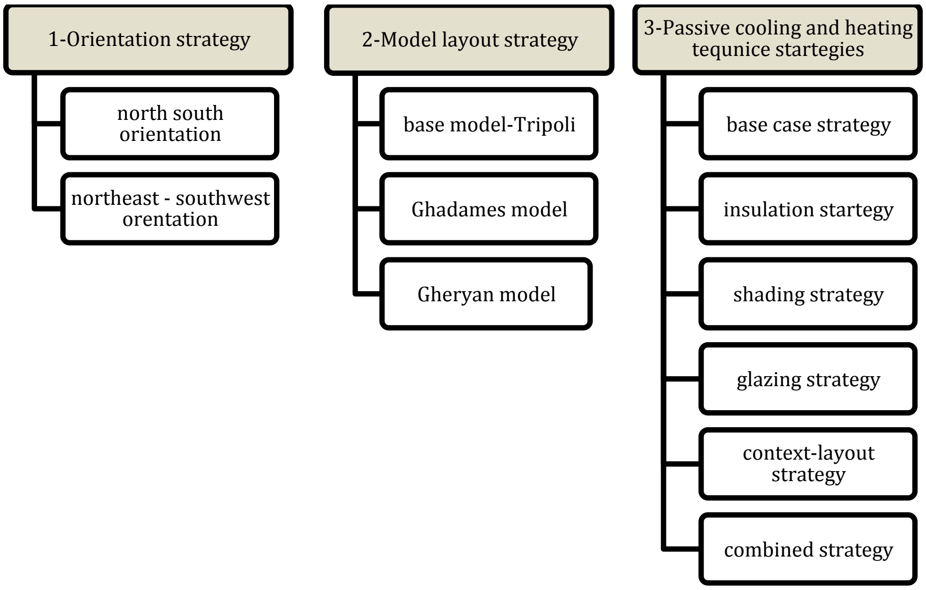


Figure (7. 10) Energy simulation strategies.

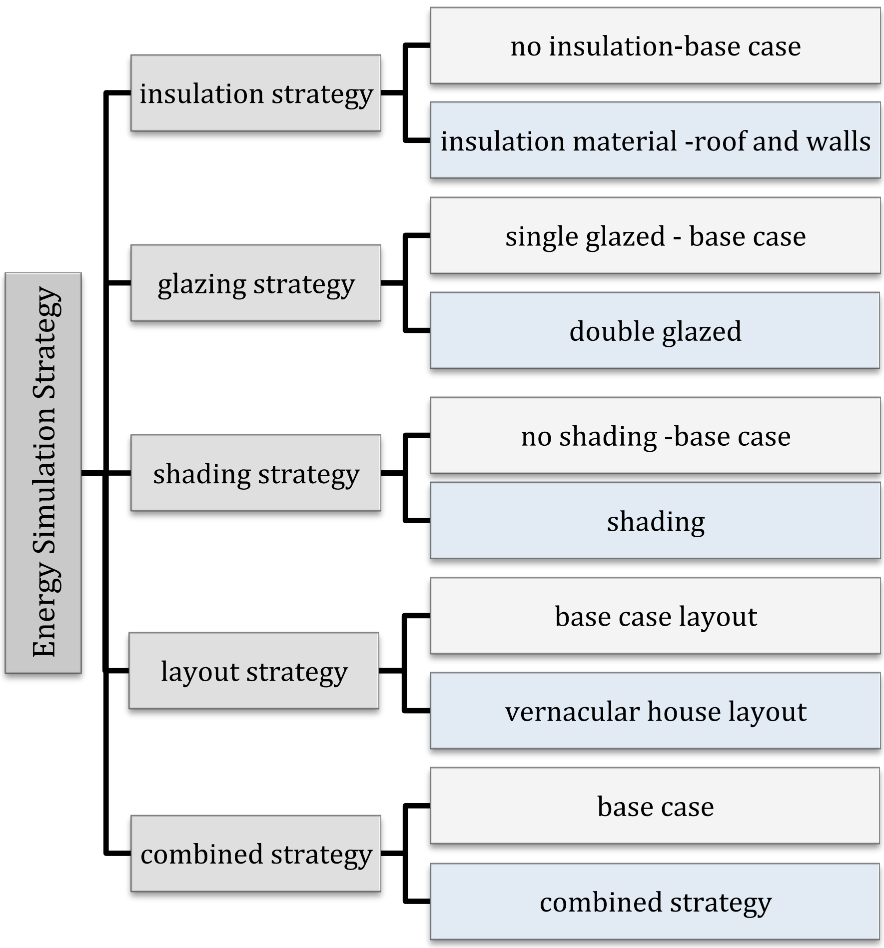


Figure (7. 11) Energy simulation strategy for each model.

7.5. Tripoli case study

Data for the city of Tripoli, Libya were added to the ESP-r programme. The climatic database was set to represent Tripoli–Libya with Latitude N-32.85^o, and Longitude E-13.2^o.

An orientation strategy simulation was first run as a model test in order to determine the best possible orientation and the optimum position for the courtyard. The model was then simulated as the base case, with the reception and living spaces located on the ground floor and the bedrooms on the first floor. Four simulation strategies were run with respect to Tripoli's climate: the insulation strategy, shading strategy, glazing strategy, and the context layout strategy. The best performance resulting from these simulations was used for the final simulation as combined strategies.

The energy simulation was run for the model during a week in January, to exemplify the cold season, and a week in July to exemplify the hot season. The simulation was firstly conducted by using the contemporary building material for the model envelope (walls and roof) as a base case, and then a simulation was run for the modified model according to the above strategy. The result was plotted as charts to illustrate the ambient temperature verses the indoor dry-bulb temperature. The results were compared to the comfort temperature for Tripoli, using equations found in chapter five, that calculate the comfort zone for Tripoli:

$$\boldsymbol{T_{comf} = 0.5T_{rm} + 14.1 \pm 2}$$

This sets the comfort zone for January (winter week) to 23°C as upper margin and 19 °C as lower margin. For July (summer week) it was set to 31°C as upper margin and 28°C as lower margin.

7.5.1. Orientation Strategy

For the purposes of the study, a geometry file was set up to test the best orientation for the model, and a four-zone block was made, each zone having a different window orientation. Firstly the model was simulated with the block oriented north south and then north east and south west, with a rotation of 45 degree; the simulation was done for the winter and summer periods.

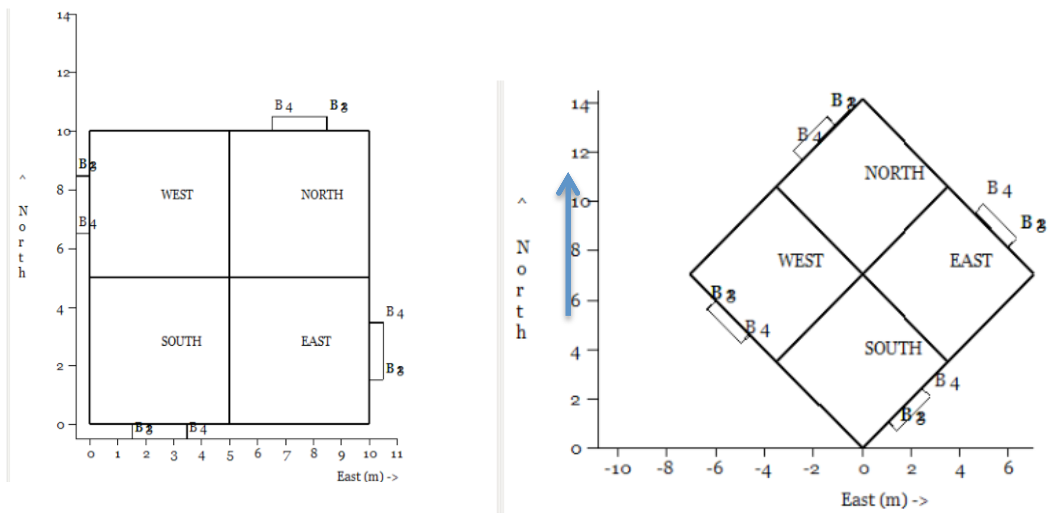


Figure (7. 12) Orientation- geometry model

The simulation results are expressed in a graphical form showing both the internal temperature and the ambient temperature plotted against time. The simulations have been run for a year, and charts plotted from 10th to the 17th of January for the winter period and from 17st to the 23rd of July for the summer period using Tripoli climate database. The graphs, Figures (7-13), (7-14) were drawn to illustrate the thermal performance of the model. The charts show that the model with north south orientation has a better performance than with northeast and southwest orientation in the summer period. However, the chart shows that within the north south orientation, with the exception of the west orientation, most of the zones have better performance than the northeast and southwest. In summer, figure (7.15), in the case of north east and south west orientation, the two south west and south east zones record higher temperatures, therefore it worsens the internal condition where the inside air temperature is higher, and requires more energy to cool it to the thermal comfort zone. As a result of the simulation, the model avoids the west orientation by locating the courtyard in the northeast position; this permitted openings to the north, south and east only.

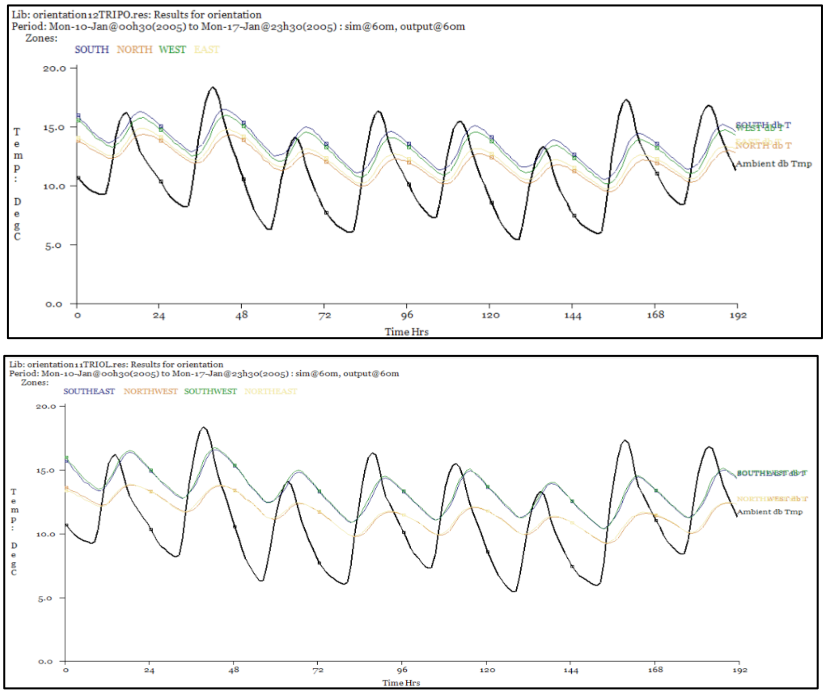


Figure (7. 13) Orientation study of the model during the coldest week in winter.

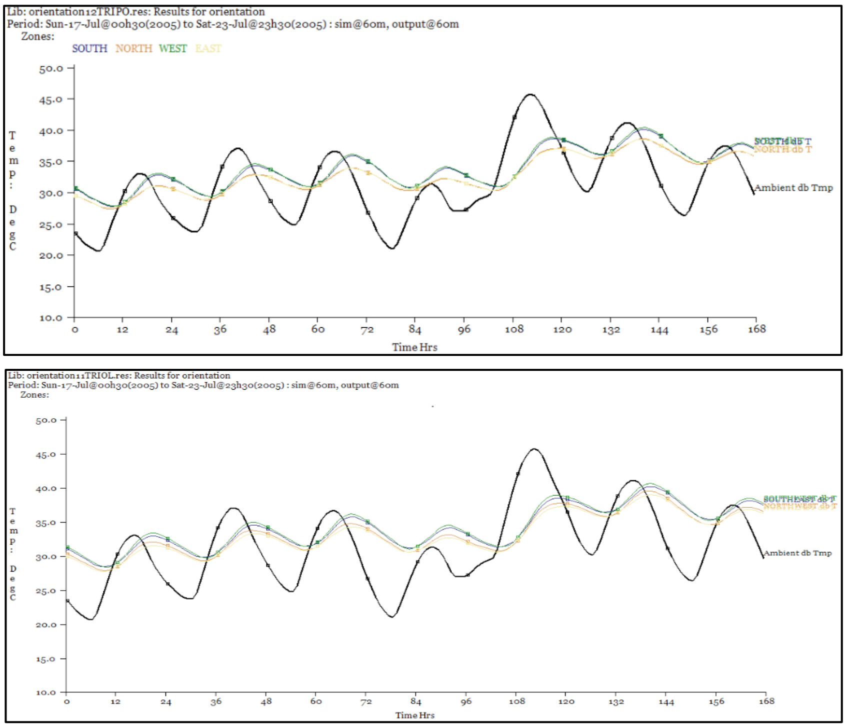


Figure (7. 14) Orientation study of the model during the hottest week in summer.

In conclusion, the best orientation for the window openings is the north, east and south, and the northeast area is the best position to allocate the courtyard.

7.5.2. The design strategy

The model layout illustrated in figure (7-15), was drawn as a base model in the (ESP-r) programme using a geometry file. The base model is built on an area of 100m^2 with a square layout to provide a suitable volume to surface ratio to reduce the exposed surface area. The model was divided to four sections, three quarters were built and the remaining quarter was left to be a courtyard. The model, therefore, was divided into six zones, three on the ground floor and three on the first floor, the courtyard was employed for the orientation, and an extra zone used for the staircase. Figure (7-15) illustrates the proposed model layout in the (ESP-r) geometry file, one of the main files required to create an ESP-r model representation of the house. The file holds the dimensions, shapes, orientations and connections of the components. The model's Plans and section included in appendix C.

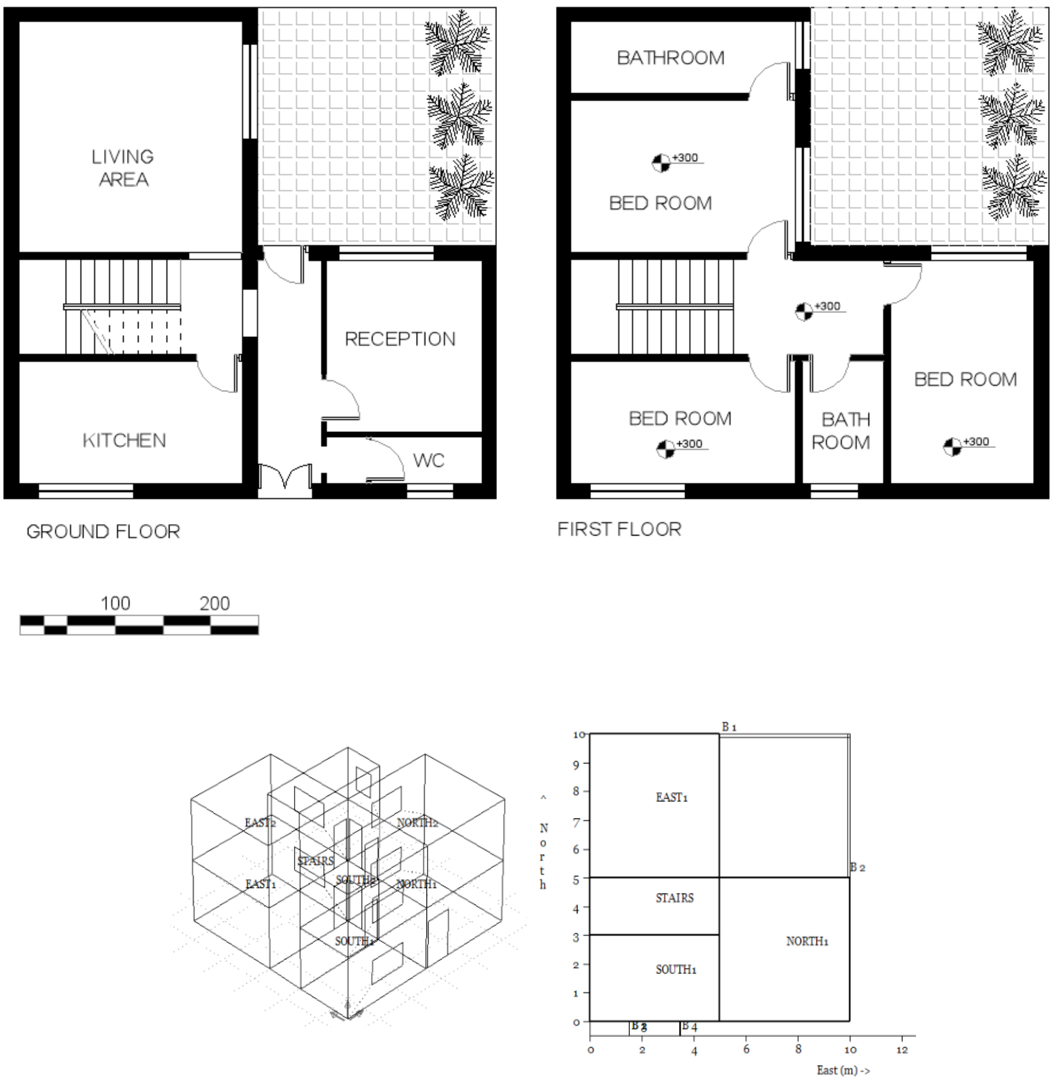


Figure (7. 15) Tripoli - the plans of the model and the geometry zones used in ESP-r

7.5.3. The Passive cooling and heating technique strategies

The model was simulated as a base case with the following input data:

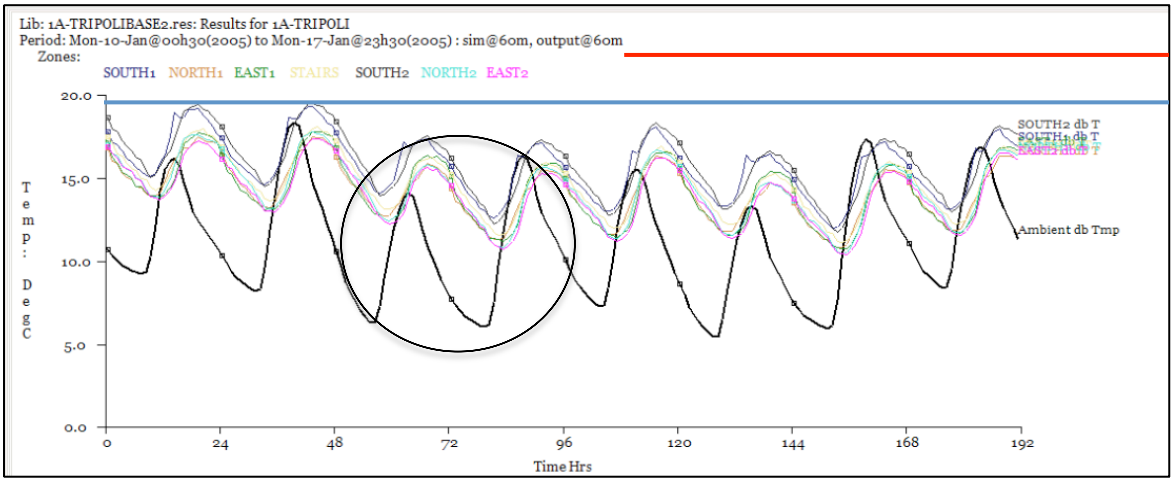
Category	Input data
Climate database	Tripoli climate
Building orientation	0- North
Building construction	Contemporary building construction material in
Terrain	Coastal –urban
Building height	8.5m
Surface to volume ratio	235 /478 = 0.49
Glazed area	$12m^2$ (6% of the elevations)
Casual heat gains	Calculated in table (7-5)
Ventilation	Natural ventilated

Table (7. 14) Tripoli - base case input data

The energy simulation results for the passive cooling strategies: insulation, shading, glazing and layout strategies, were compared to the base case strategy, that represent the contemporary houses in the region.

7.5.3.1 The base strategy

An energy simulation was run for a year and the coldest week in winter has been illustrated in graph Figure (7.16). The graph shows the thermal performance of the model during the coldest week in winter (10th January to the 17th January), the ambient temperature for Tripoli ranges from 5.3 °C to 18.4 °C in. The ambient temperature is plotted against the inside air temperature for the seven zones; the comfort zone have been highlighted with two lines ranges between 24.3°C as upper margin and 20.3°C as lower margin for winter. According to the chart, the seven zones recorded a lower temperature than the comfort temperature required for the region in January. Therefore, by using the contemporary building material for the Tripoli model will lead to lower thermal performance of the model, where more heating will be required to achieve comfort temperature. However, in the south-1 zone (kitchen) the internal temperature briefly rises to the comfort zone at noon, it is related to the indoor activity (cooking) and casual heat gains as illustrated in the casual gains provided in figure (7.6).



	24.9 °C upper margin		**Ambient temperature**
	20.9°C lower margin	**Others**	**Indoor air temperature (zones)**

*The area circled is shown in greater detail in the next graph

Figure (7. 16) Base case, the thermal performance of the zones during the coldest week in winter.

In order to illustrate the zonal performance a more detailed graph was plotted for the seven zones during the coldest day in winter, with the base case illustrated in figure (7-17). The graph shows that the south oriented zones have the highest temperature due to the higher solar heat gains through the windows; whereas the east and north zones recorded 1-2 K lower than the south zone.

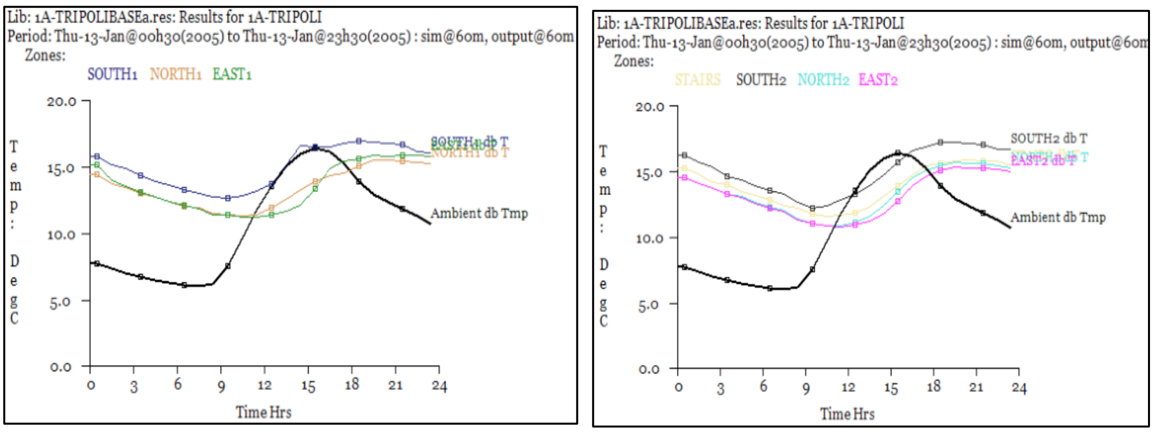
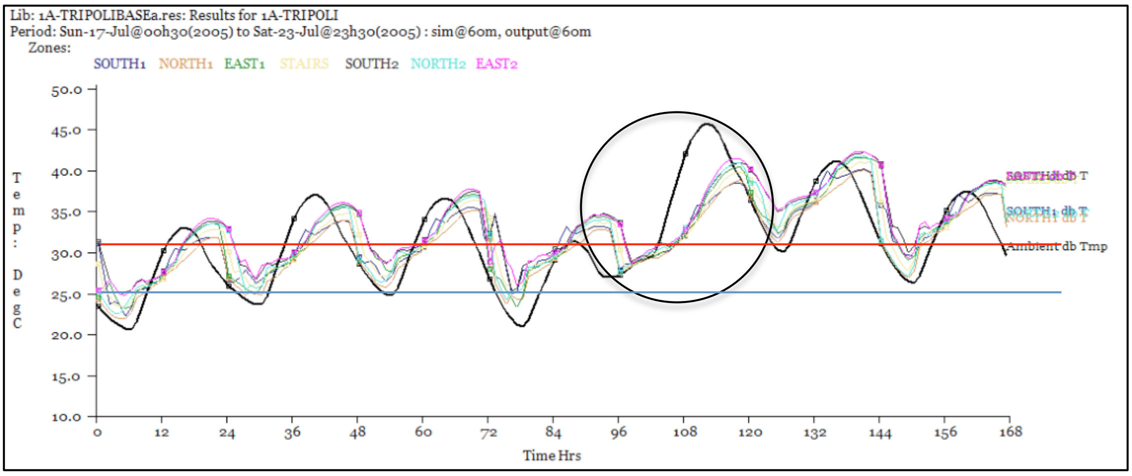


Figure (7. 17) Thermal performance of the zones during a day in winter

The chart also illustrates that the first floor recorded a higher temperature than the ground floor; this can be associated with the solar heat gain transmitted through the roof. Therefore, in order to improve the indoor air temperature, the physical and thermophysical properties of the model should be tested and changed in order to reduce heat loss through the building envelope and increase the effect of the solar heat gain through windows and exposed roof.

The simulation was run for a year and a graph has been plotted for the hottest week in summer season; the graph Figure (7.18) illustrating the hottest week for the summer period. The ambient temperature ranges from 21°C at night to maximum 45 °C at 16:00 after noon. With reference to the comfort temperature zone for Tripoli the upper margin of the comfort zone was set to 30.6°C with 26.6°C as the lower margin. The simulation shows that the indoor air temperature in the seven zones was recorded as above the comfort zone in most of the period, therefore the thermal performance of the model is above the comfort zone in seven zones, which requires cooling loads in order to achieve comfort temperature. However, the simulation allowed the human behaviour factor to be added to the comfort equation; therefore the temperature drops from 33.5°C to 30 °C, this being related to human behavior in terms of opening windows to allow for night-time cooling ventilation. The control was set for opening windows if the inside temperature is



(red line)	**30.6 °C upper margin**	(black line)	**Ambient temperature**
(blue line)	**26.6°C lower margin**	**Others**	**Indoor air temperature (zones)**

*The area circled is shown in greater detail in the next graph

Figure (7. 18) Base case, the thermal performance of the zones during the hottest week in summer.

above 26 C from 24:00 to 8:00.

The graphs illustrated in figure (7-19) show that air temperature in summer in the seven zones ranges from 40°C to 38°C at 21:00 as a result of the delay of the afternoon (16:00) ambient temperature by the thermal property of the house envelope, with a time lag of nearly 5 hours, this drops the air temperature from nearly 46 °C to 37 °C and 38°C respectively in the first and ground floors.

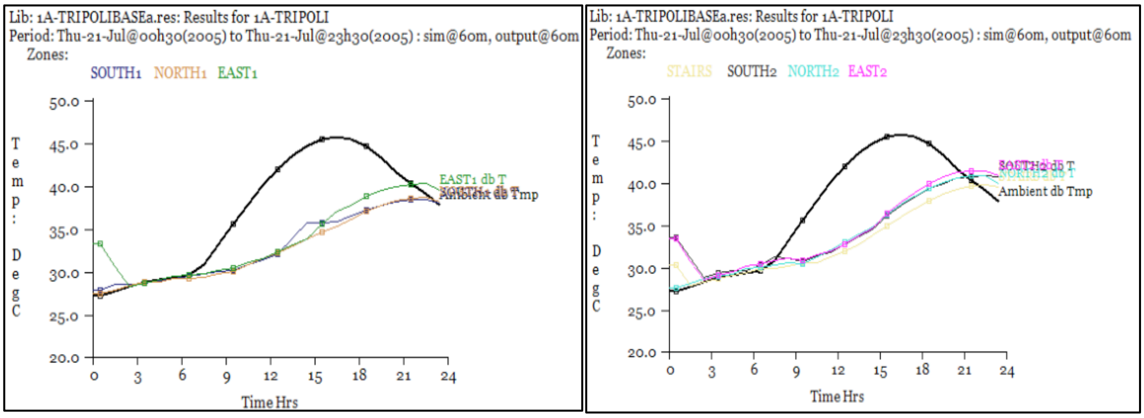
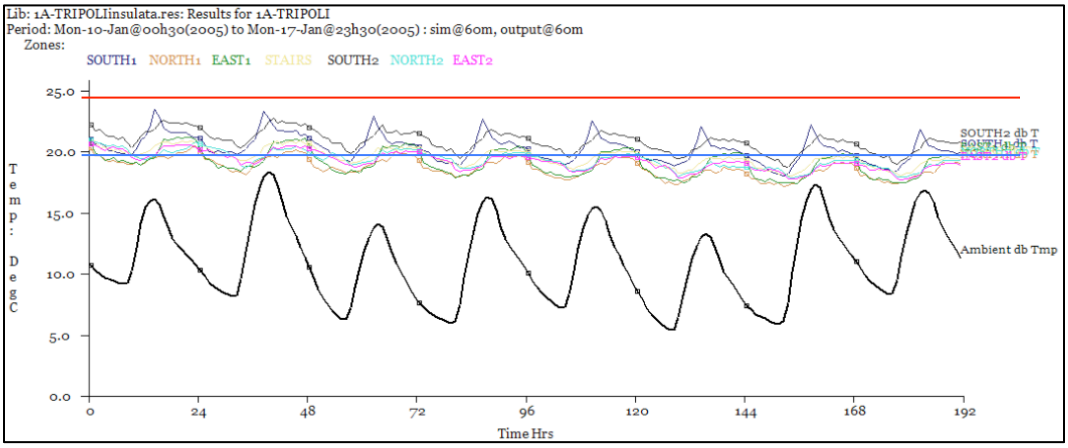


Figure (7. 19) Base case, the thermal performance of the zones during a day in summer.

7.5.3.2 Insulation strategy

The new construction materials were chosen for Tripoli with respect to their availability in the region. Furthermore, a careful examination has been made of the thermal properties and thickness of the material, in addition to a study of the insulation placement in the house envelope. The new wall is constructed based on a thermal mass strategy with U-value of 0.574W/m^{2}K and a time lag of 17.2 hours, by adding date palm insulation in the cavity wall made internally of limestone and externally of breeze block as shown in table (7-10). The contemporary roof was modified by adding an insulation layer (date palm wood) with a thickness of 50mm and U value of 0.56W/m^{2}K, table (7-12). An energy simulation was run for the model for the cold season and hot season, and the result was plotted in the following graphs. The first graph (figure 7-20) illustrates the ambient temperature verses the indoor dry-bulb temperature for the seven zones during the coldest week in winter. It is clear that with insulation added the temperature increases in all zones.



	24.9 °C upper margin		Ambient temperature
	20.9°C lower margin	Others	Indoor air temperature (zones)

Figure (7. 20) Insulation strategy, the thermal performance of the zones during the coldest week in winter.

By zooming in for a day in winter and comparing the result of the insulation strategy with the base case where no insulation add, as shown in figure (7-21), it is shows that the temperature increased in the six zone, the curve was flattened showing the effect of thermal insulation layer. The red arrows in the two charts show that at 12:00 the temperature increases nearly 4K from 11°C to 16°C in the East oriented zones, and nearly 3K in the South oriented zones. However the inside air temperature failed to reach the comfort zone, this can be related to heat loss through the glazed area.

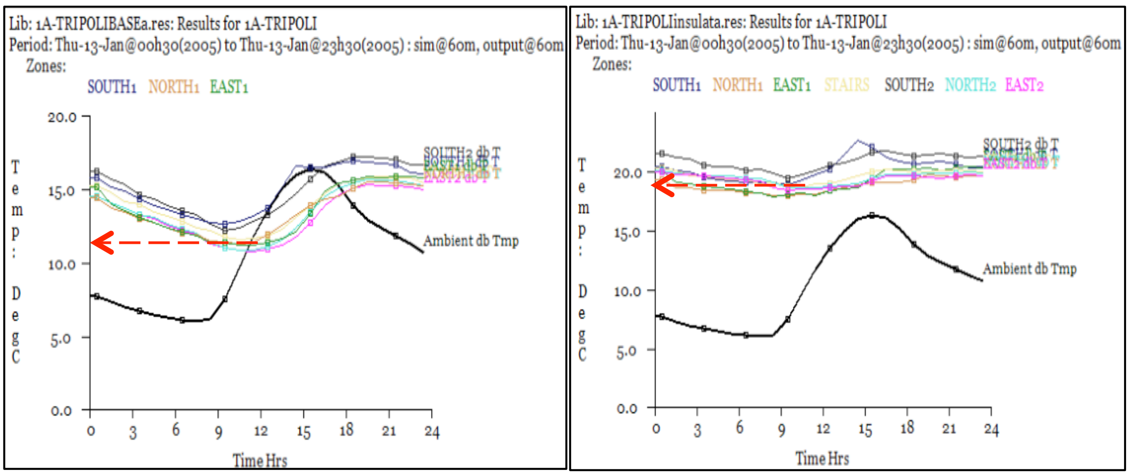
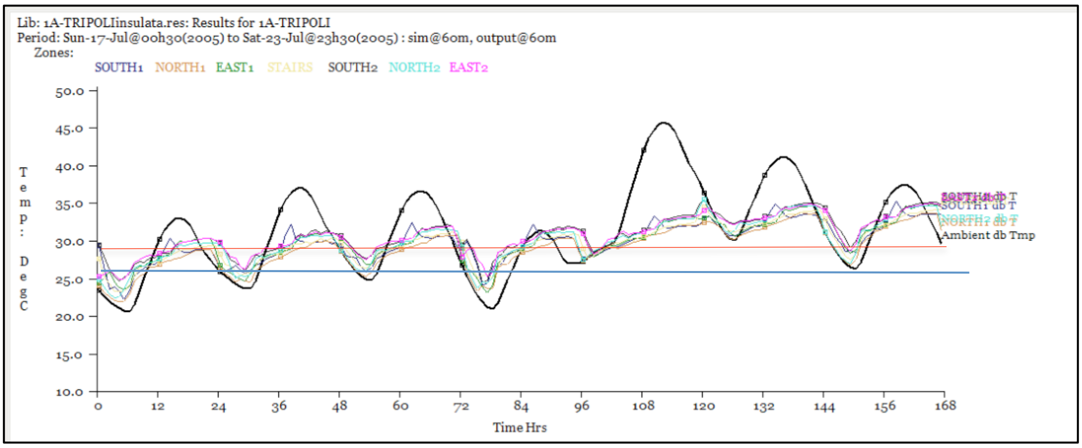


Figure (7. 21) The comparative study between the base case and the insulation strategy - the thermal performance of the zones during a day in winter.

The simulation results were plotted for the model during the hottest week in summer, as shown in figure (7-22); the indoor air temperature of the model was plotted against the ambient temperature. The graph shows a remarkable drop in indoor temperature during the whole week for the seven zones. However, it shows that the inside air temperature failed to reach the comfort zone for most of the week especially when the night temperature was recorded as higher than the comfort zone.



	30.6 °C upper margin		**Ambient temperature**
	26.6°C lower margin	**Others**	**Indoor air temperature (zones)**

Figure (7. 22) Insulation strategy, the thermal performance of the zones during the hottest week in summer

A more detailed graph illustrating the thermal performance of the model during the hottest day and a comparison study with the base case strategy is illustrated in the graph of figure (7-23). It must be noted that the human behaviour in terms of opening windows at nighttime was added; the windows should be open when indoor air temperature is higher than 26°C. From the graphs, it is clear that in all zones, adding insulation to the wall has a mean effect on the inside air temperature, and a recognizable improvement to the air temperature for all zones. The inside temperature decreased by almost 5 K in the hottest hours of the day, where the temperature dropped from 41°C to 34°C at 20:00 hours. This is due to the thermal mass which delay the external heat flow into the model for more than 17.2 hours. However the indoor temperature failed to reach the comfort zone during the hottest days; this can be related to the window thermal conductivity and the effect of solar radiation through the windows, that could cause overheating to the inside environment by increasing the heat gain through the windows.

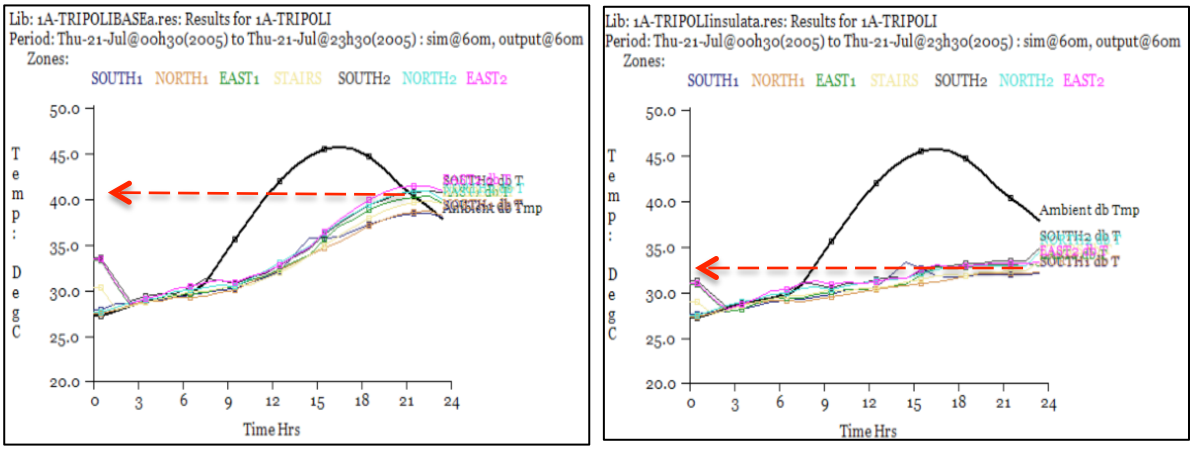
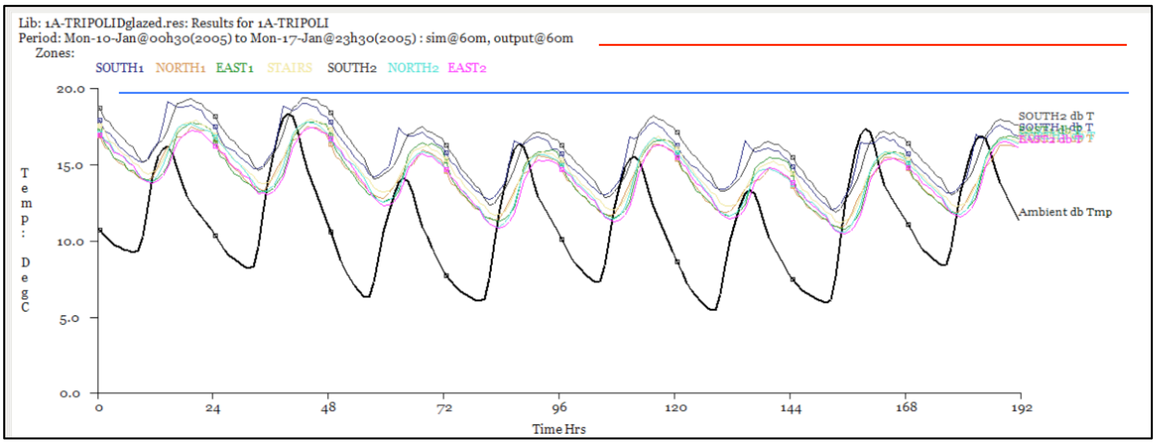


Figure (7.23) Comparative studies between the base case and the insulation strategy- the thermal performance of the zones during the hottest day in summer.

7.5.3.3 Glazing strategy

A window is an element in a house that has an important effect on heat loss/gain, due to its high conductivity. In the base case, the use of single clear glazed windows with no shutters leads to high heat gain; therefore using a double glazed panel can improve the thermal performance of the building. If double-glazed windows are used as replacement for single glazed windows; this will reduce the U value from 5.8 for single glazed windows to less than 2.7 W/m^{2}K. Double glazed windows are a most effective way to reduce the heat loss through the windows (by 63%), while adding timber shutters to single glazing reduces heat loss by 51% and curtains reduce it by 14% (Hegger et al. 2008).



(red line)	**24.9 °C upper margin**	(black line)	**Ambient temperature**
(blue line)	**20.9°C lower margin**	**Others**	**Indoor air temperature (zones)**

Figure (7. 24). Glazing strategy, the thermal performance of the zones during the coldest week in winter

The simulation was rerun after replacing the single glazed windows with double glazed windows, and from the result a week was plotted in figure (7-24). Using a double glazed window has a barely noticeable effect in comparison with the insulation strategy; this can be related to the small area of the glazed windows that accounted for only 6% of the elevations of the model. However using new windows with draught proofing is a one way to reduce air leakage and therefore heat loss through windows.

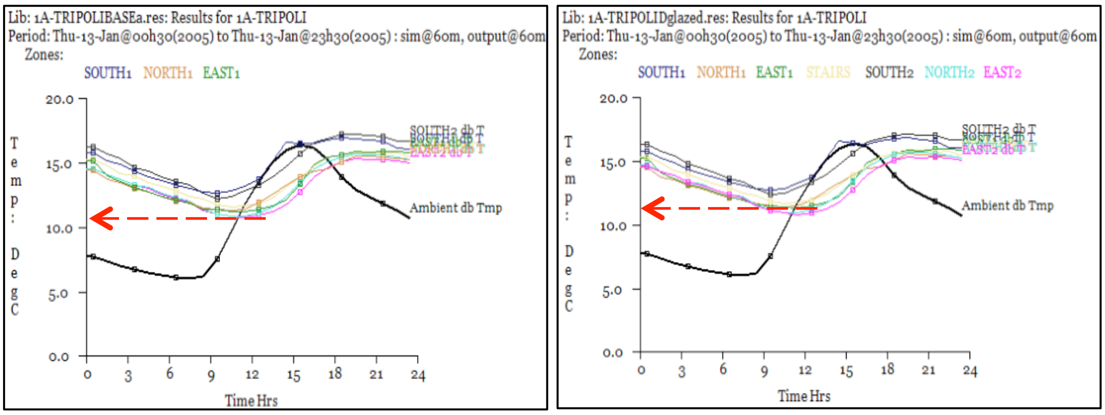
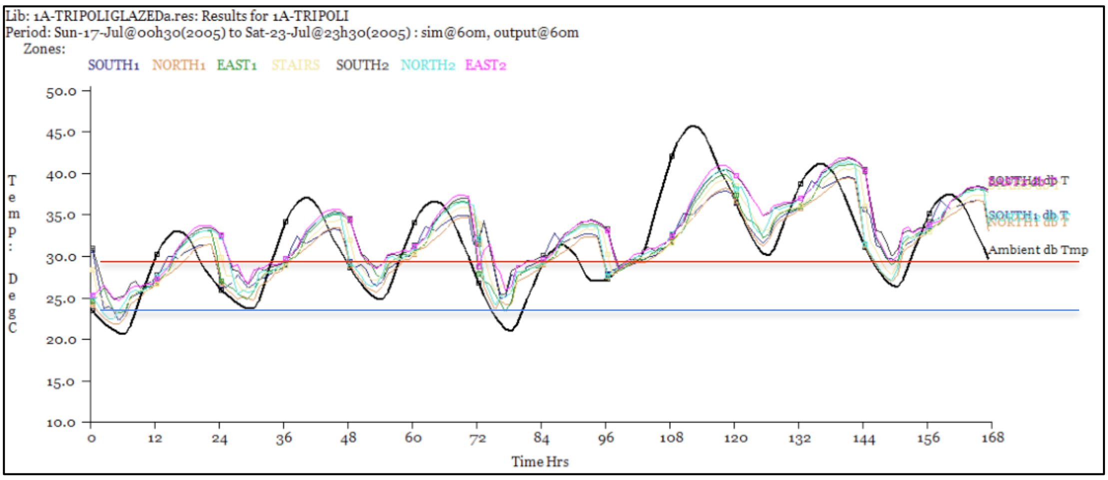


Figure (7. 25) Comparative studies between the base case and the doubled glazed strategy - the thermal performance of the zones during a day in winter

A detailed graph was plotted for one day in summer and compared to the base case figure (7-26). The graphs show the effect of the double glazed windows especially on the south oriented zones, as the air temperature dropped compared to the base case. However, the double-glazing strategy has a small effect on the internal environment, which failed to reach the comfort zone in both summer and winter.



(red line)	**30.6 °C upper margin**	(black line)	**Ambient temperature**
(blue line)	**26.6°C lower margin**	**Others**	**Indoor air temperature (zones)**

Figure (7. 26) Glazing strategy, the thermal performance of the zones during the hottest week in summer.

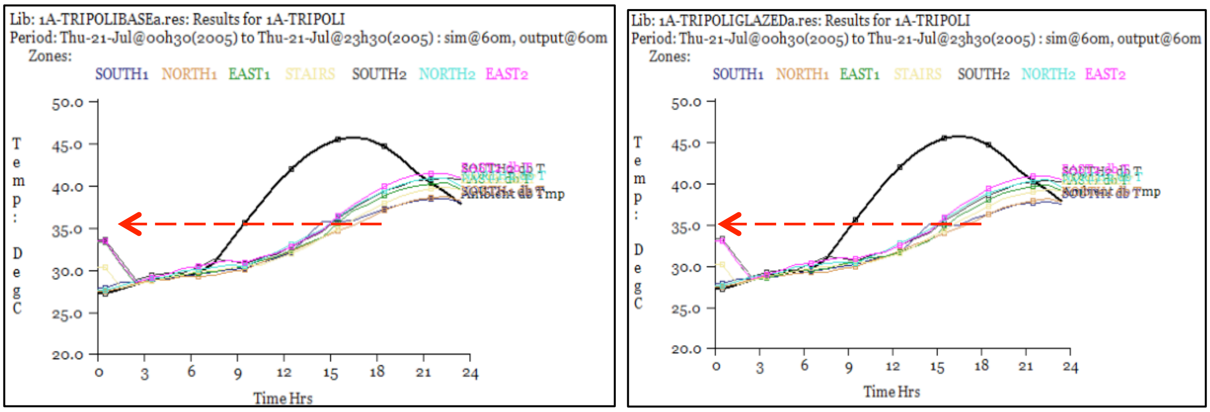
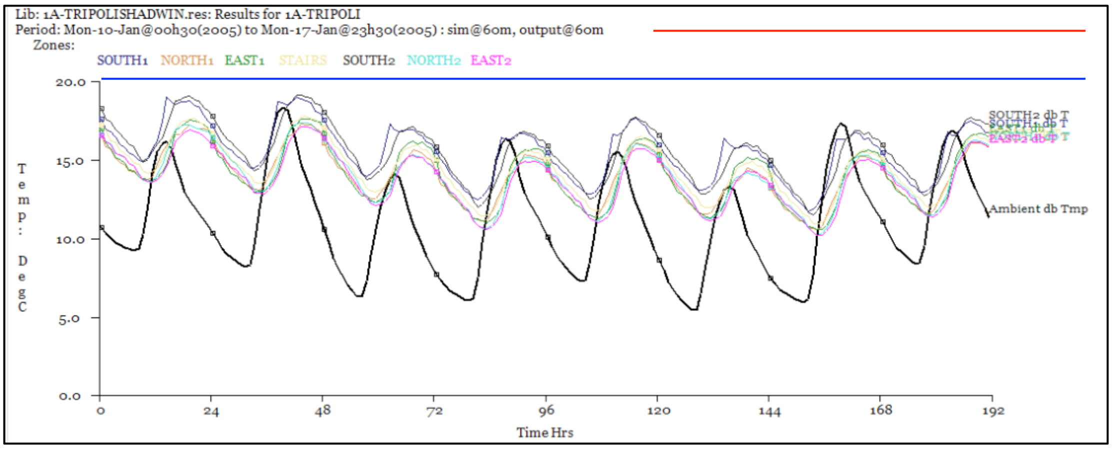


Figure (7. 27) Comparative studies between the Base case and the double-glazed strategy, during a day in summer

7.5.3.4 Shading strategy

The simulation was run using the base construction data, and modified shade files, by adding shading devices to three component of the model; firstly timber shutters and window reveals, and secondly using a high parapet on the roof and a secondary roof to protect the roof from direct solar radition.



(red line)	**24.9 °C upper margin**	(black line)	**Ambient temperature**
(blue line)	**20.9°C lower margin**	**Others**	**Indoor air temperature (zones)**

Figure (7. 28) Shading strategy- the thermal performance of the zones during the coldest week in winter

During the coldest week in winter the graph figure (7-28) shows no effect from the shading strategy on the model during this period. However, the simulation was run for the model using only the fixed shading devices, in terms of window reveals and roof parapet walls. The result illustrated in figure (7-30) shows no effect from the shading devices in the internal air temperatures compared to the base case.

Moreover, adding a fixed secondary roof has a negative effect on the first floor (SOUTH2, NORTH2 and EAST2), as a result of obstructing the solar radiation on the roof; this can be resolved by using natural obstruction such as vine shading, that permits solar radiation during winter, a device widely used in the vernacular traditional houses in Tripoli.

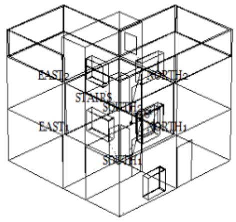


Figure (7.29) Shading strategy for the cold season

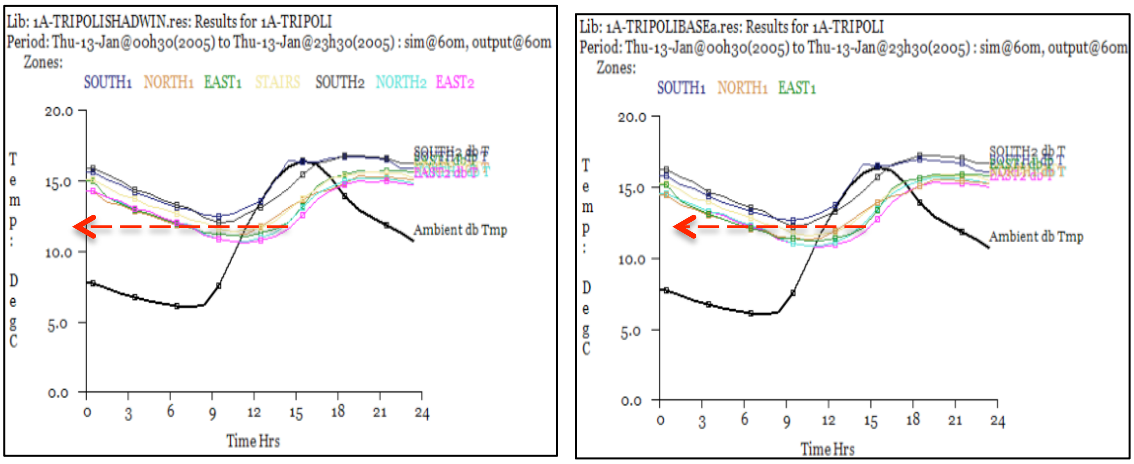


Figure (7. 30) Comparative study between the base case and the shading strategy

The shading devices are designed to be used in summer to their full capacity, as shown in figure (7-31), by using the timber shutter, window reveals and overhangs, in addition to the secondary roof, and increasing the height of the roof parapets.

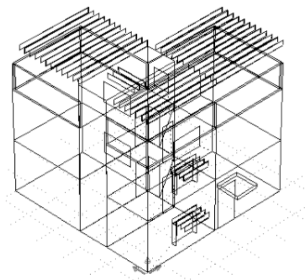
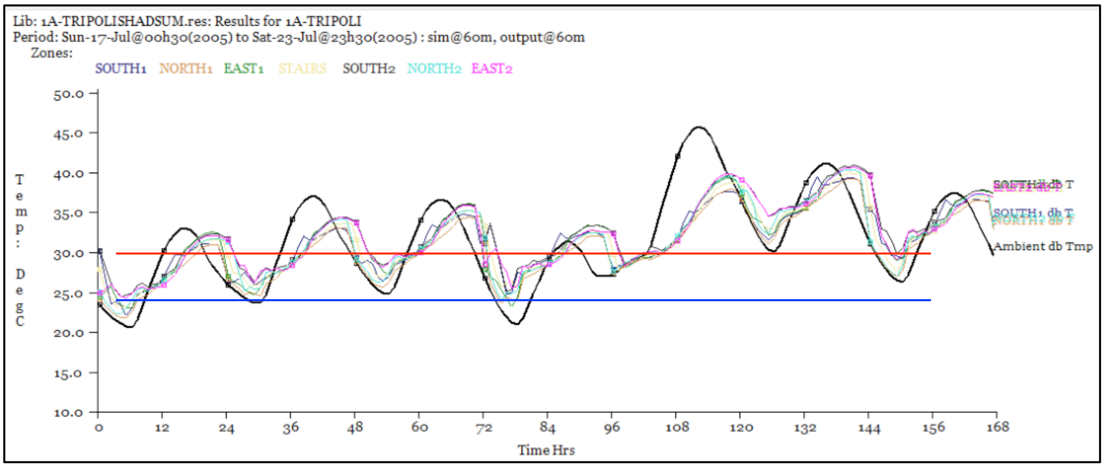


Figure (7. 31) Shading strategy for the hot season

The timber shutters are used to protect the model from the high solar radiation, the graph shown in figure (7-32) illustrating the effect of the shading strategy on the model during the hottest week of the summer. The graph shows a great effect on the zone's air temperature during most of the week; however it failed to reach the comfort zone at 16:00 during the hottest days.



	30.6 °C upper margin		Ambient temperature
	26.6°C lower margin	Others	Indoor air temperature (zones)

Figure (7. 32) Shading strategy - thermal performance of the zones during the hottest week in summer

The simulation was plotted for one day in summer figure (7-33) and compared with the base case. It shows that the shading strategy has a remarkable effect on the south oriented zones, as air temperature dropped nearly 4 K at 16:00, and nearly 3 K in the other zones.

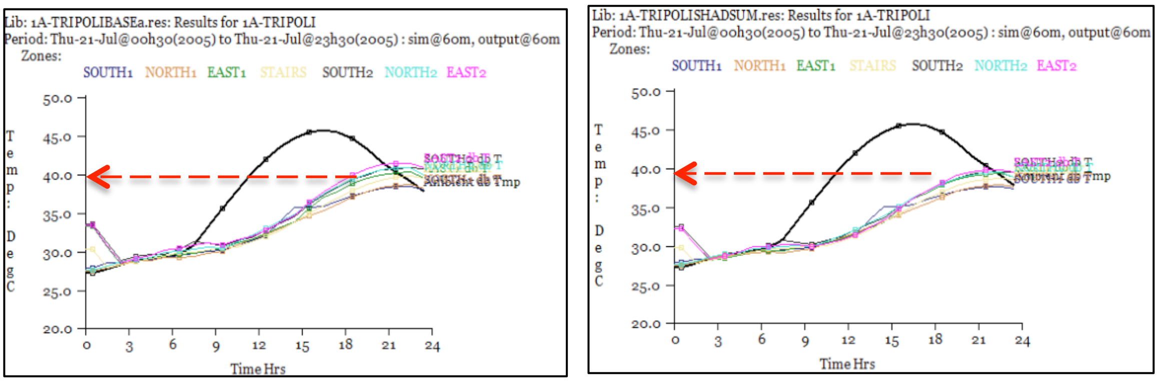


Figure (7. 33) Comparative study between the base case and the shading strategy, during a day in summer

7.3.3.4 Layout and contextual impact strategy

The fourth strategy is related to the model position in a residential complex, the row house type was adopted to create a complex of houses, an arrangement which can reduce the surface area exposed to the environment and therefore reduce heat gain and loss through the walls. The simulation was run to study the effect of the

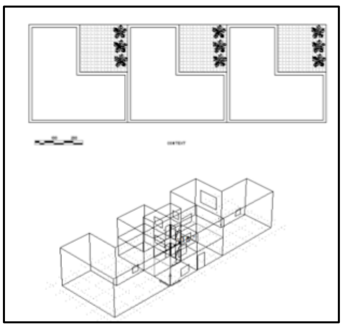
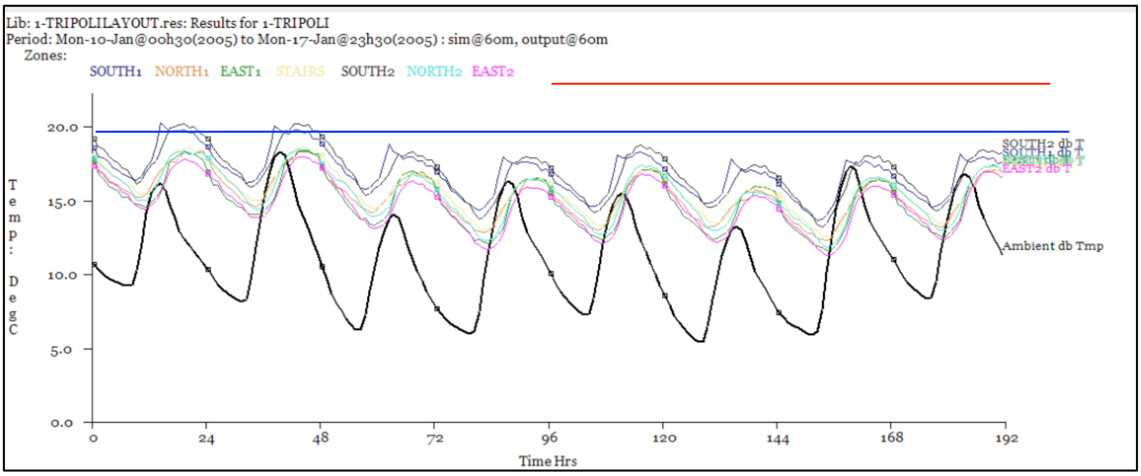


Figure (7. 34) The model in contextual strategy.

contextual impact on the model, using the base data for the model construction.



	24.9 °C upper margin		Ambient temperature
	20.9°C lower margin	Others	Indoor air temperature (zones)

Figure (7. 35) Layout strategy, the thermal performance of the zones during the coldest week in winter

The day simulation was run in order to examine the effect of the layout on the thermal performance of the model. The graph, figure (7-36), represents the layout strategy for the model during the coldest day in winter. The strategy has a small effect on the south zones, as a result of the west block (adjacent house) reducing the heat loss through the west elevation. However, the graphs show that the strategy has no effect on the east and north zones during the cold seasons.

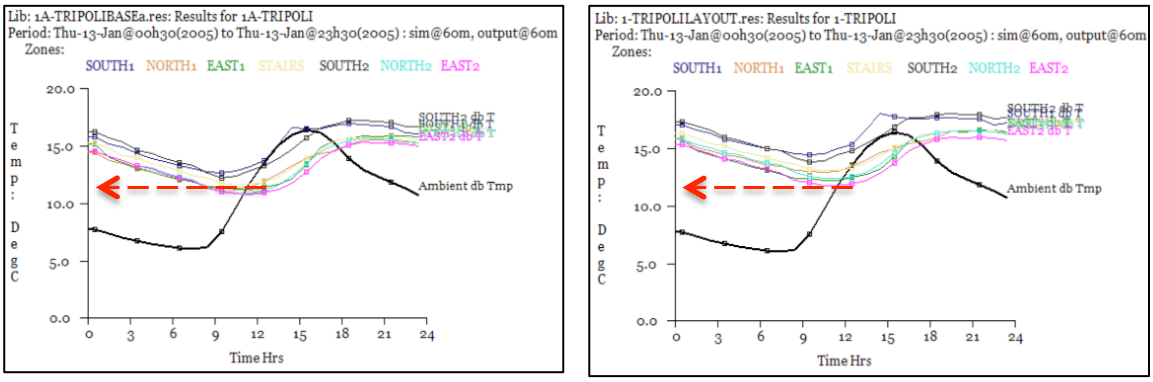
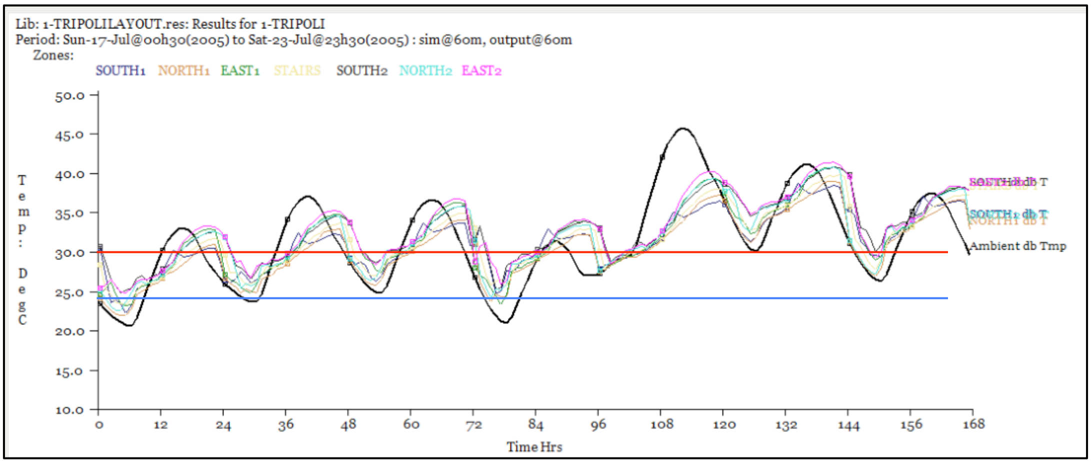


Figure (7. 36) Comparative study between the base case and the Layout strategy during a day in winter

Figure (7-37) illustrates the effect of the layout strategy on the model during the hottest period; the graph shows recognizable temperature changes in the south zones. This is as a result of the west block that is connected to the south zones, protecting the west elevation from solar radiation from the west and reducing heat gains through the western walls.



(red line)	30.6 °C upper margin	(black line)	Ambient temperature
(blue line)	26.6°C lower margin	Others	Indoor air temperature (zones)

Figure (7. 37) Layout strategy, the thermal performance of the zones during the hottest week in summer

By comparing the layout strategy with the base strategy shows that the air temperature in all zones dropped by 1 K to 3 K at 21:00, as shown in figure (7-38). However, air temperature in all zones failed to reach the comfort zone in the peak heat of the day from 15:00 to 18:00 on the 21th and 22th of July. The layout strategy simulation clarifies that the strategy is more effective during summer than in winter.

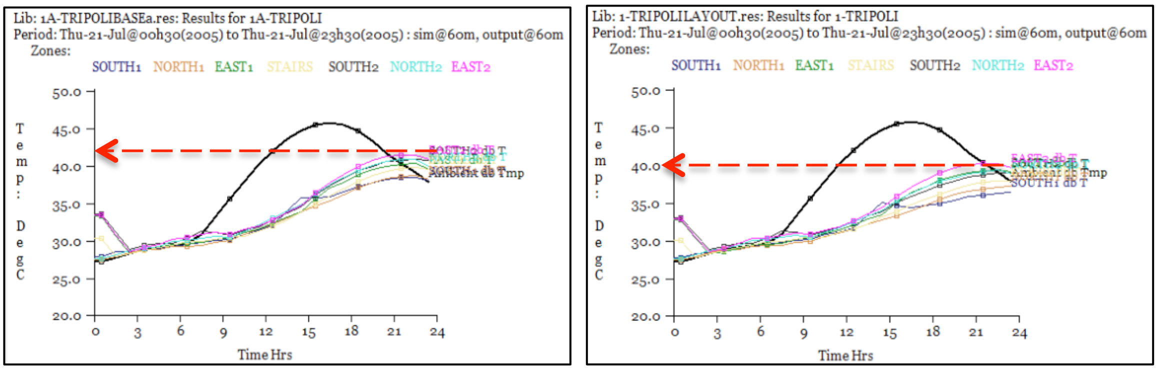


Figure (7. 38) Comparative study between the base case and the layout strategy during a day in summer.

7.3.3.5 Combined strategy

The final strategy in this case study combines all the previous strategies. A simulation was carried out using the insulation, double glazed windows, shading devices and layout strategies. The simulation was run in two stages, firstly using the shading strategy for winter with the flexible shading devices and minimizing the effect of shading to reflect natural shade from plants. The second was run using the summer shading strategy, using window reveals, secondary roof, and timber shutters.

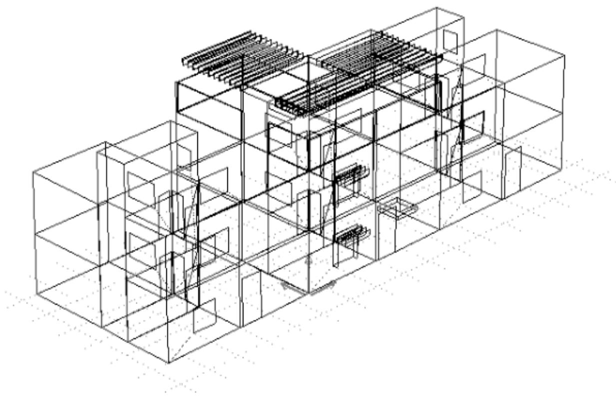
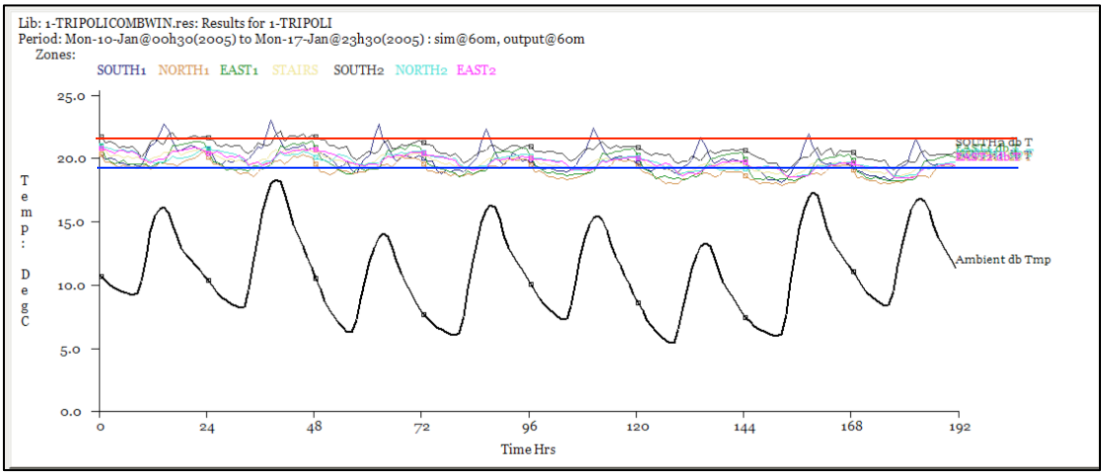


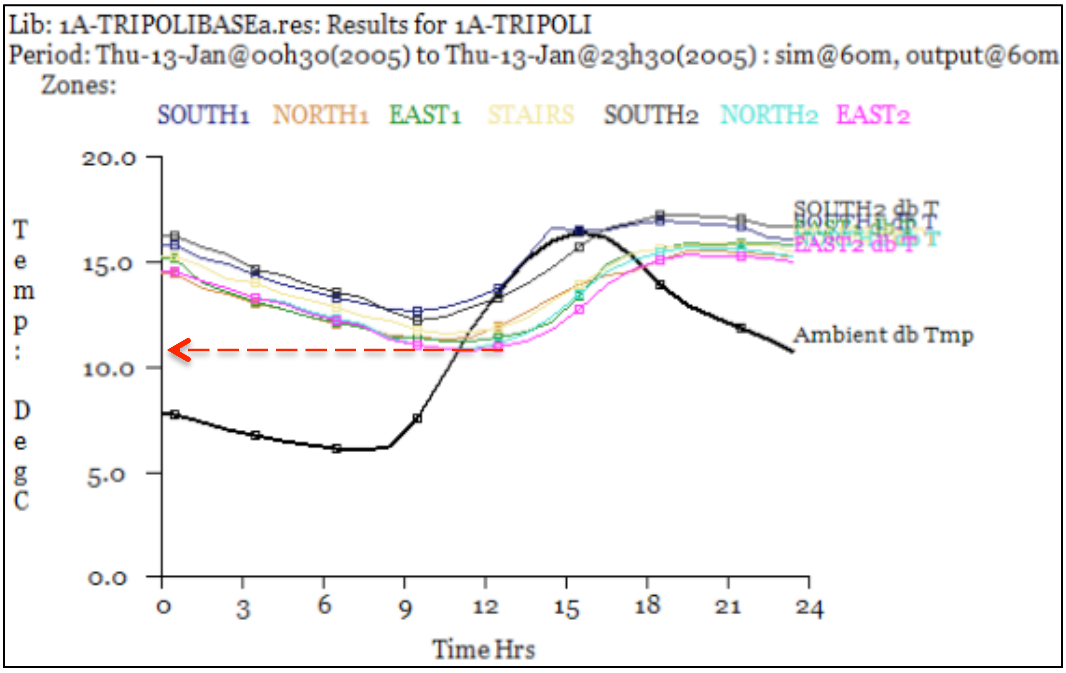
Figure (7. 39) Combined strategy.

The graph figure (7-40) illustrates the results for the simulation for the final model during a week in winter, it shows that air temperature in the zones rooms reached the comfort zone, while only in two days did the indoor air temperature fail to reach the comfort zone, with nearly 1 to 2 K at 6:00, when the ambient temperature dropped below 6°C.



(red line)	24.9 °C upper margin	(black line)	Ambient temperature
(blue line)	20.9°C lower margin	Others	Indoor air temperature (zones)

Figure (7. 40) Combined strategy, thermal performance of the zones during the coldest week in winter.



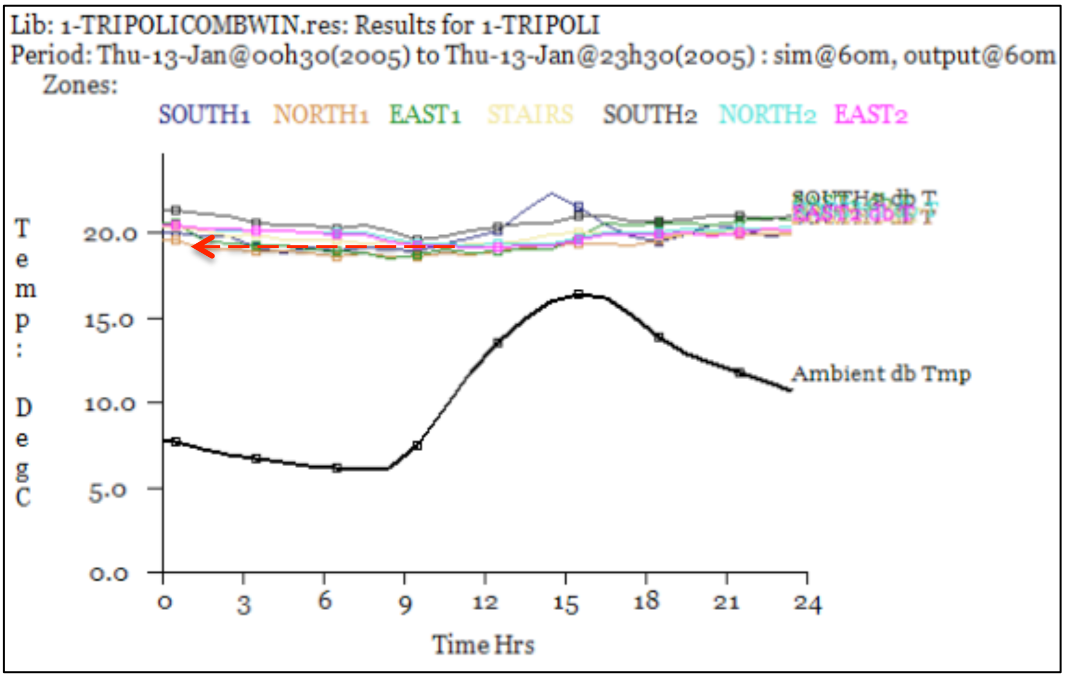
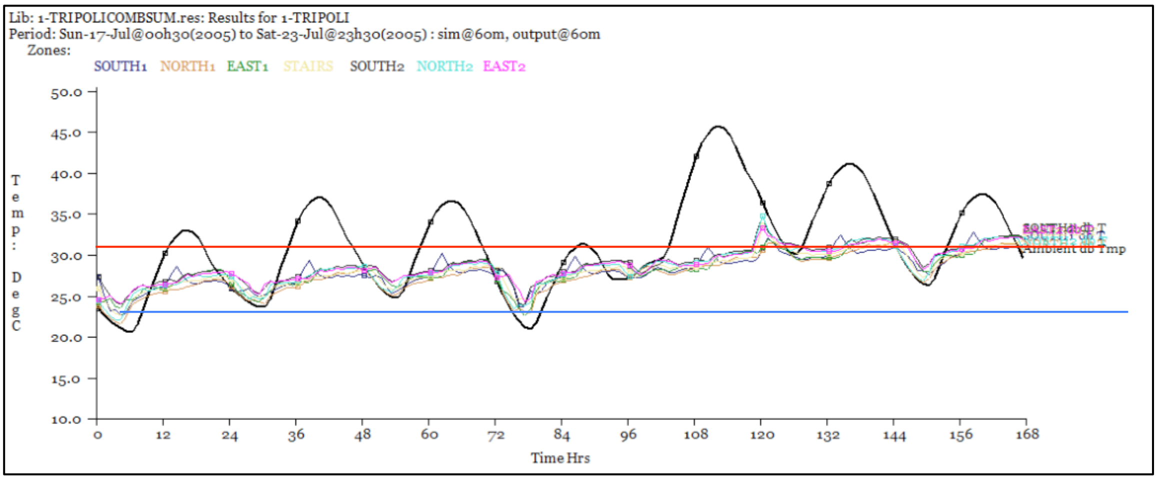


Figure (7. 41) Comparative study between the base case and the combined strategy during a day in winter.

From the graphs in Fig (7.42), the comparison between the combined strategy and the base case shows that the model improves the thermal performance of the contemporary Libyan house in winter. At 12:00 the air temperature increases from 11°C to 19.5°C in the east oriented zones. Although the results show a great improvement in internal conditions of the house, it will require minimum heating load to achieve the comfort zone

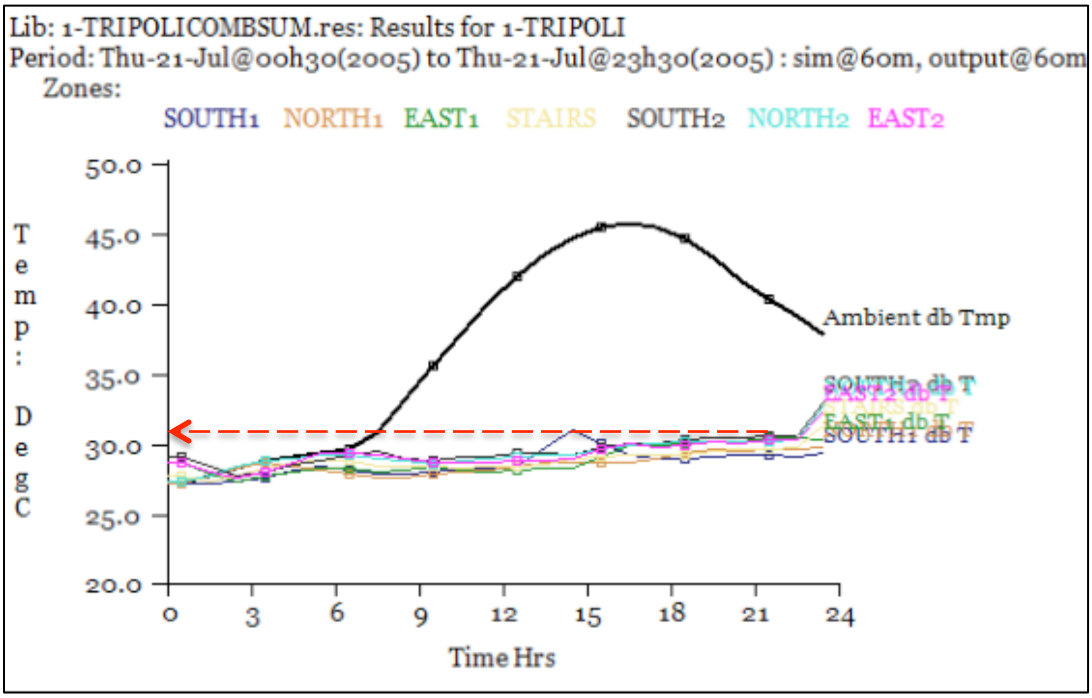


	30.6 °C upper margin		**Ambient temperature**
	26.6°C lower margin	**Others**	**Indoor air temperature (zones)**

Figure (7. 42) Combined strategy, the thermal performance of the zones during the hottest week in summer

The summer result, Figures 7-42 and 7-43, shows a dramatic improvement in most of the weeks, the air temperature dropping by approximately 7K to 11K in most of the zones, to reach the comfort zone where no cooling is needed. However it failed to achieve the comfort zone in extreme conditions when the external ambient temperature is nearly 45°C and the night temperature is above the comfort zone.

It can be concluded that the insulation strategy has the most impact on improving the indoor thermal condition in both seasons, while shading is considered being the second influential element in the summer season. Therefore, for Tripoli and the coastal region indoor comfort temperature can be achieved in both winter and summer by using passive heating and cooling strategies with minimal heating or cooling.



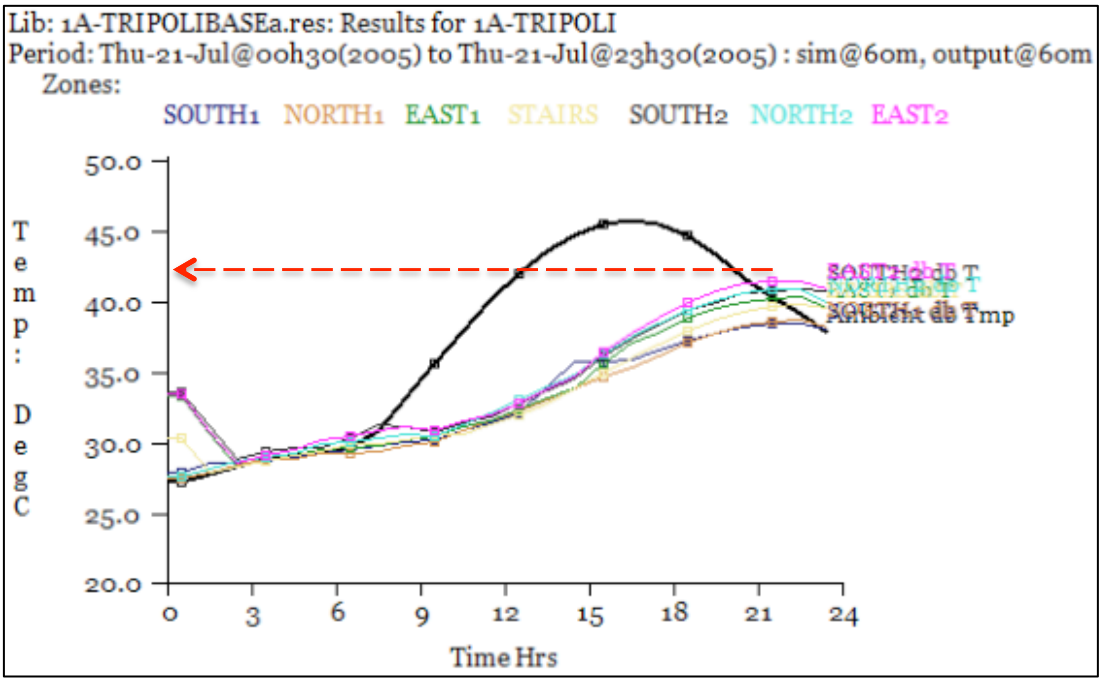


Figure (7. 43) Comparative study between the thermal performance of the base case and the combined strategy during a day in summer.

7.6. Ghadames case study

Data for the city of Ghadames has been added to the (ESP-r) programme, and the climatic database was set to represent with Ghadames with Latitude N-30.1^{o}, and Longitude E-9.5^{o}. The study for the Ghadames case can be divided into three stages: firstly to test for the optimum orientation for the model openings, and running a simulation to assign the best location to the courtyard, secondly to test different designs for the model, the Tripoli model, and a modified model to set a typical model for Ghadames and finally the Ghadames model was tested by running four simulation strategies: insulation strategy, shading strategy, glazing strategy, and layout strategy.

The best performance from these simulations was used for the combined strategy simulation. An energy simulation was run to test the model for a week in January, to exemplify the cold season, and a week in July to exemplify the hot season, first by using the contemporary building materials for the model envelope (walls, roof and windows) as a base case, and then running a simulation on the modified model according to the above strategies. The result was plotted as charts showing the variation of ambient temperature and indoor dry-bulb temperature. The results were compared to the comfort temperature for Ghadames using equations found in chapter five, to calculate the comfort zone for Ghadames. The equation for the upper margin and the lower margin for city is found from:

$$\boldsymbol{T_{comf} = 0.46T_{rm} + 16.7} \pm 2$$

This set the comfort zone for January (winter week) to 24.2°C as upper margin and 20.2°C as lower margin. For July (summer week) it was set to 35.2°C as upper margin and 31.2°C as lower margin.

7.6.1. Orientation strategy

A test model was set up to test the best orientation for the main model, the test model consists of four zones, where each zone has a window positioned to different orientations. The model was simulated with the block oriented north-south and then northeast-southwest, with a rotation of 45°. The simulation was run for the winter and summer periods using the Ghadames climate data, including the solar radiation and wind speed and orientation. The results have been plotted on a chart to illustrate the thermal performance of the model. The graphs in figure (7-44) show that, during the winter season, the southeast – northwest orientation has worsened the indoor conditions, where the air temperature decreased nearly 2K in most of the zones, especially in the northeast zone.

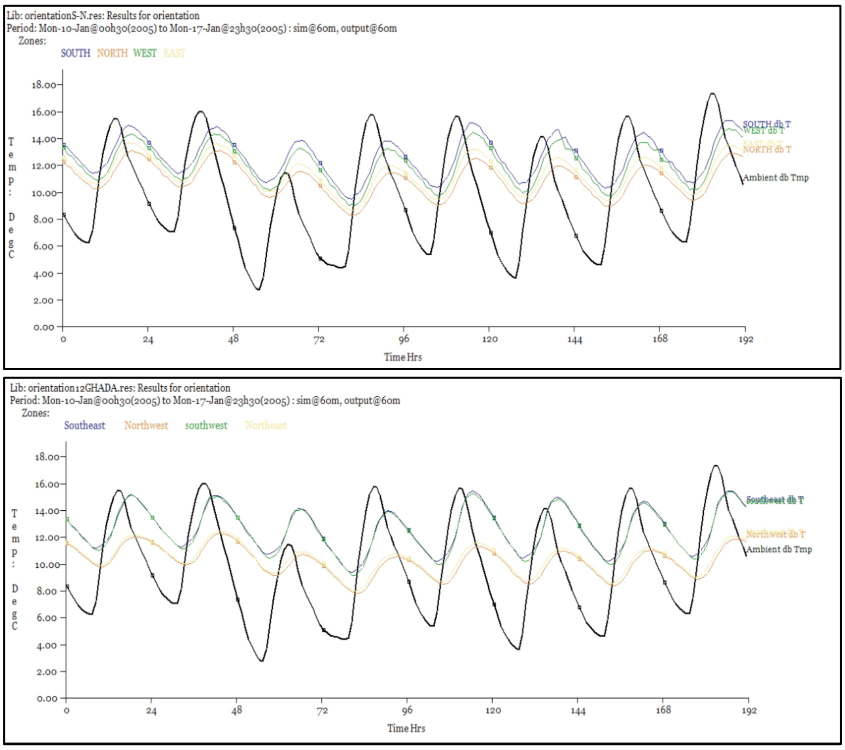


Figure (7. 44) Orientation strategy; compare the two orientation strategy, north-south and northeast-southwest during a week in winter

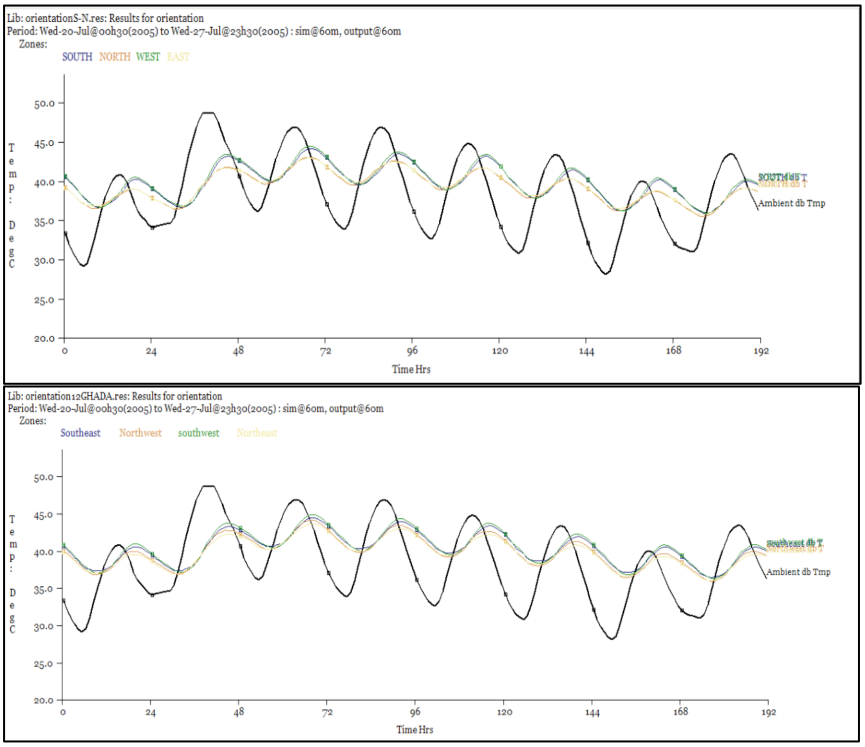
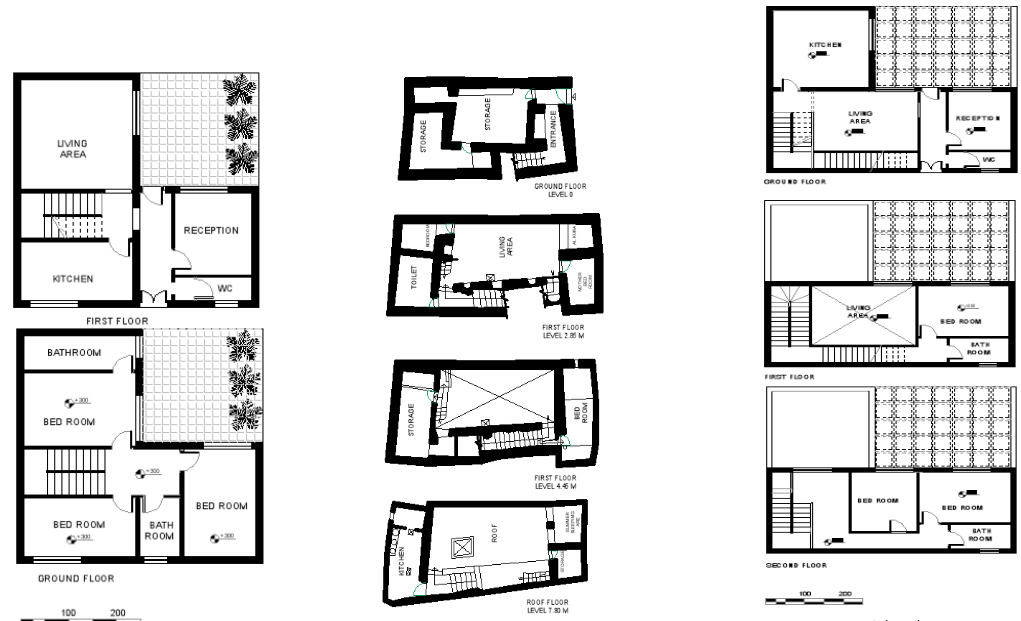


Figure (7. 45) Orientation strategy, comparison of the two orientation strategies. north-south and northeast-southwest

7.6.2. The design strategy

The ambient temperature in Ghadames increases to nearly 50°C in summer and drops in winter to nearly 3°C and in extreme cases may drop below zero. This extreme fluctuation in ambient temperature creates a great challenge to building houses that have good thermal performance in both winter and summer.

The Tripoli model was modified and tested, the zones having been moved in order to create a house with three storeys rather than two. This will minimize the heat gain and loss from the roof area and floor. In addition, the kitchen has been separated in order to reduce the effect of casual heat gains on the other zones. Finally, changing the level of openings in the staircase in order to create the stack effect will enhance the airflow through the building. These strategies are used in the vernacular traditional houses in Ghadames, where small openings were added between the levels to enhance air movement, in order to reduce air temperature on the upper floors in summer. Moreover, the staircase and the corridor act as a barrier between the model and the south orientation. The Figure (7-46) illustrates the modification for the model to adopt the vernacular passive cooling strategies. The model's Plans and section included in appendix C.



The model   Ghadames Houses   Ghadames

model

Figure (7. 46) the Ghadames model adjustment.

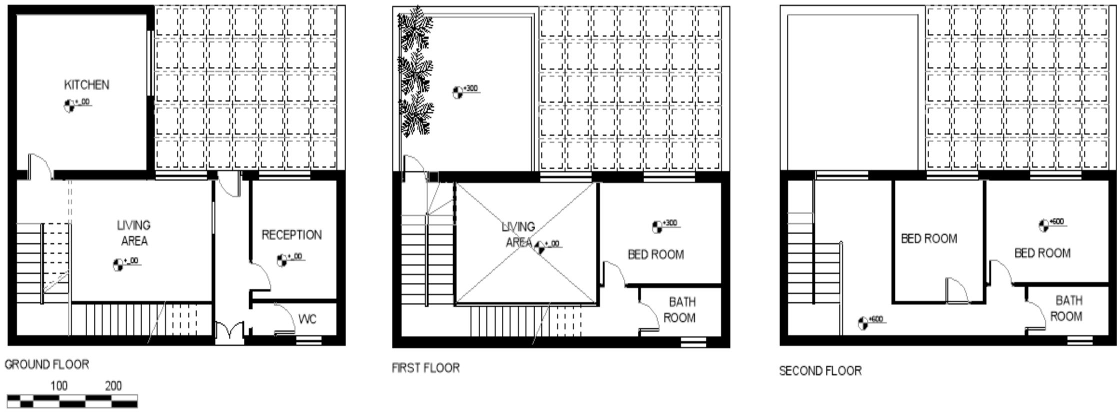


Figure (7. 47) Ghadames model ground, first and second floor

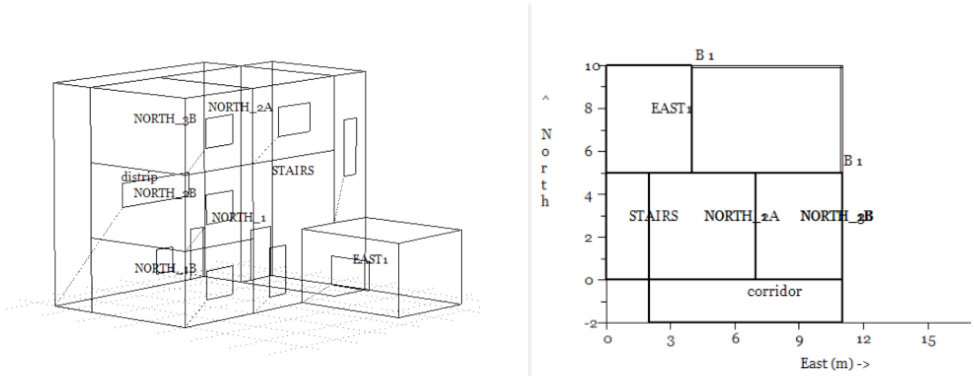


Figure (7. 48) ESP-r Geometry file for Ghadames model

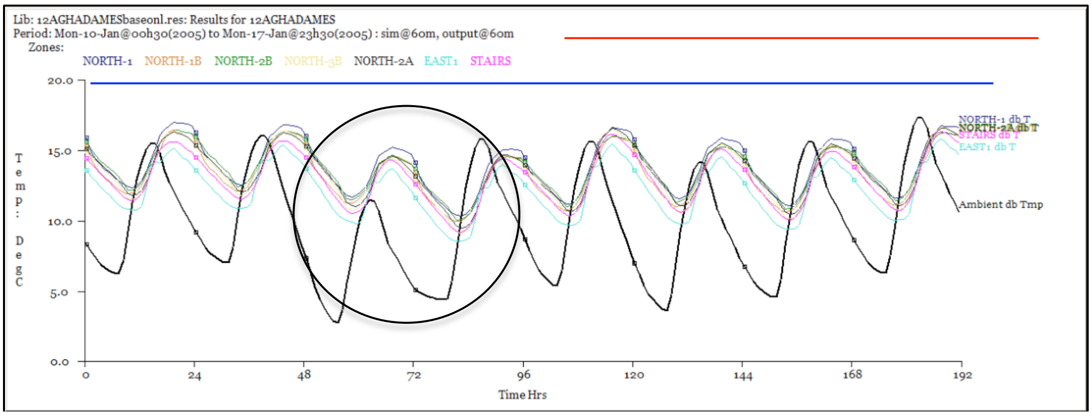
7.6.3. Passive cooling and heating technique strategies

The simulation was run during the coldest week from the 10th to the 17th of January and during the hottest week from the 20th to the 27th of June using the following data.

Category	Input data
Climate database	Ghadames climate
Building orientation	0- North
Building construction	Contemporary building construction material in
Terrain	Desert terrain
Building Height	9 m
Surface to volume	475/377
Glazed area	7% of the elevations
Family	5-6 members
Casual heat gains	Calculated – as shown in table (7-15)
Ventilation	Natural ventilated

Table (7. 15) Base case input data

7.6.3.1 Ghadames model of the base case



	25.2 °C upper margin		Ambient temperature
	21.2°C lower margin	Others	Indoor air temperature- dbT

*The circled area is plotted in more detailed graph

Figure (7. 49) Base strategy, thermal performance of the zones during the coldest week in winter

The graph illustrated in figure (7-49) illustrates the indoor air temperature in the model during a week in winter. It shows that the indoor air temperature in all zones remained below the comfort temperature zone for the region during the whole week, which required heating load in order to achieve thermal comfort temperature.

As result of the time lag of the building construction the indoor air temperature was recorded as lower than the ambient temperature from 10:00 to 17:00.

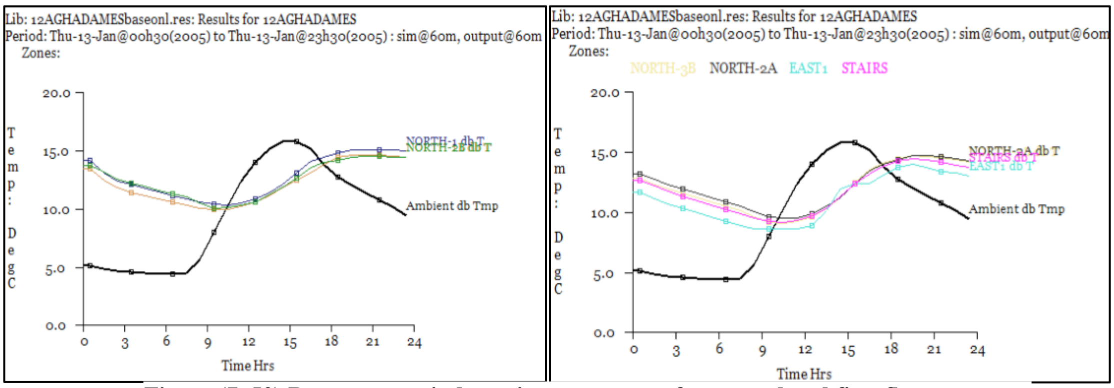
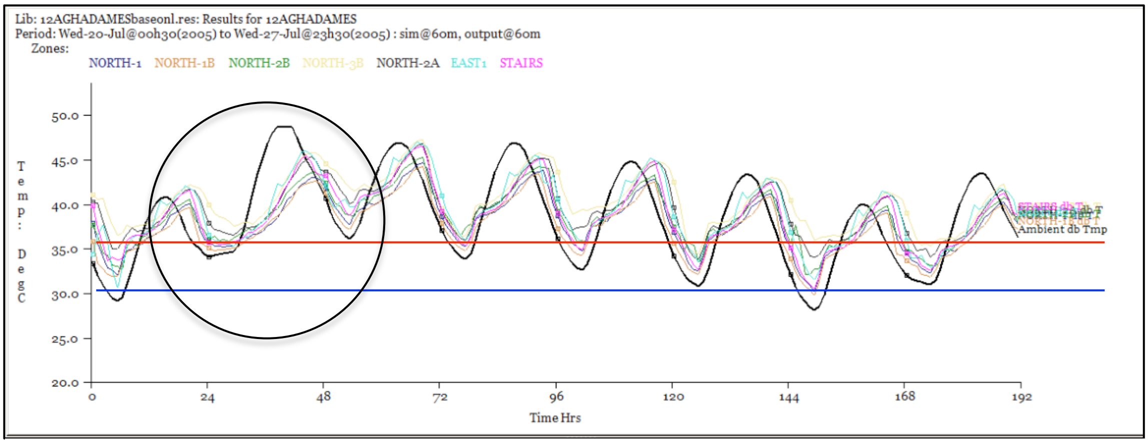


Figure (7. 50) Base strategy indoor air temperature for ground and first floor

The results from the simulation for a day shown in the graph, figure (7-50), prove that the zones on the ground floor have a better thermal performance than the zones in the higher floors; this is because the zones in the ground floor have less surface area exposed to the external environment.



	35.2 upper margin		Ambient temperature
	31.2 lower margin	Others	Indoor air temperature- dbT

*The circled area is plotted in more detailed graph

Figure (7. 51) Base strategy, the thermal performance of the zones during the hottest week in summer

The simulation was run for the model during the hottest week in summer; the ambient temperature was plotted against the zones air temperature. During the hottest week the ambient temperature rises to over 45°C and drops to nearly 29°C, the fluctuation between day and night temperatures can be used as an advantage point, by applying the night cooling strategy to the simulation in the base stage. Nevertheless, most of the zone failed to reach the comfort zone for the region.

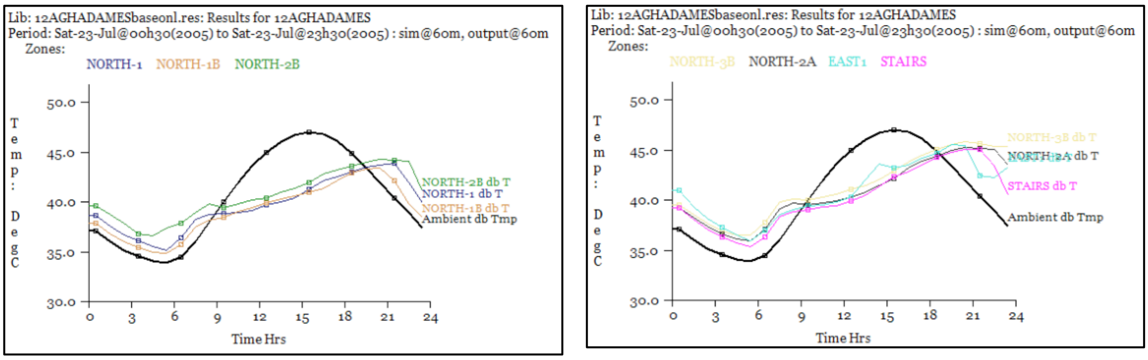
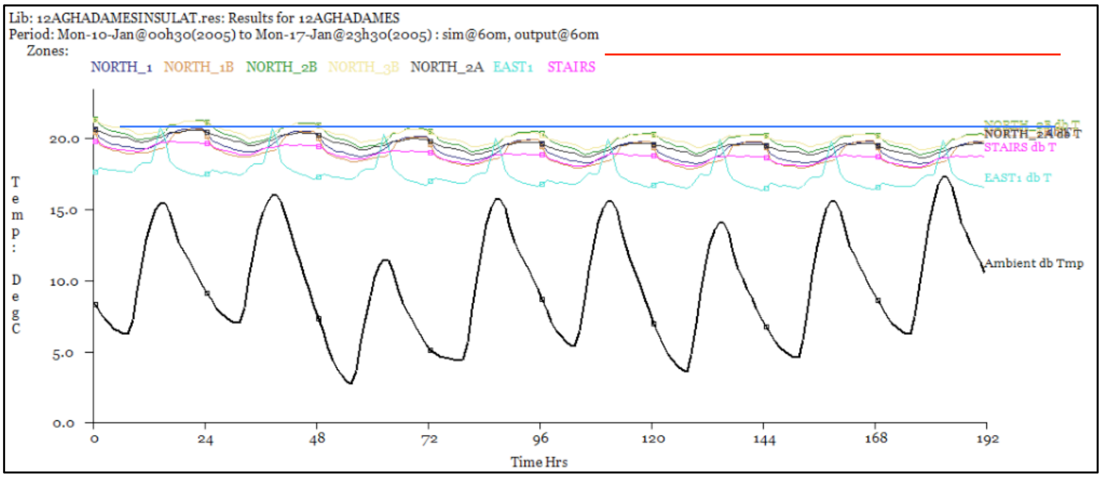


Figure (7. 52) The indoor air temperature in the zones for a day in summer

A focused study for the thermal performance of the model during a hot day in summer shows that the lower zones have a better thermal performance in summer. Minimizing the area of the roof was achieved in the old city of Ghadames by building multi-story houses.

7.6.3.2 The insulation strategy

Date palm wood is one of the main components in the construction of the traditional vernacular houses in Ghadames; therefore, in this study, date palm wood has been used in the model as the thermal insulation material as shown earlier in table (7-9). The insulation has been applied to the wall and roof construction, and a new insulated but high thermal mass layer was added, made of 100 mm of date palm wood mixture insulation and laid between the two layers of an outer wall made of sand blocks and breeze blocks. The new wall was constructed based on a thermal mass strategy with U-value of 0.578W/m^{2}K and a time lag of 16.8 hours. The contemporary roof was modified by adding an insulation layer (date palm insulation) with a thickness of 50mm and U value of 0.56W/m^{2}K, table (7-12).



	25.2 °C upper margin		Ambient temperature
	21.2°C lower margin	Others	Indoor air temperature- dbT

Figure (7. 53) Insulation strategy, the thermal performance of the zones during the coldest week in winter

The daily fluctuation of the indoor air temperature changes dramatically with the use of insulation As illustrated in Figure 7-54, the air temperature of the zones improved by nearly 5 K in all zones. Nevertheless, the indoor air temperature failed to reach the comfort zone by nearly 2-5 K.

The day simulation graphs in figures (7-54) show that the indoor air temperature increases by nearly 5 K compared to the base case. In order to achieve indoor thermal comfort additional strategies need to be applied.

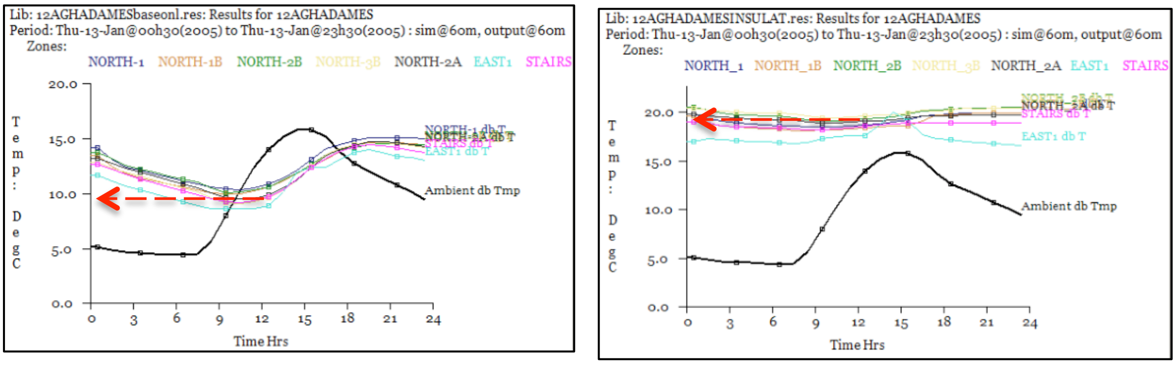
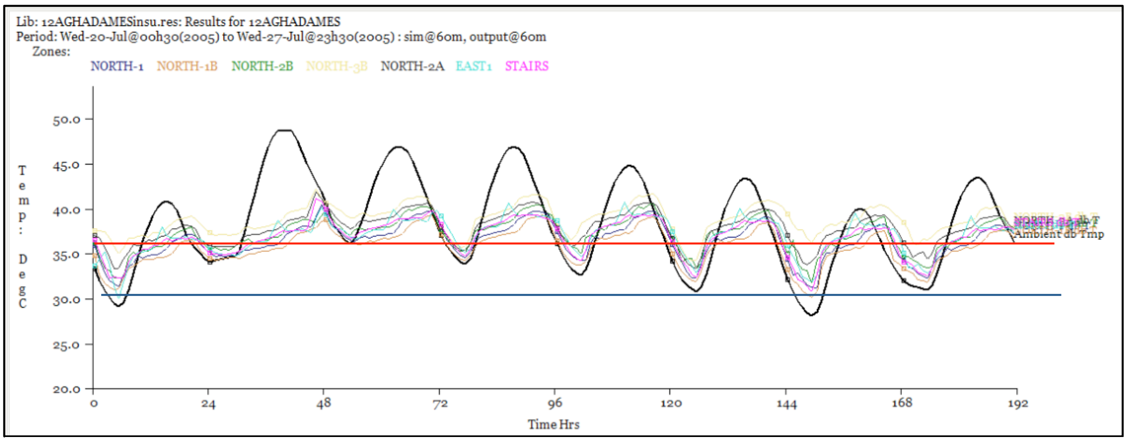


Figure (7. 54) Comparison between base case and the insulation strategy during a day in winter

The graph figure (7-55) for summer indicates the great impact of the insulation strategy in reducing the indoor temperature in the zones. The night cooling strategy has been applied by controlling the window opening during the summer season.



(red line)	35.2 upper margin	(black line)	Ambient temperature
(blue line)	31.2 lower margin	Others	Indoor air temperature- dbT

Figure (7. 55) Insulation strategy, the thermal performance of the zones during the hottest week.

The extreme ambient temperature, which rises to 49°C, creates difficulty in achieving thermal comfort in the zones, nevertheless the indoor temperature decreases by more than 7 K in all zones compared with the external environment.

To highlight the thermal performance in the zones, a zoom-in graph was plotted to compare the results for the insulation strategy with those for the base case strategy. During the hottest day the air temperature dropped nearly 5 K in all zones. However, it failed to achieve thermal comfort, Figure (7-56).

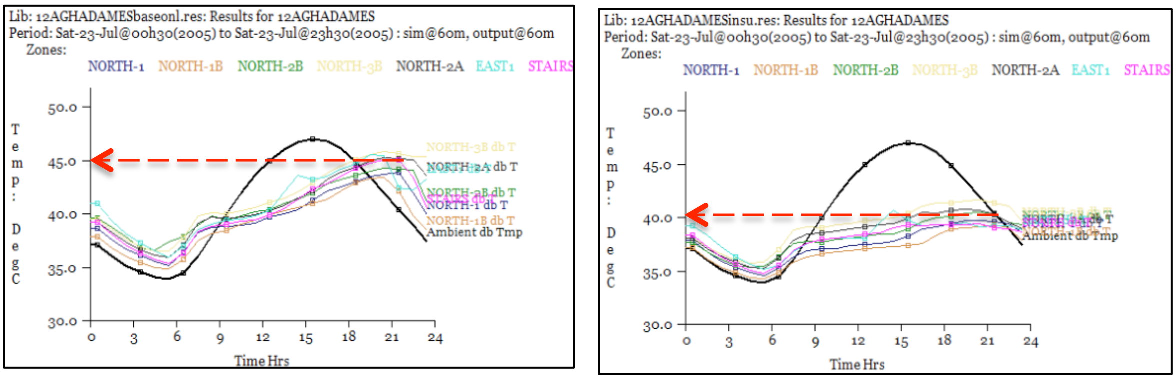


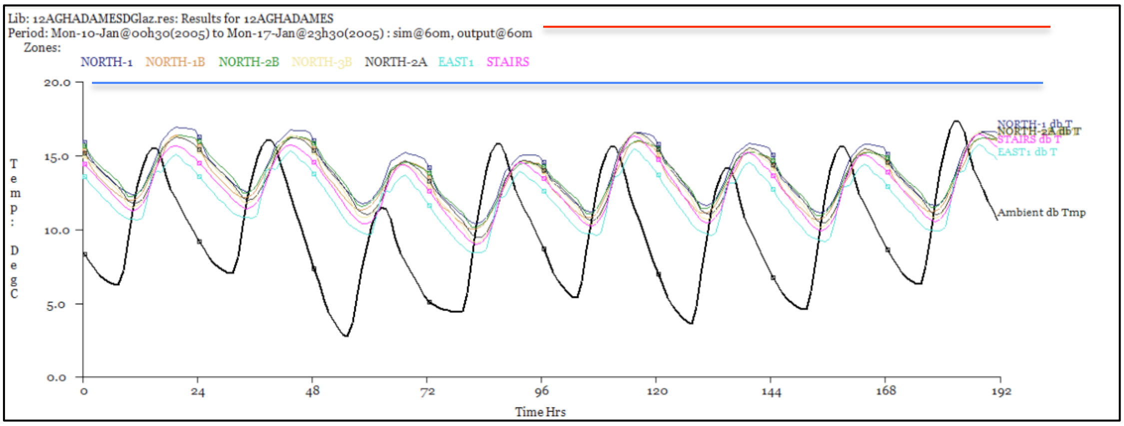
Figure (7. 56) Comparative study between the base case and the insulation strategy during a day in summer. Red arrow indicates maximum internal temperature

The indoor air temperature was recorded as higher than the comfort zone by nearly 4K in the lower floor zones and 5K in the upper floors Therefore it would seem necessary to use further strategies; adding roof shading to the model can produce better thermal performance for the upper zone. In addition, using double glazed windows and shutters also can reduce the solar heat gains.

7.6.3.3 Glazing strategy

The Ghadames vernacular traditional house uses windowless rooms to reduce solar heat gains, and enhances the internal daylight level by using reflecting surfaces; this strategy can be considered an extreme solution that neglects the need for a view in the house. Tregenza and Wilson (2011) point out that a windowless room is strongly disliked and the existence of a link with the outside is valued..

Windows can provide a significant contribution to heat gains and losses; therefore, using windows with low thermal conductivity is essential to reduce heat gain in summer and heat loss in winter. Using a double-glazed window reduces the thermal conductivity typically from 5.6 U to 2.8 U, therefore in this study the single glazed windows have been replaced by double glazed windows in the model and summer and winter simulation have been run.



	25.2 °C upper margin		Ambient temperature
	21.2°C lower margin	Others	Indoor air temperature- dbT

Figure (7. 57) Glazing strategy, the thermal performance of the zones during the coldest week in winter

It was found that the glazed strategy had a minimal effect on the internal air temperature. This can be related both to the small area of the glazed surface (only 7% of the elevations) and the windows orientation toward the north. However, heat losses through windows are also related to the infiltration, so using a draft proof window has a good effect on the thermal performance of the windows, provided there is still sufficient ventilation.

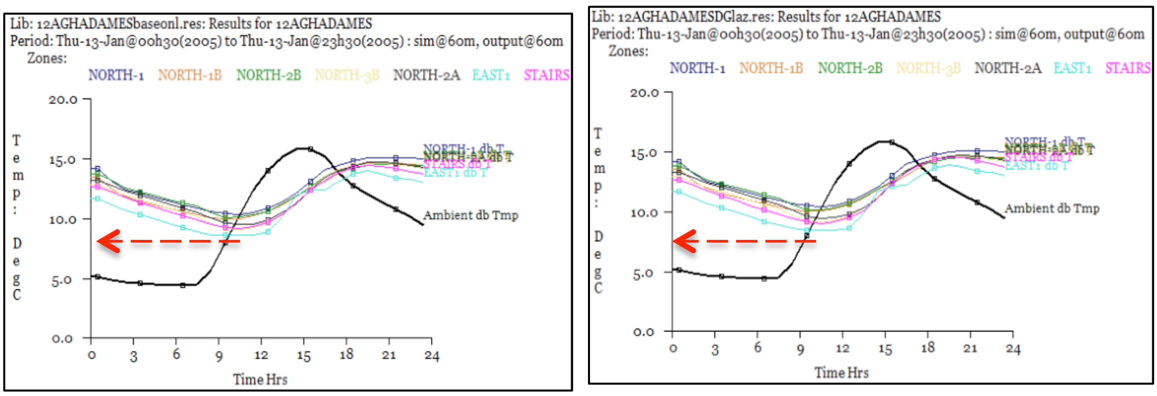
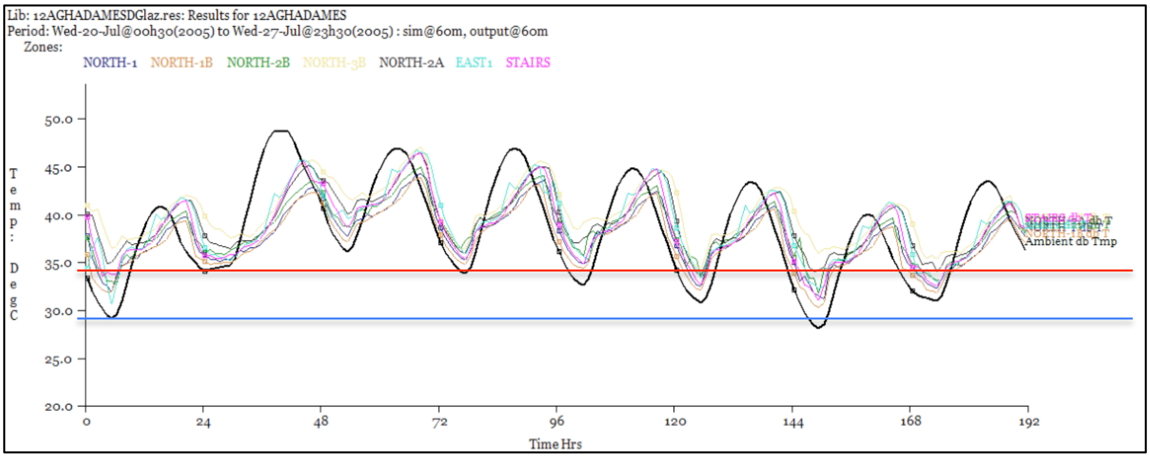


Figure (7. 58) Comparative study between the base case and the doubled-glazed strategy for a day in winter

The double-glazed windows had a minor effect on the internal air temperature; this results from the small opening in addition to north orientation of the windows in the model. The air temperature in all zones recorded a small change, and the daily indoor temperature plotted over the comfort zone, the hourly simulation graph in figure (7-59) shows that the temperature dropped nearly 1K on the east zone.



(red line)	35.2 upper margin	(black line)	Ambient temperature
(blue line)	31.2 lower margin	Others	Indoor air temperature- dbT

Figure (7. 59) Double-glazed strategy, the thermal performance of the zones during the hottest week in summer

The glazing strategy alone cannot significantly reduce the heat gain in summer; therefore replacing single glazed windows with double-glazed ones should be applied with shading devices and shutters to improve the thermal performance of the windows.

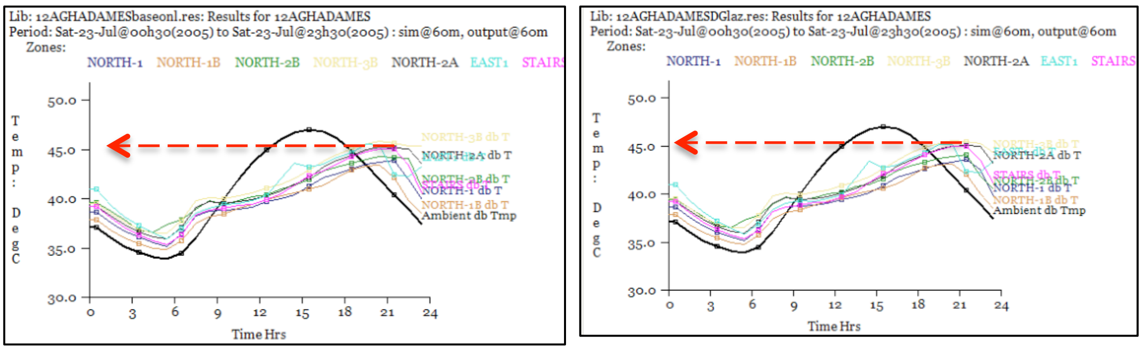
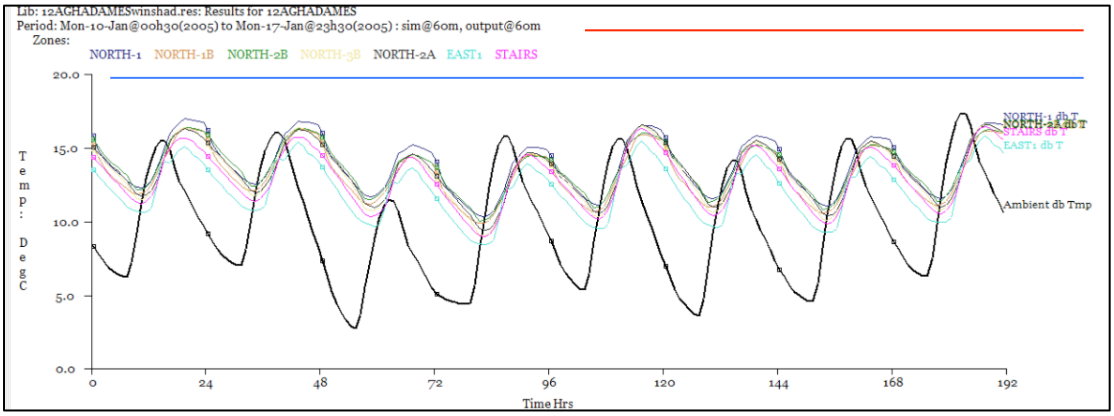


Figure (7. 60) Comparative study between the base case and the double-glazed strategy during a day in summer

7.6.3.4 Shading strategy



	25.2 °C upper margin		Ambient temperature
	21.2°C lower margin	Others	Indoor air temperature- dbT

Figure (7. 61) Shading strategy, the thermal performance of the zones during the coldest week in winter

In the hot climate of Ghadames, blocking the solar radiation is considered one of the effective solutions. The local builders have adopted such a solution to reduce heat gain, using a high parapet on the roof to provide more shade, and by covering the courtyard. This strategy is adopted by the study to reduce the amount of heat gain in the summer.

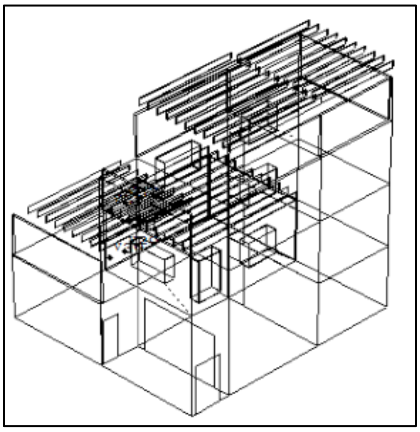


Figure (7. 62) summer shading strategy.

As discussed earlier in the Tripoli case study, in Ghadames, a city with high solar radiation applying this strategy is essential; however, any shading strategy should be designed carefully to provide ventilation and daylight... The simulation was run using the base construction data, and with modified shade files, by adding shading device to the three component of the model: providing timber shutters and window reveals, protecting the roof from the direct solar radiation by adding an adjustable secondary roof and incorporating high parapets on the roof, and finally covering the courtyard space with flexible cover that protects the court from the solar heat gain without preventing daylight and ventilation.

The simulation was run in two stages; firstly in cold season mode where the use of the shading devices is at a minimum and secondly during the hot season mode where the use of shading is at a maximum.

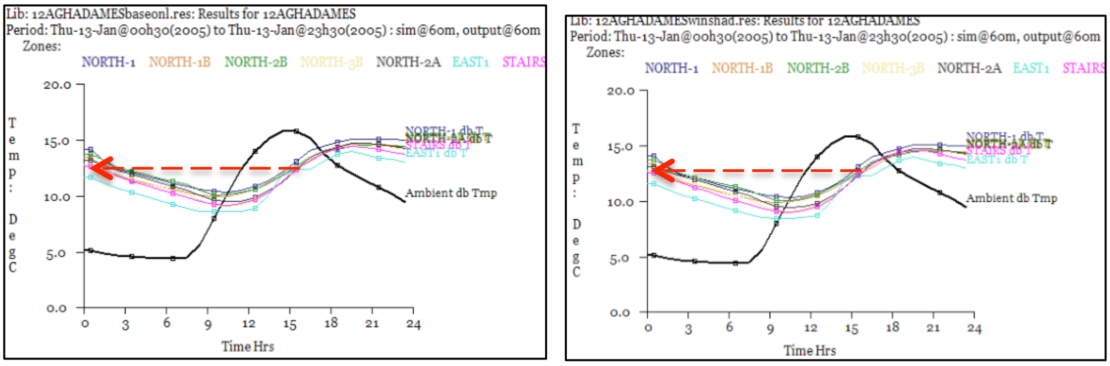
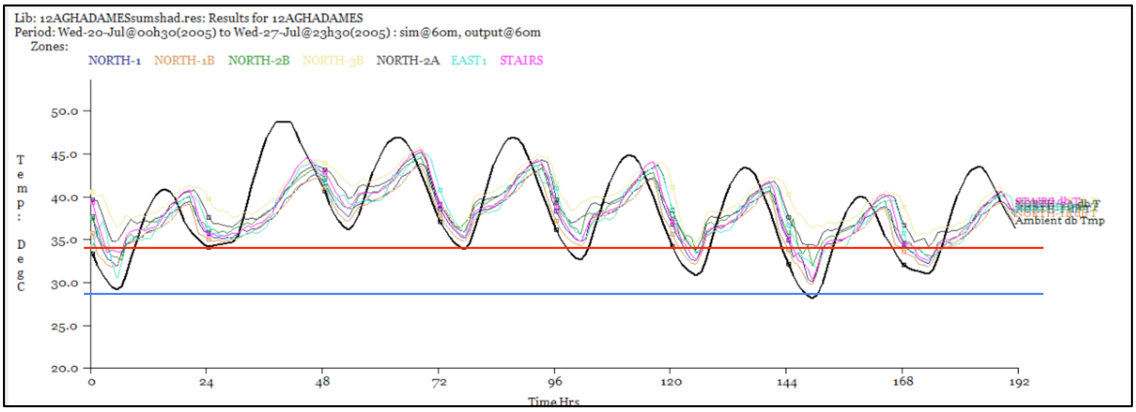


Figure (7. 63) Comparative study between the base case and the shading strategy during a day in winter

From the previous graphs figure (7.63), it can be seen that the shading devices used in the model did not have a negative impact on the indoor air temperature. Moreover, using flexible shading devices helped to achieve shading impact in summer and eliminate its effect in winter in order to allow solar heat gains through the windows and roof

The shading strategy has been very efficient in the hot season, as the indoor temperatures dropped by almost 3K in most of the zones. The effect of the secondary roof is greatest



(red line)	35.2 upper margin	(black line)	Ambient temperature
(blue line)	31.2 lower margin	Others	Indoor air temperature- dbT

Figure (7. 64) Shading strategy, the thermal performance of the zones during a week in summer

on the upper floors zones (NorthA2, NorthB3, and East) and the shutters and shading devices had a great impact on the East zone, producing a great improvement in air temperature.

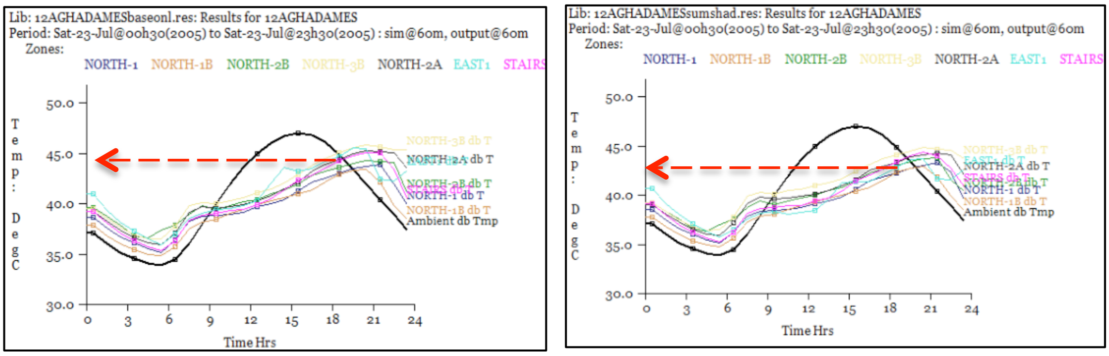
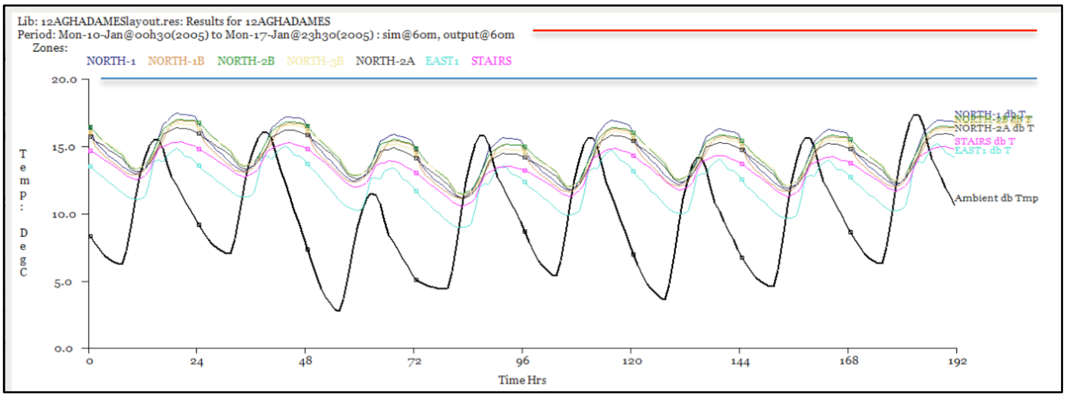


Figure (7. 65) comparative study between the base case and the shading strategy during a day in summer

The shading strategy alone does not achieve the required indoor comfort temperature for the region. Therefore we need to investigate whether the effect of the surroundings on the model could add more shade on the surfaces and protect the walls from heat loss and gain.

7.6.3.5 Layout and contextual impact strategy

In the old city of Ghadames the compact urban fabric, covered streets, and narrow passageways provides good adaptation to the extreme annual and diurnal variation and severe ambient environment. Thus, this aspect is applied in the model layout for Ghadames, in order to reduce the area of the exposed wall to the environment, as well as to suit the requirements of modern life in the city.



	25.2 °C upper margin		Ambient temperature
	21.2°C lower margin	Others	Indoor air temperature- dbT

Figure (7. 66) Layout strategy, thermal performance of the zones during the coldest week in winter

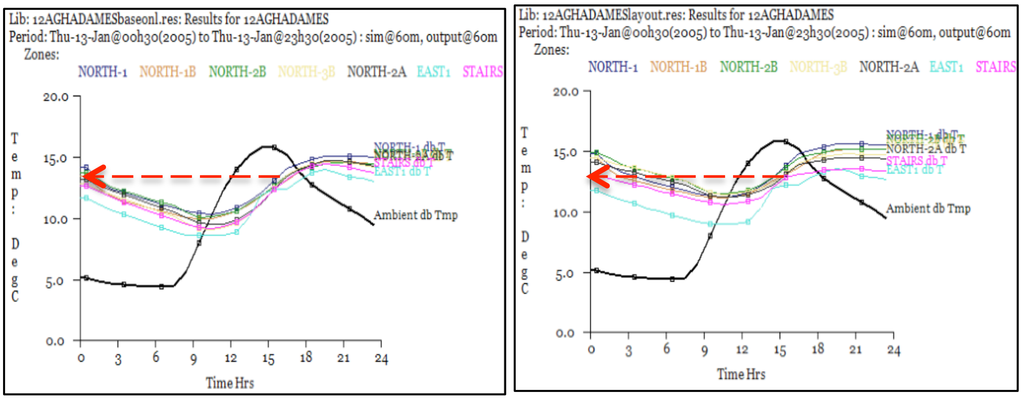


Figure (7. 67) Comparative analysis between the base case and the layout strategy during a day in winter

Two blocks were created on the geometry file to represent the neighbouring houses in order to study the effect of the surrounding on the model; moreover the casual heat gains were added in the two blocks, and a simulation was run for a week in the summer season, and for a week in winter. The effect of the layout strategy on the model during the winter week is shown on the graph below. It is clear that the indoor temperature lay under the comfort zone and heating load must be added in order to achieve thermal comfort.

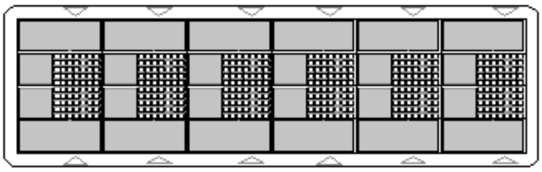
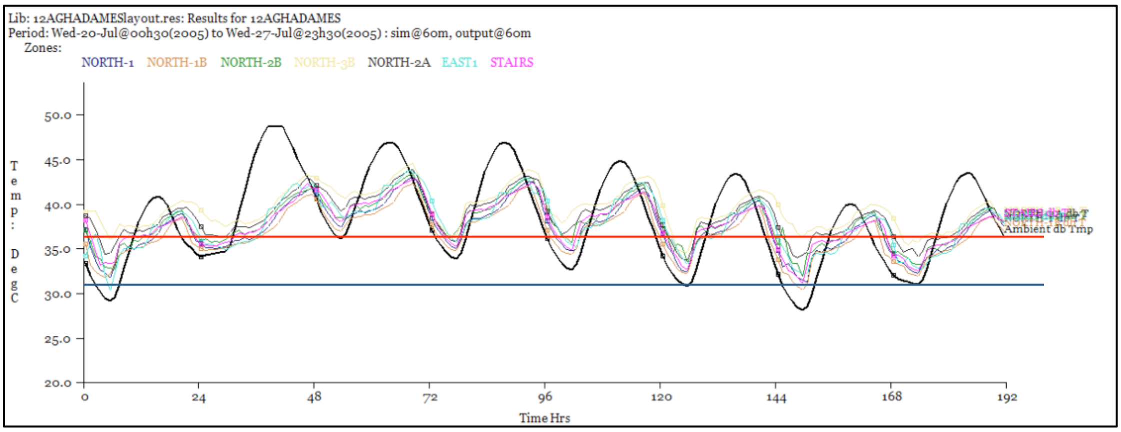


Figure (7. 68) Layout strategy



	35.2 upper margin		Ambient temperature
	31.2 lower margin	Others	Indoor air temperature- dbT

Figure (7. 69) Layout strategy - thermal performance of the zones during the hottest week in summer

The comparative study between the base case and the layout strategy illustrated in graph figure (7-67) shows that the indoor temperatures are improved in the zones that are adjacent to the new blocks north B1, B2 and B3, with drops of nearly 3K.

During the summer season the effect of layout strategy is noticeable in all zones with drops in temperature of nearly 3K. The strategy has an obvious contribution in reducing the indoor air temperature; therefore utilizing this strategy with the combined strategies of insulation, glazed and shading may reduce the indoor temperature to within the comfort zone.

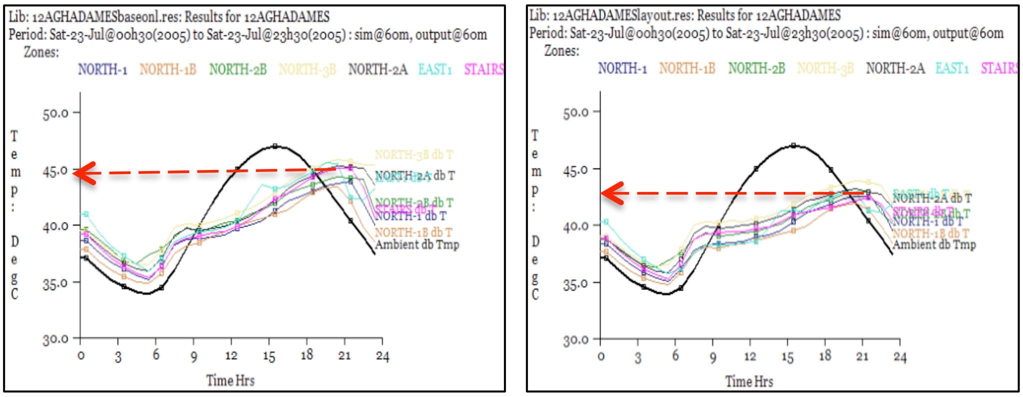
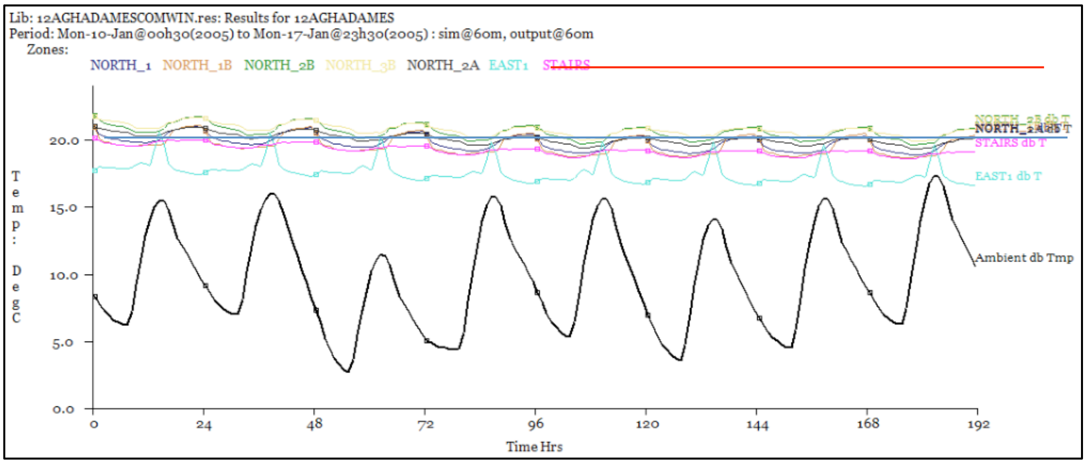


Figure (7. 70) Comparative study between the base case and the layout strategy

7.6.3.6 Combined Strategy

The best results from the previous simulations have been combined into the model, and a final simulation run of the model for a week in winter and summer.

In the winter week, Figure 7.71, the combined strategy was seen to be effective, and a remarkable increase in air temperature was seen, nearly 8K in all zones. However, the indoor air temperature lay just below the comfort zone with less than 1K for the north oriented rooms and over 3.5K for the east oriented zone.



(red line)	25.2 °C upper margin	(black line)	Ambient temperature
(blue line)	21.2°C lower margin	Others	Indoor air temperature- dbT

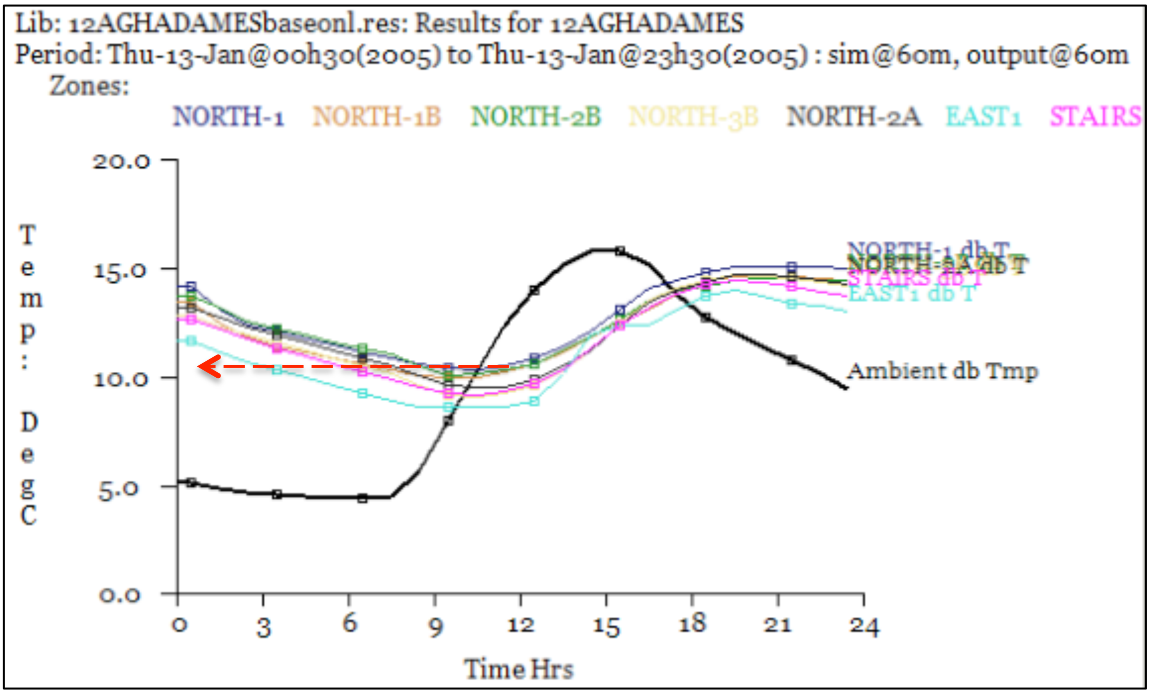
Figure (7. 71) Combined strategies, the thermal performance of the zones during the coldest week in winter

The best results from the previous simulations have been combined into the model, and a final simulation run of the model for a week in winter and summer.

In the winter week, Figure 7.71, the combined strategy was seen to be effective, and a remarkable increase in air temperature was seen, nearly 8K in all zones. However, the indoor air temperature lay just below the comfort zone with less than 1K for the north oriented rooms and over 3.5K for the east oriented zone.

The results have been analyzed on a daily and hourly basis for the model during the coldest day; it showed an outstanding improvement in the indoor air temperature, all the zones lying in the comfort zone with the exception of the east zone. Although the zone functions as a kitchen, with high casual gains, it fails to reach the comfort zone except between 13:00 and 14:00, when the casual heat gain in the zone at its peak.

In conclusion, although the comfort zone is considered high the indoor comfort temperature can be achieved by passive means, using insulation, shading and orientation strategies.



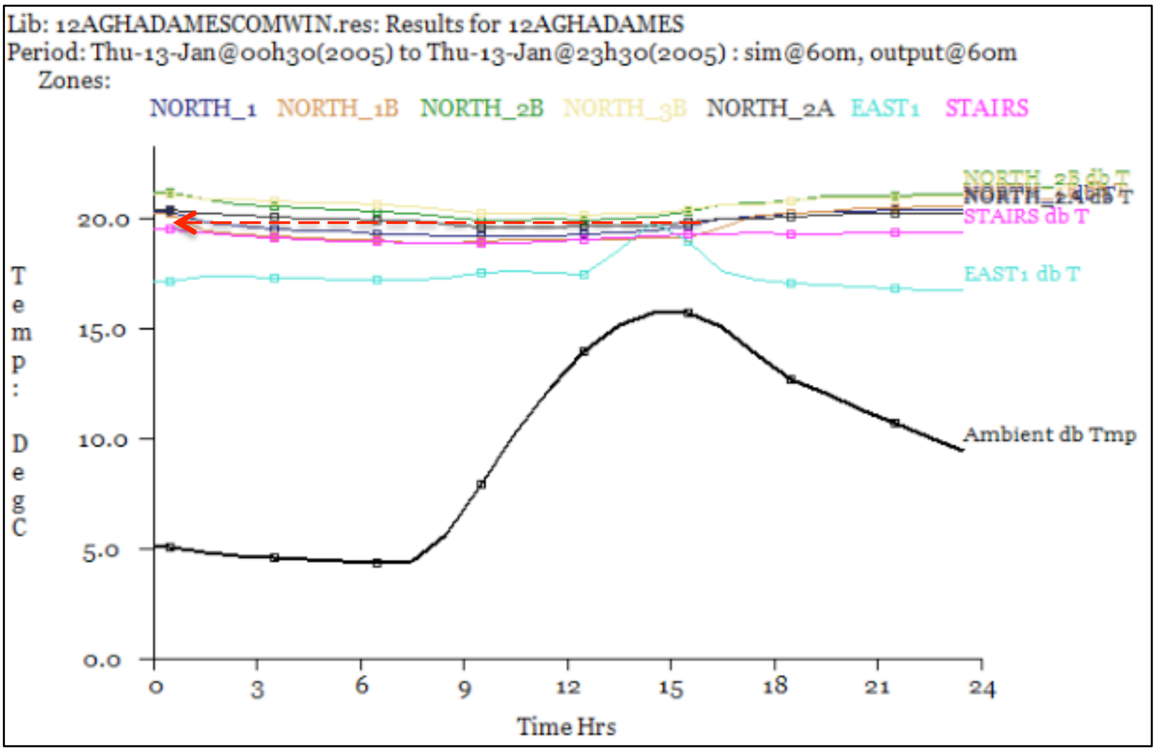
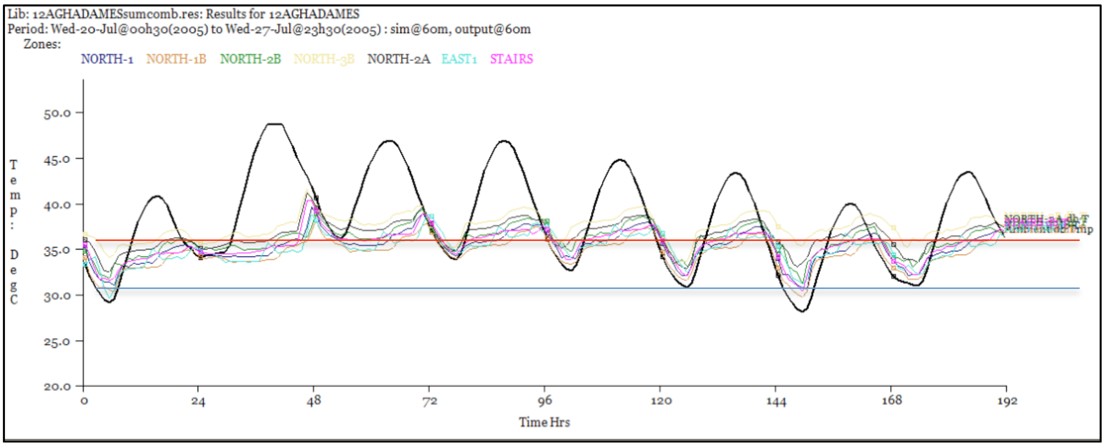


Figure (7. 72) Comparative study between the base case and the combined strategies during a day in winter



(red line)	35.2 upper margin	(black line)	Ambient temperature
(blue line)	31.2 lower margin	Others	Indoor air temperature- dbT

Figure (7. 73) Combined strategies, the thermal performance of the zones during the hottest week in summer

On the other hand the model recorded great thermal performance during the summer season as illustrated in the graph above figure (7-72). The indoor temperature was recorded at just around the upper margin in the hottest days when the ambient temperature rises above 49°C, and the indoor temperature was recorded at more than 10K below the ambient temperature.

Studying the hourly graph figure (7-73) shows the effect of combined strategies compared to the base case The indoor temperature dropped by nearly 6K for most of the zones during the hottest hour at 15:00. The graphs also indicate that the lower floors had a better thermal performance than the upper floors during the day when these spaces are in use On the other hand the bedroom air temperature is in the comfort zone during the occupied hours.

During the summer the combined strategies did not achieve the comfort zone; this was because the night air temperature is just above the comfort zone, therefore the night cooling strategy cannot be applied on these days. However, by applying the combined strategies to the model its thermal performance improved in both winter and summer as a result of using local materials and the vernacular houses design passive cooling strategy.

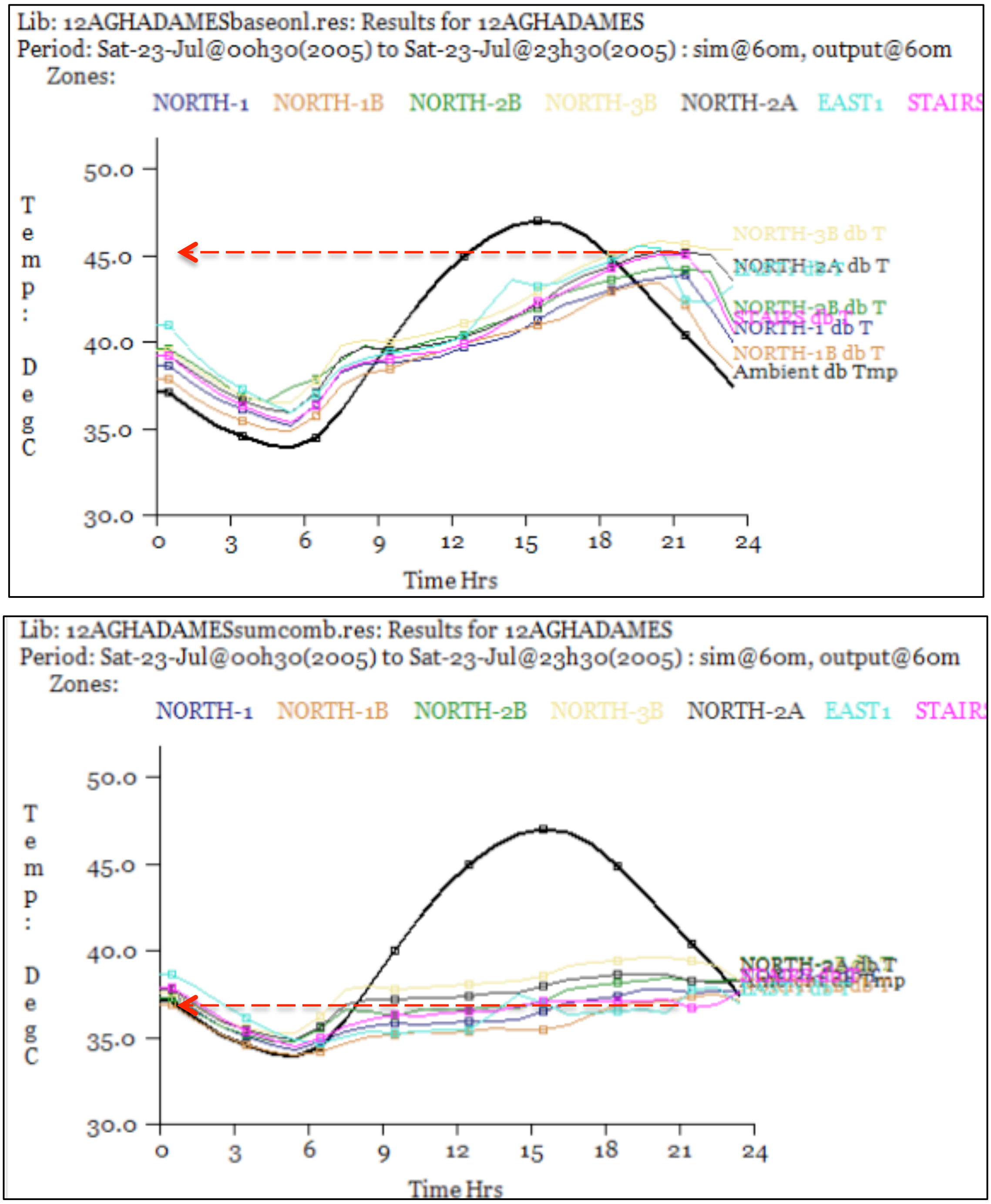


Figure (7. 74) Combined strategy, a comparative study with the base case for the hottest day in summer

7.7. Gheryan case study

Data for the city of Gheryan, were added to the ESP-r programme. The climatic database was set to represent Gheryan–Libya with Latitude N-32.17^o, and Longitude E-13.1^o, climate database sets for one year from 1 January to 31 December.

The model was tested in three steps, orientation strategy, design layout and energy simulation strategies. Four simulation strategies were run with respect to Gheryan climate, insulation strategy, shading and glazing strategy, and the layout passive cooling strategies. In the Gheryan case study the passive cooling strategies were adopted from the traditional vernacular architecture solution presented in chapter four. The best performance resulted from these simulations, was used for the final simulation as a combined strategy.

An energy simulation was run for the model for a week in January to exemplify the cold season and for a week in July to exemplify the hot season, using the contemporary building material for the model envelope (walls and roof) as a base case, and then a simulation of the modified model was run, according to the above strategies. The result was plotted as charts of the ambient temperature and the indoor dry-bulb temperature against time. Moreover, the results were compared to the comfort temperature for Gheryan, using the equations found in chapter five, that calculate the comfort zone for Gheryan, the upper and lower margin for city being found by:

$$\boldsymbol{T_{comf} = 0.47T_{rm} + 14.3 \pm 2}$$

This set the comfort zone for January (winter week) to 22.8°C as upper margin and 18.8°C as lower margin. For July (summer week) it was set to 30.5°C as upper margin and 26.5°C as lower margin.

7.7.1. Orientation Strategy

For the purpose of this study, a geometry file was set up to test the best orientation for the model; a four-zone block was made, each zone having a window oriented to different directions. The model was simulated with the block oriented north-south at first, and then northeast-southwest, with a rotation of 45 degree and the simulation was done for the winter and summer periods.

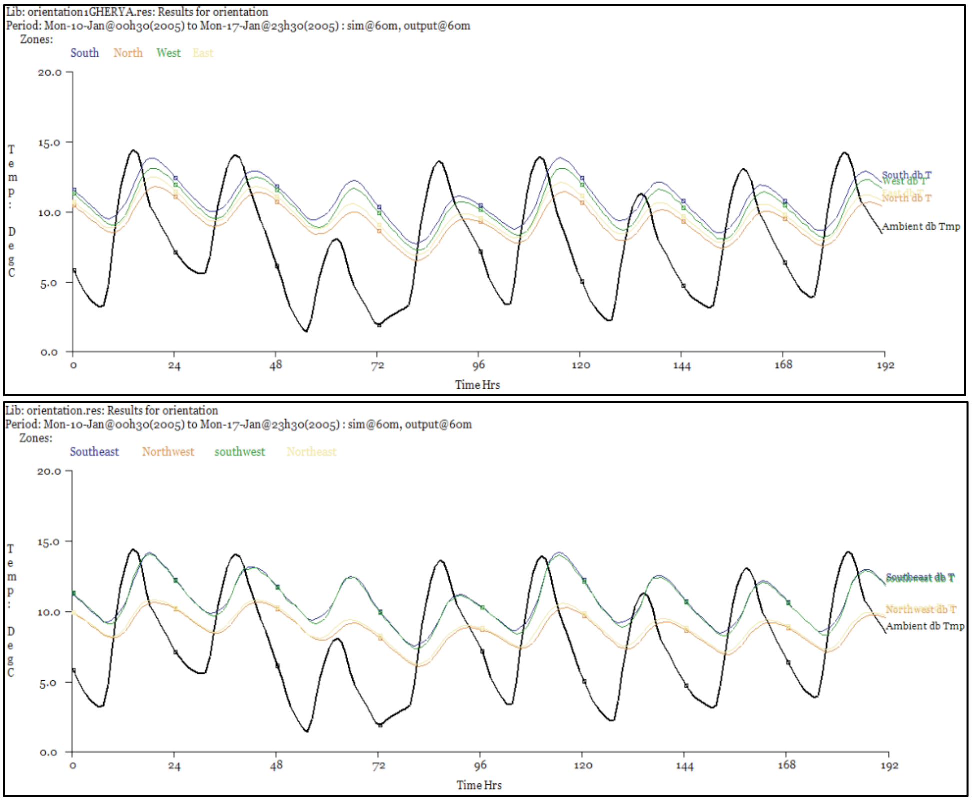


Figure (7. 75) Orientation strategy for the coldest week in winter

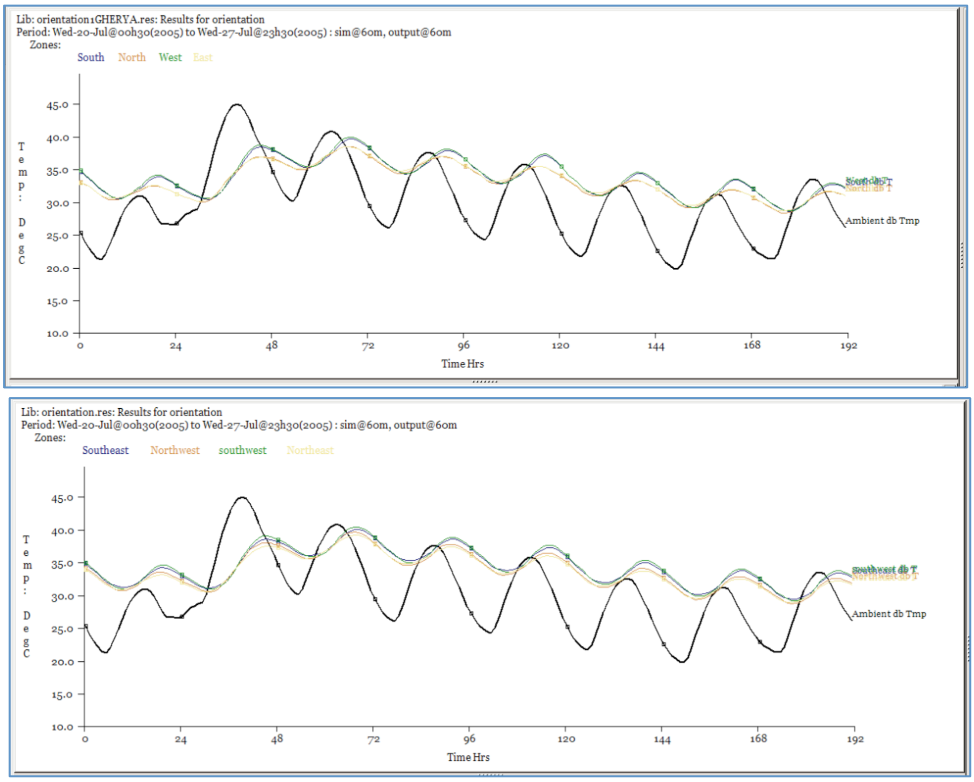


Figure (7. 76) Orientation strategy for the hottest week in summer

The simulation results are expressed in a graphical form where the internal temperature and ambient temperature are plotted against time. The model was simulated with the Gheryan climate database from the 10^{th} to the 17^{th} of January for the winter period and from 7^{th} to the 14^{th} of July for the summer period. A chart shown in figure (7.75) was drawn to illustrate the thermal performance of the model

From the charts shown in figures (7.75) and (7.76), it is clear that in Gheryan the model with North South orientation has better performance than northeast and southwest in the summer period. However, the chart shows that within the north-south orientation with the exception of the west orientation most of the zones have better performance than the northeast and southwest. In summer, in the case of northeast and southwest orientations two zones, southwest and southeast recorded higher temperatures; therefore it worsens the internal conditions, giving higher temperatures, which required more energy to cool it down to thermal comfort zone. As a result of the simulation, the orientation of the model to the west was avoided and the courtyard was located in the northeast position, permitting openings to the north, south and east only.

In conclusion, the better orientations for the window openings are the north, east and south; on the other hand, the west zone recorded the worst thermal performance. Therefore, in the proposed model, the courtyard is located in the northeast area, in order to allow north and east opening.

7.7.2. The design strategy

In this section the various designs of Gheryan models have been tested in order to produce an optimum design with the best thermal performance, using contemporary construction materials as the base case. The design should be modifiable so that vernacular techniques of passive cooling and heating can be applied to the model, as well as to fulfill the people's modern needs. The model's Plans and section included in appendix C.

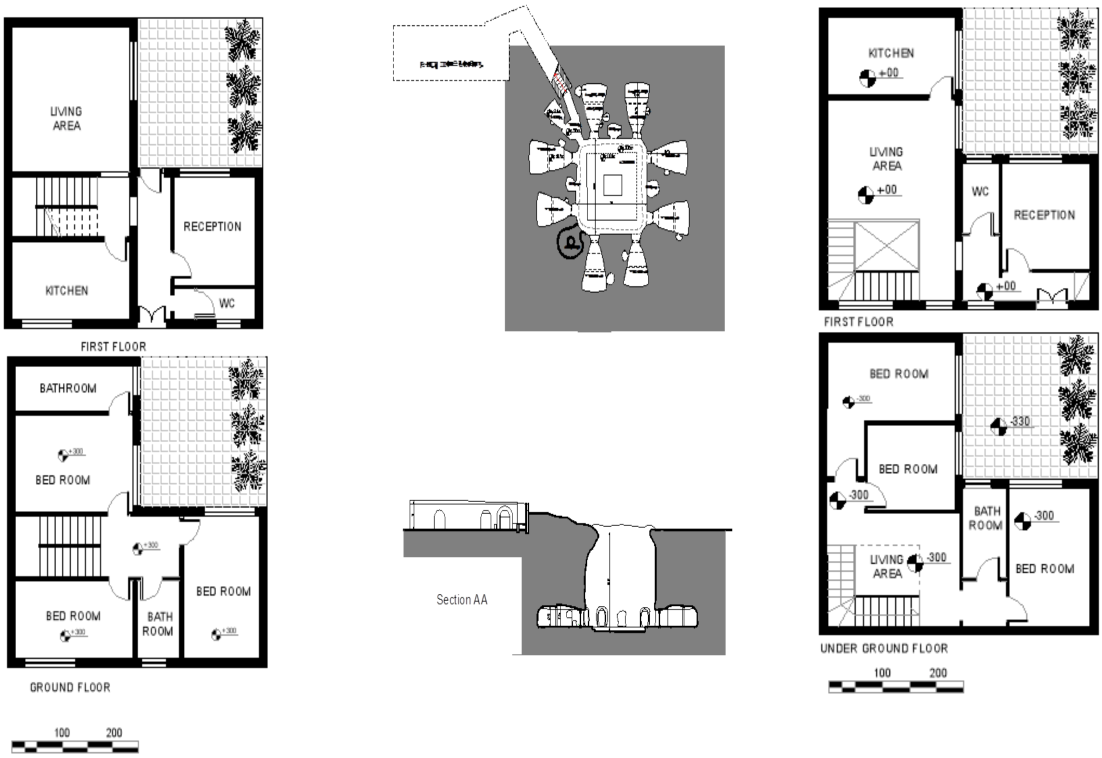


Figure (7. 77) Modification to the model to adopt the traditional vernacular heating and cooling strategies.

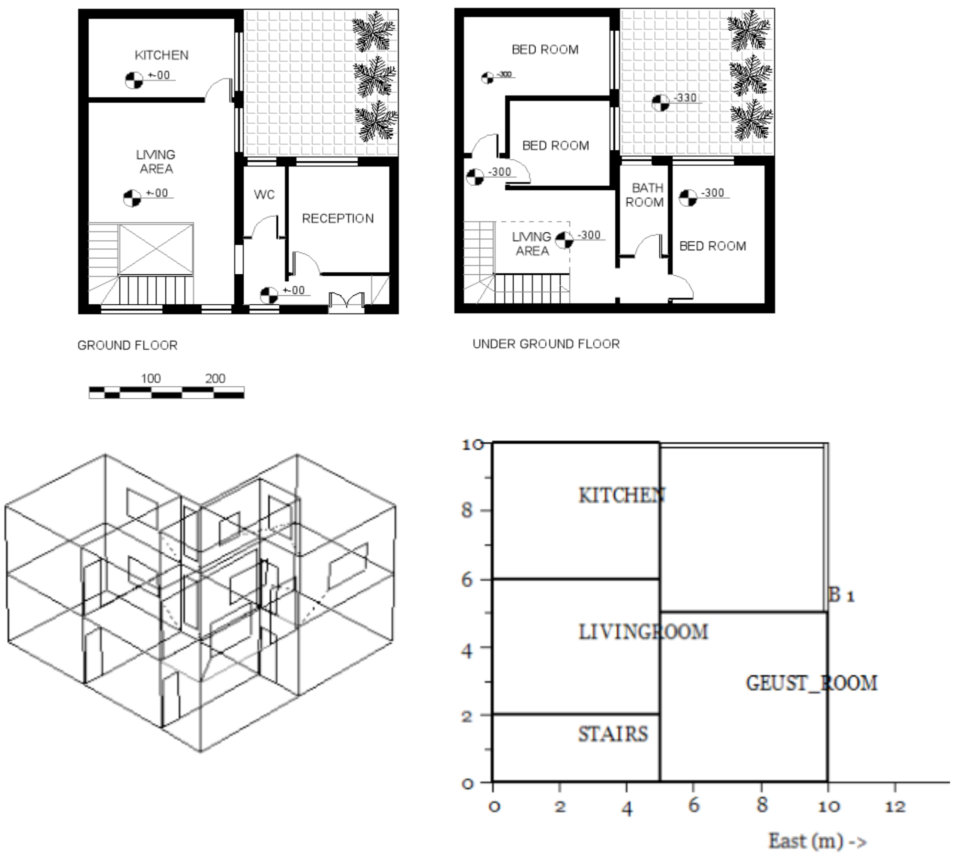


Figure (7. 78) Gheryan model, ground, first floor and the model in ESP-r geometry

Using the earth cooling strategy can improve the thermal performance of the model. Therefore the model has only two external elevations to allow burying the first floor of the model into the ground, and simulations were run for both models and the results are illustrated in figure (7.76).

The model consists of three bedrooms located on the ground floor and a living room, kitchen and guest room located on the first floor. The idea is to evolve the model with respect to the vernacular house passive cooling and heating strategy in order to achieve better performance for the requirements of modern houses.

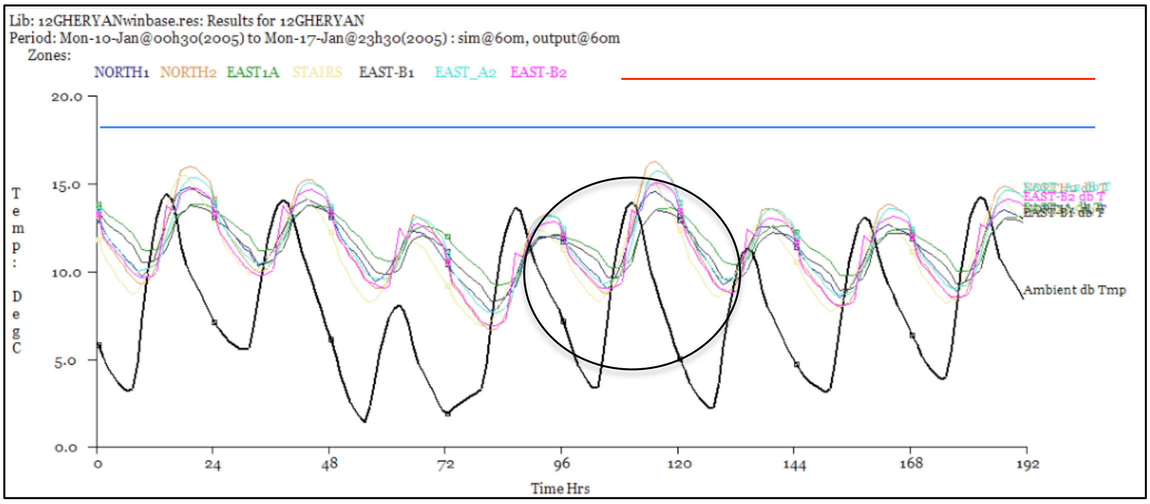
7.7.3. Passive cooling and heating technique strategies

The model was simulated as a base case using the following data.

Category	Input data
Climate database	Gheryan climate
Building orientation	0- North
Building construction	Contemporary building construction material in Gheryan
Terrain	Mountainous terrain
Building Height	5.5 m – 8 .5 m
Underground level	-3 m
Family	5-6 members
Casual heat gains	Calculated –table (7-12)
Ventilation	Natural ventilated
Glazed area	6% of the elevations

Table (7. 16) Base case input data

7.7.3.1 The Base case strategy for Gheryan



	22.8 °C upper margin		Ambient temperature
	18.8°C lower margin	Others	Indoor air temperature- dbT

*The circled area is shown in detailed in the next graph

Figure (7.78) Base case strategy, the thermal performance of the zones during the coldest week in winter

The simulation was run for the model in its base case strategy using contemporary materials during the coldest and hottest weeks. The result of the simulation for the coldest week was plotted on the graph (7.78) shown above, it illustrates that the indoor temperature in all zones failed to reach comfort temperature.

The aim of the experiment is to increase the indoor temperature form 7°C to 18.8°C, the average lower margin for this region during this week.

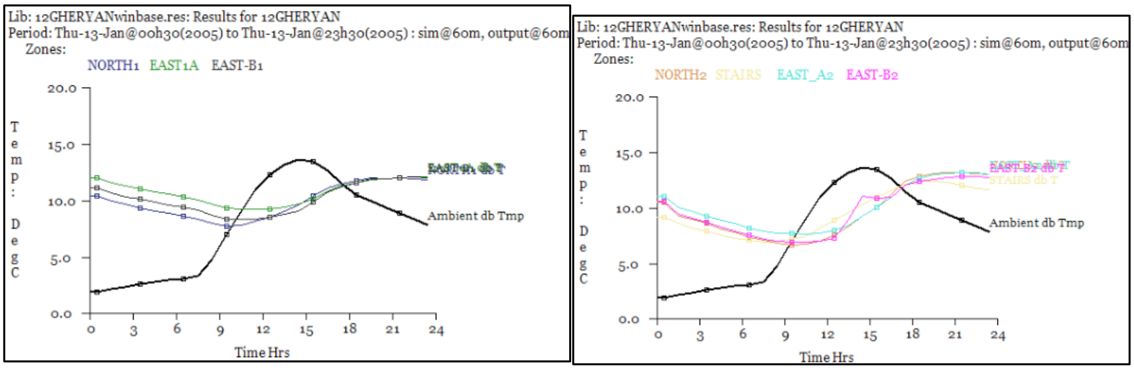
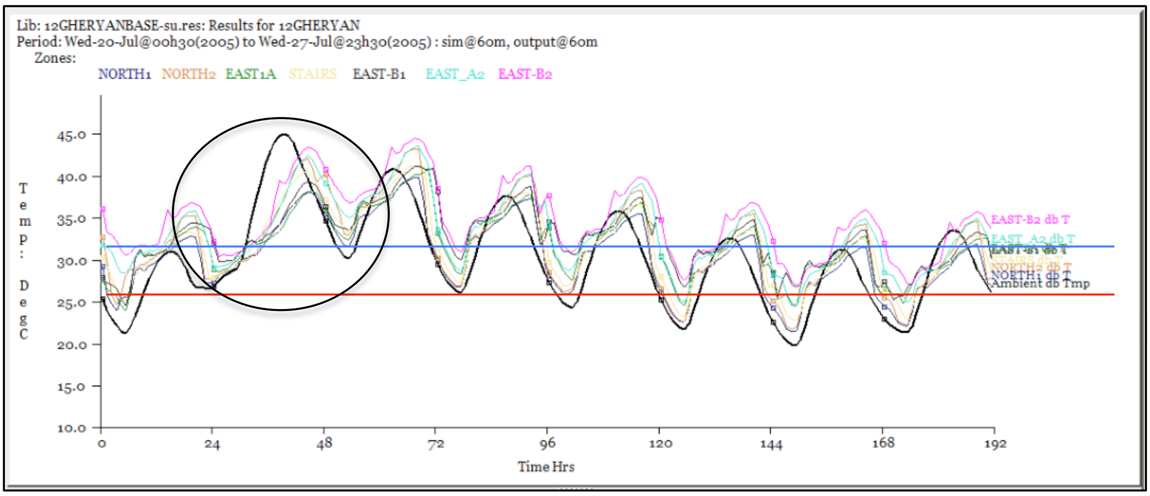


Figure (7. 79) Base case, thermal performance of the lower and upper floor zones during a day in winter

The hourly thermal performance of the zones illustrated in graph figure (7.79), shows that the lower level zones have a higher air temperature than the upper level, because of the heat losses through the roof.



	30.5 °C upper margin		Ambient temperature
	26.5°C lower margin	Others	Indoor air temperature (zones)

* The circled area is shown in detailed in the next

Figure (7. 80) Base case, the thermal performance of the zones during the hottest week in summer

Running the simulation for the model during the summer week, Figure 7-81, shows that the indoor air temperature. It was recorded as in the comfort zone during the night and early morning from 22:00 to 06:00, while it was recorded as very high during the midday. This result indicates the importance of using the night temperature for ventilation in order to reduce the day temperature.

The comparison between the zones in figures (7-81) shows that the lower floor zones had a better thermal performance than the upper floor zones. On the other hand the zones connected to the stairs had a better thermal performance than the segregated zones, taking advantage of the air circulation created by the stuck effect in the stair zone.

In order to reduce the indoor temperature for these zones openings must be added between the zones and the stairs to provide additional ventilation. The aim of the experiment is to reduce the indoor temperature from 40°C to 28.9°C, the average upper margin for this region during this week.

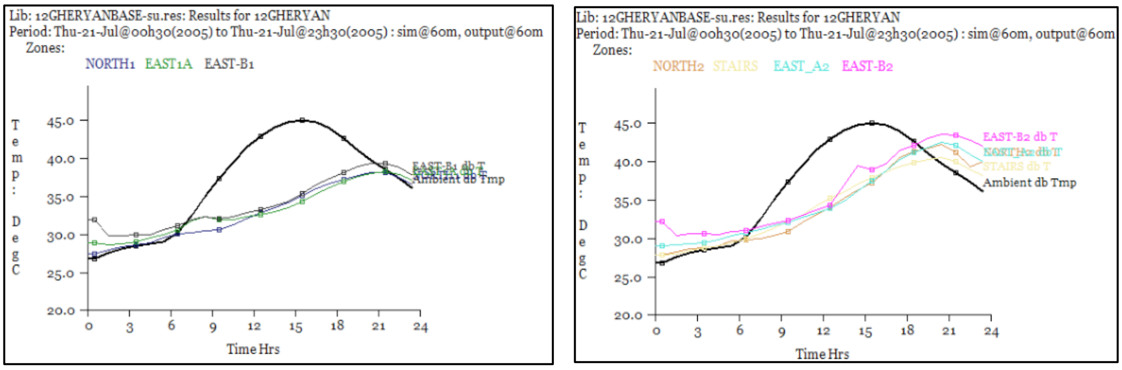
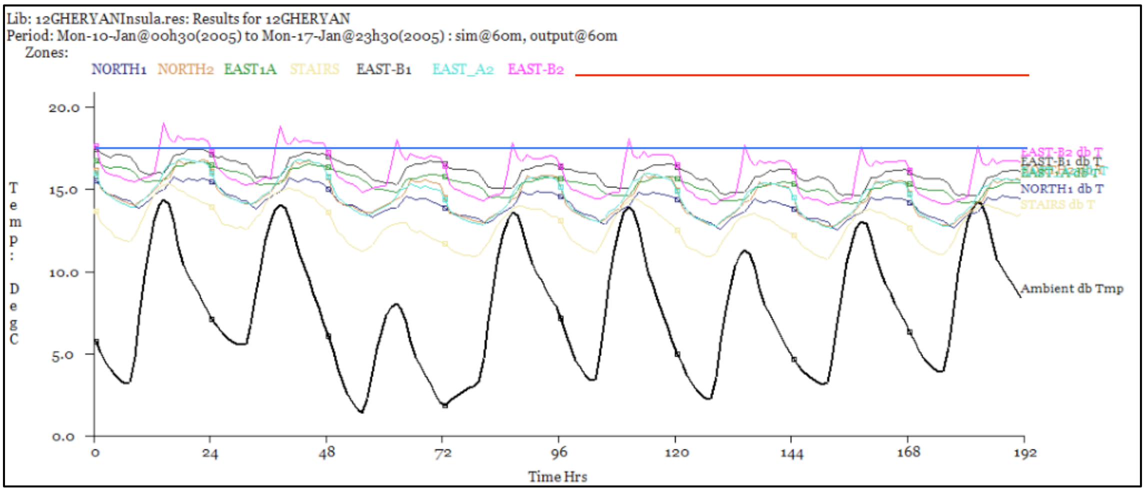


Figure (7. 81) Base case, thermal performance of the zones during a day in summer

7.7.3.2 Insulation Strategy

Thermal insulation layers have been added to the wall and roof constructions using material construction Table (7-10). The new wall construction is based on a thermal mass strategy with U-value of 0.574W/m^{2}K and a time lag of 17.2 hours, by adding date palm insulation in the cavity wall made, internally of limestone and externally of breeze block as shown in table (7-9). The contemporary roof was modified by adding an insulation layer (date palm wood) with a thickness of 50mm and U value of 0.56W/m^{2}K, table (7-12). The result was plotted on the graph shown in figure (7.82).



	22.8 °C upper margin		Ambient temperature
	18.8°C lower margin	Others	Indoor air temperature- dbT

Figure (7. 81) Insulation strategy. The thermal performance of the zones during the coldest week in winter

The result indicates that adding thermal insulation had a remarkable effect on the internal air temperature where indoor temperatures increased significantly in all zones. The East-B2 zone recorded a comfort temperature during the midday but the other zones failed to reach the comfort zone. This shows that using the insulation strategy alone is not enough to achieve thermal comfort. The east zones had a better thermal performance than the other zones related to the solar radiation from the solar heat gains through the eastern window and to casual gains.

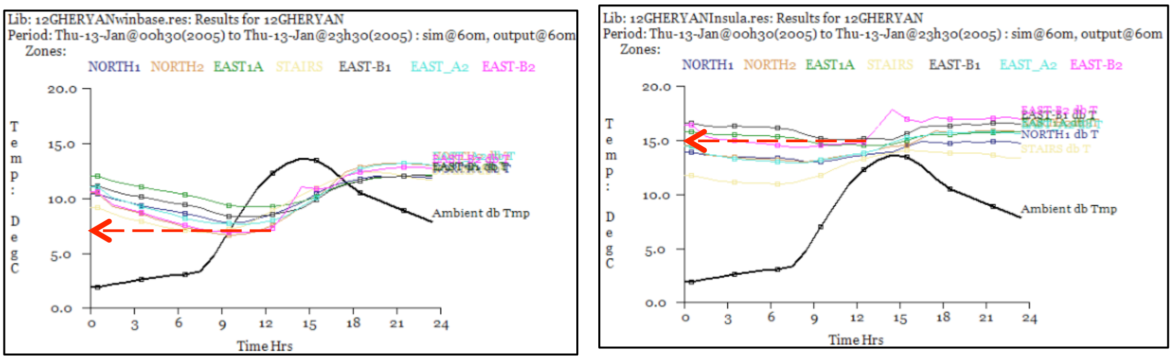
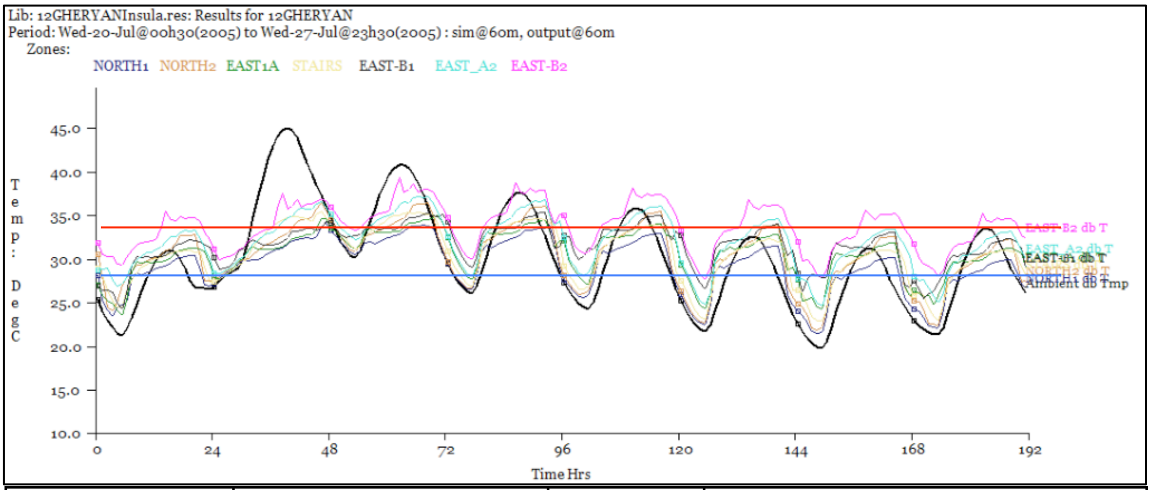


Figure (7. 82) Comparative study between the base case and the insulation strategy in winter

Insulation is an efficient strategy in both winter and summer; it prevents heat loss in winter and heat gain in summer. In Gheryan in order to decrease the indoor temperature to the comfort zone, it has to be reduced by more than 14K during the day in most zones; by using the contemporary construction material it drops only 4K.



(red line)	30.5 °C upper margin	(black line)	Ambient temperature
(blue line)	26.5°C lower margin	Others	Indoor air temperature (zones)

Figure (7. 83) The thermal performance of the zones during the hottest week in summer

However, by using the insulation strategy the indoor temperature drops nearly 10K; this can be considered a remarkable drop in air temperature compared to the base case results Although the insulation strategy had a great effect on the internal air temperature it failed to achieve the comfort zone, therefore considering the addition of another strategy is required in order to reach the comfort zone.

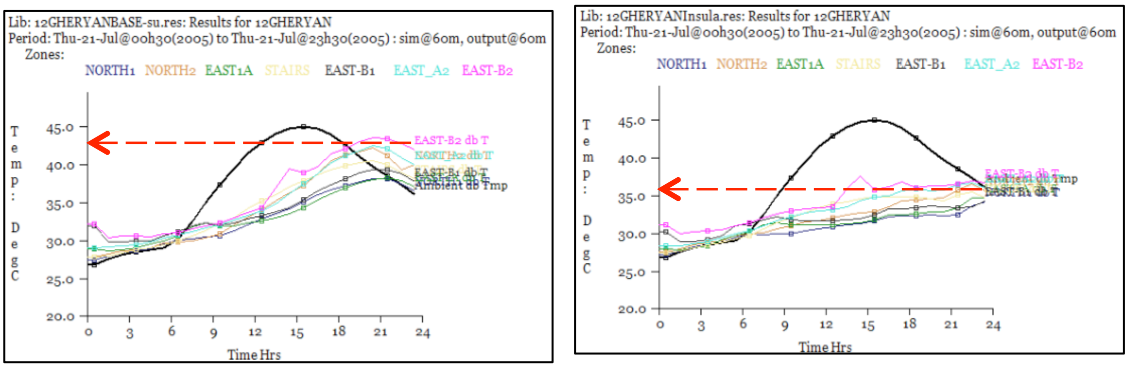
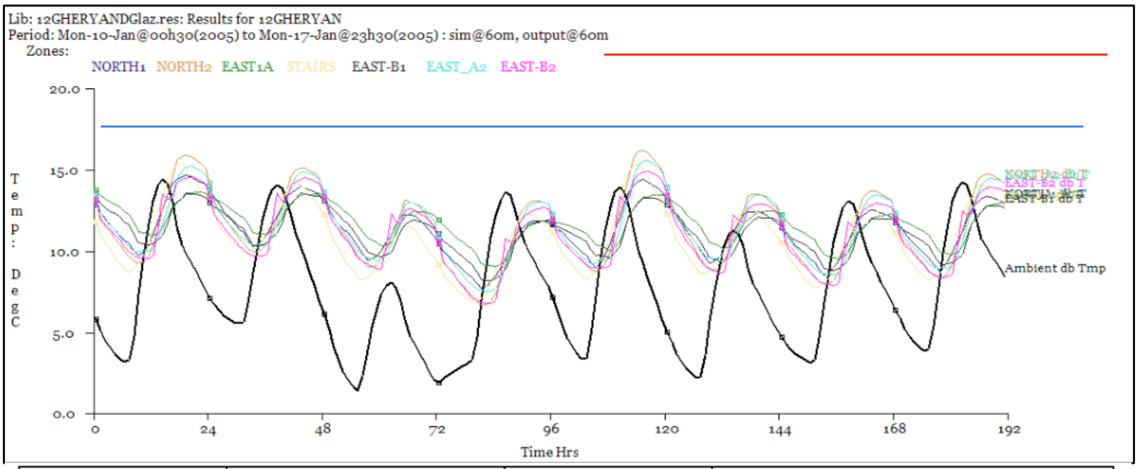


Figure (7. 84) Comparative study between the base case and the insulation strategy during a day in summer

7.7.3.3 Glazing strategy

The windows are responsible of three types of energy flow: non-solar heat losses and gains, solar heat gains and air flow in terms of infiltration and ventilation. Replacing single glazed windows that have a U value of 5.4, with double-glazed windows with a low U value of 2.9, will reduce the heat flow through the windows.



	22.8 °C upper margin		Ambient temperature
	18.8°C lower margin	Others	Indoor air temperature- dbT

Figure (7. 85) Glazing strategy, the thermal performance of the zones during the coldest week in winter

The effect of the double-glazing on the indoor temperature is minor as a result of the small percentage of the glazed area in the model. This indicates that using the double glazed windows is not enough to significantly reduce heat losses through the windows, however the rate of infiltration was constant in both cases with 0.008m^3/sec.

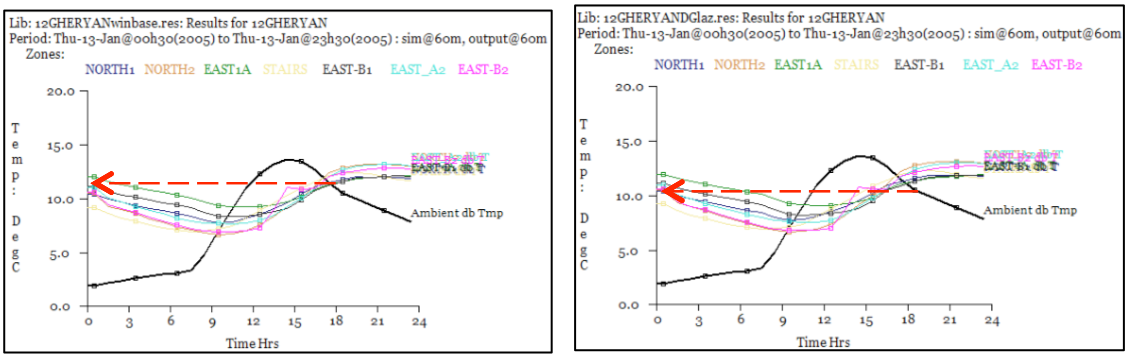
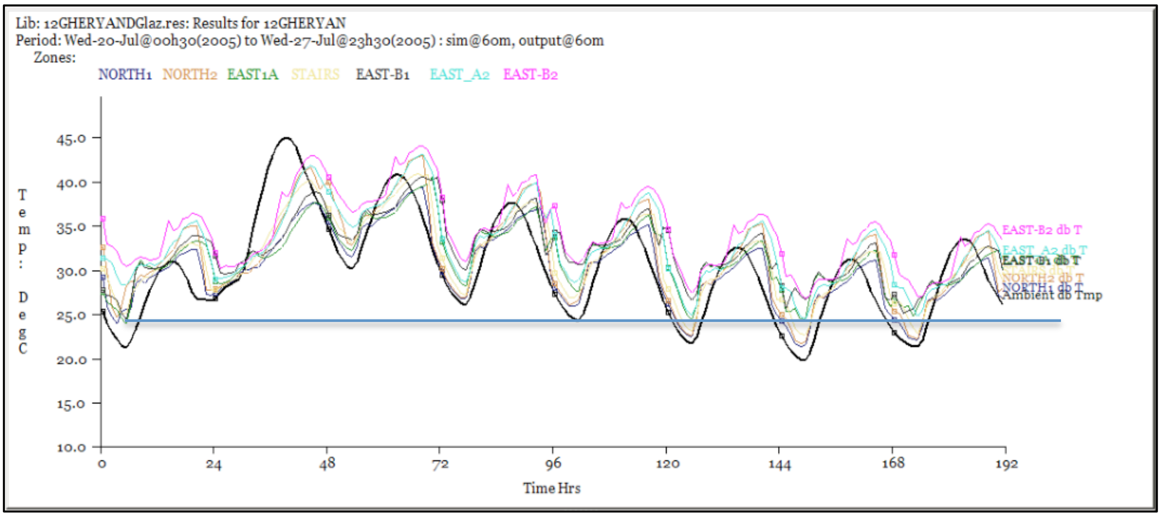


Figure (7. 86) Comparative study between the base case and the double-glazed strategy during a day in winter

During the hottest season the double-glazed windows have small effect on the internal air temperature. The comparison graphs in figure (7-88) show a minor improvement in the internal air temperature. This indicates the zones required more cooling strategies in order to achieve the thermal comfort zone.

The glazing strategy in this model did not provide the required control of the heat flow through the glazed area. Therefore we need to add a shading strategy to the model to further improve the thermal performance of the windows.



	30.5 °C upper margin		Ambient temperature
	26.5°C lower margin	Others	Indoor air temperature (zones)

Figure (7. 87) Glazing strategy, the thermal performance of the zones during the hottest week in summer

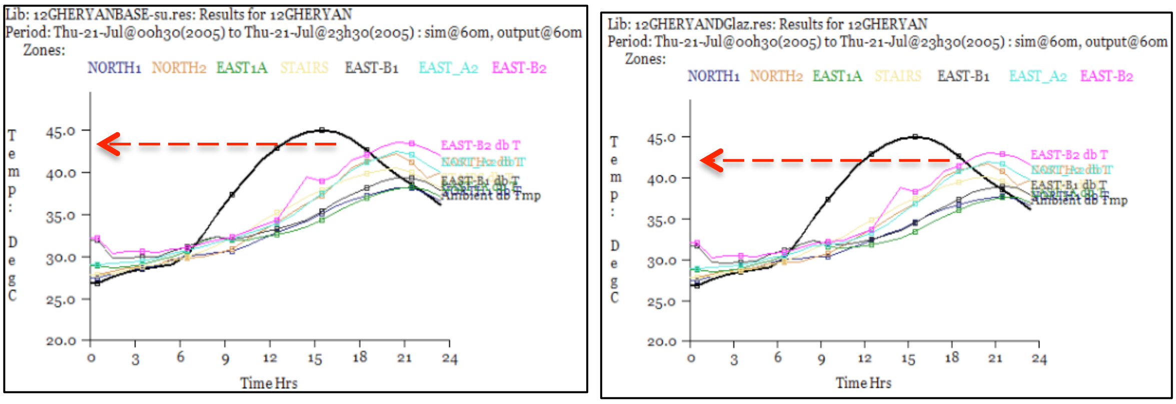


Figure (7. 88) Comparative study between the base case and the double-glazed strategy during a day in summer

7.7.3.4 Shading strategy

The design of the shading devices depends on the building orientation and the local climate conditions. Two types of shading device have been designed for the model: fixed and flexible shading devices. During the cold season the solar heat flow is required, therefore the fixed shading devices should not obstruct the solar radiation.

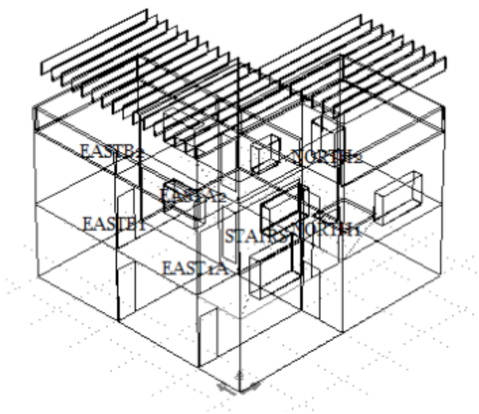
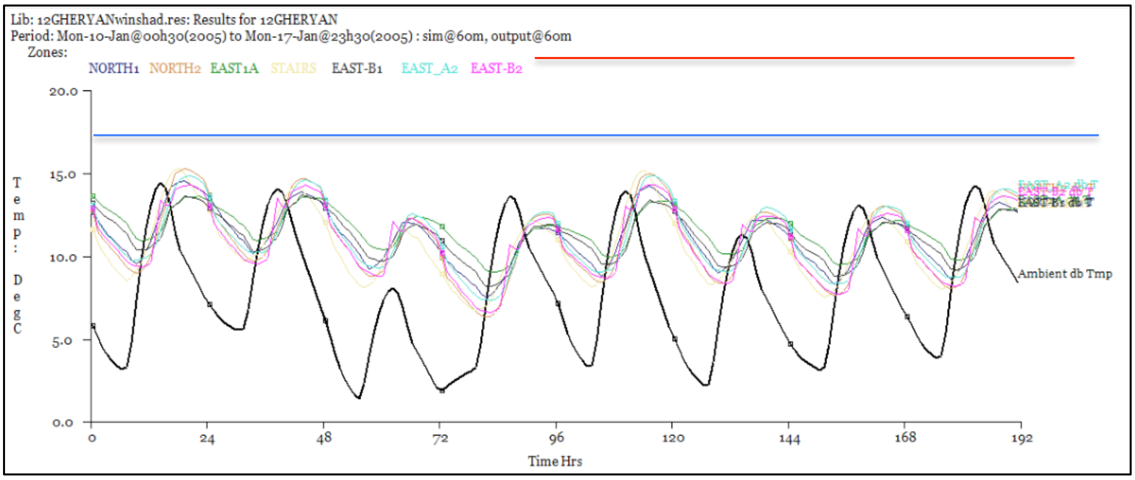


Figure (7. 89) shading strategy during hot season

Thus, when compared it with the base case, it should have no effect on the internal air temperature.



	22.8 °C upper margin		Ambient temperature
	18.8°C lower margin	Others	Indoor air temperature- dbT

Figure (7. 90) Shading strategy, the thermal performance of the zones during the coldest week in winter

The results of the shading strategy during a day in winter have been plotted to compare the effect of the fixed shading devices on the internal air temperature. The graphs show that the winter shading devices strategy has no perceptible effect on the internal air temperature. It should be noted that a fixed vertical and horizontal shading devices were located on the south and east windows, whereas the north oriented windows have no shading devices. The depth of the shading was carefully tested in order to meet the required shade criteria

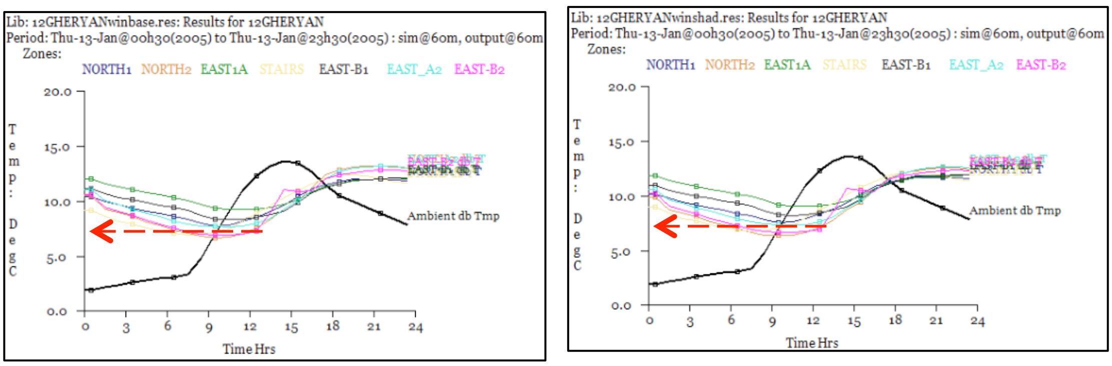
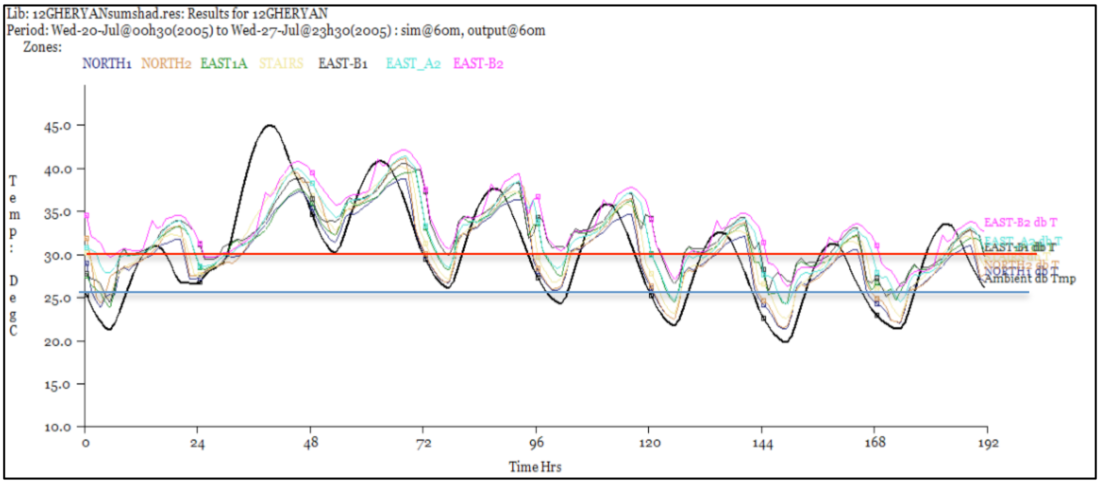


Figure (7. 91) Comparative study between the base case and shading strategy during a day in winter



	30.5 °C upper margin		**Ambient temperature**
	26.5°C lower margin	**Others**	**Indoor air temperature (zones)**

Figure (7. 92) Shading strategy, the thermal performance of the zones during the hottest week in summer

The impact of the external shading devices on the internal air temperature is remarkable during the hot season. Use of shading devices gives energy savings by reducing direct solar gain through the windows; in addition it reduces the glare in the interior spaces.

It is important to note that direct solar radiation transfers heat into a room by two types of heat transfer; convection and radiation. Convective transfer raises the indoor air temperature immediately while thermal radiation is absorbed by the walls, ceiling and floors and converted to heat gain after a period of time. Therefore, the effect of the solar heat gain can be noted after sunset in the base case. The indoor air temperature dropped at 15:00 by nearly 5K in the eastern zones, as an outcome of obstructing the direct solar radiation through the windows by the windows shading device. On the other hand at 21:00 the air temperature dropped nearly 3.5 K in the upper floor zones, because of the roof shading, which prevents direct solar radiation on the roof as well as the solar heat gains through the roof's construction.

Finally comparing the simulation results for the glazing strategy and shading strategy it is noticed that using exterior shading devices with less expensive glazing can result in a remarkable reduction in indoor air temperature.

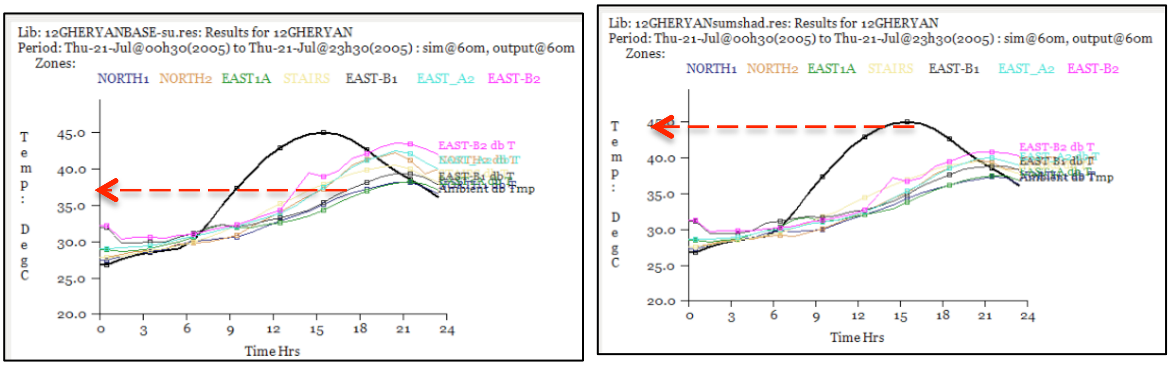
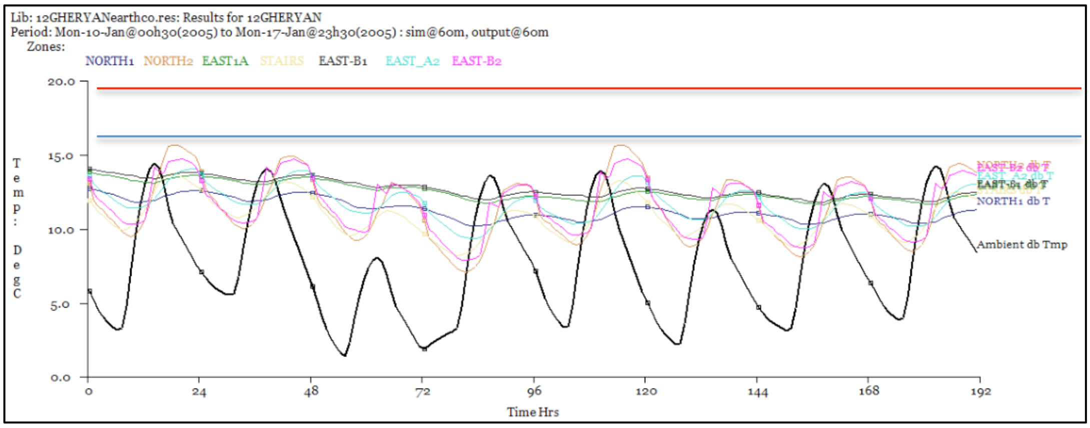


Figure (7. 93) Comparative study between the base case and the shading strategy during a day in summer

7.7.3.5 Earth heating and cooling strategy- Layout and contextual impact

As discussed earlier in chapter four, in Gheryan, given the proper geology and hydrology, the city has the perfect aspects for the earth sheltered houses construction. The nature of the soil is an important aspect in the thermal performance of the earth shelter house. The soil temperature varies with the depth, type of the soil, time, and climate; therefore applying this technique can improve the indoor environment.



	22.8 °C upper margin		Ambient temperature
	18.8°C lower margin	Others	Indoor air temperature- dbT

Figure (7. 94) Layout strategy, the thermal performance of the zones during the coldest week in winter

In this study, the lower zones of the model were built 3 meter below the surface of the ground level creating a basement where the external wall was replaced with earth, except of the wall that facing the courtyard. According to Givoni, at a depth of 3m, the soil temperature dropped to one third of the ambient temperature (Givoni 1994).

Simulations were run for a winter week and a summer week, to examine the effect of earth sheltering on indoor temperature in both seasons. For the winter week, Figure (7-

94), the internal temperature of the lower zones had a good improvement, with nearly 3K, and it was recorded as 5K at 12:00 in EAST-B1 zone.

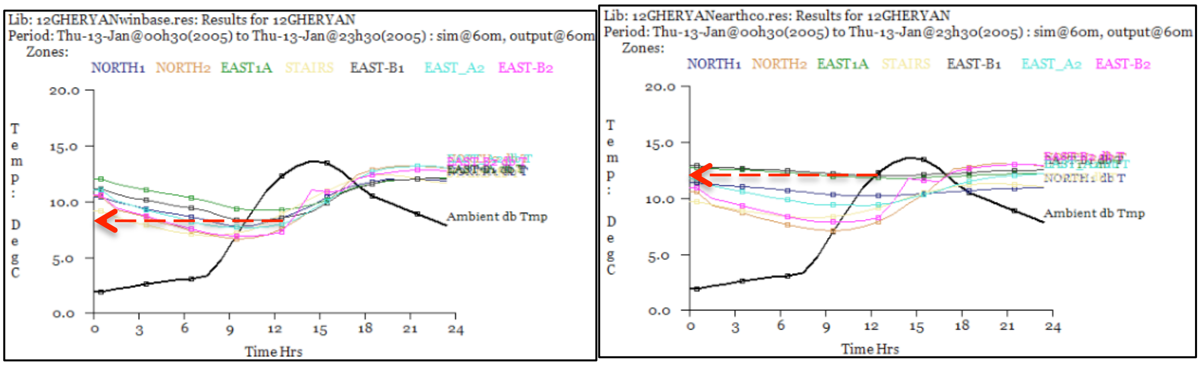
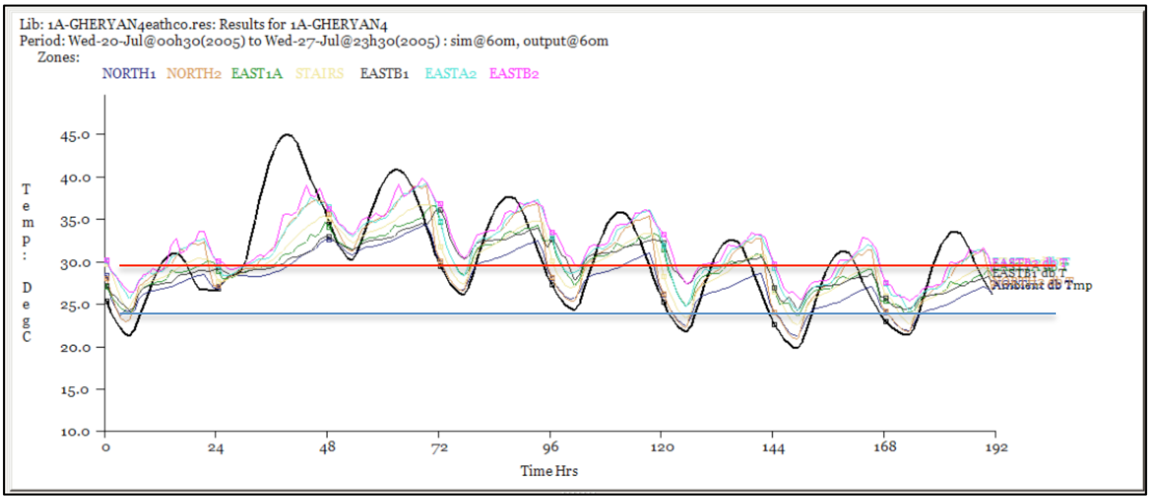


Figure (7. 95) Comparative study between the base case and the layout strategy during a day in winter



	30.5 °C upper margin		**Ambient temperature**
	26.5°C lower margin	**Others**	**Indoor air temperature (zones)**

Figure (7. 96) Layout strategy, the thermal performance of the zones during the hottest week in summer

The earth cooling strategy was applied to the model and the simulation run for the hottest week, Figure (7-96). The results show that the strategy has an astonishing impact on the internal air temperature; on the hottest day the internal temperature was nearly 14 K below the ambient temperature .

A comparison was made between the model with earth cooling strategy and the base case and the results show that the air temperature in the lower floor dropped nearly 6.5K, while in the stairs and the area adjacent to the stairs it dropped by nearly 3K. The results suggested that creating a connection between the lower floor and the upper floors in order to allow air circulation between zones, may improve the air temperature in the upper zones .

As a result of the depth of the basement (- 3 metres), the temperature of the earth did not vary, therefore using only the earth cooling and heating strategies in this model will not achieve the comfort zone, in both winter and summer.

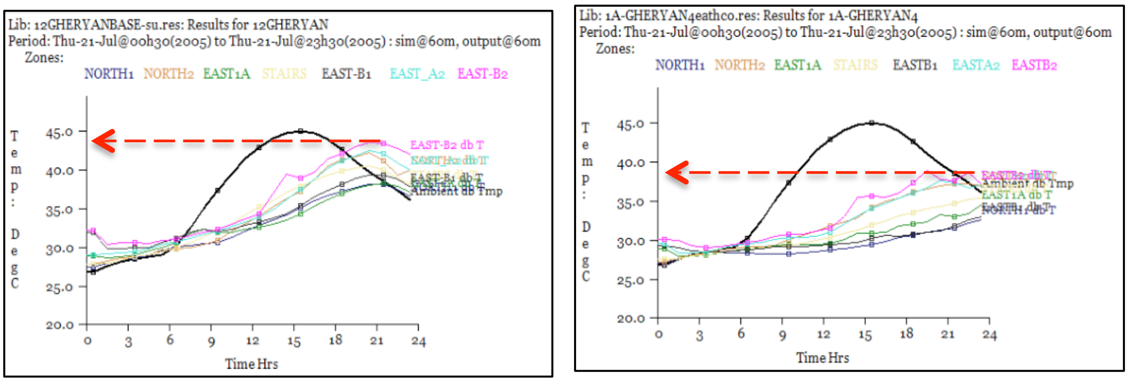
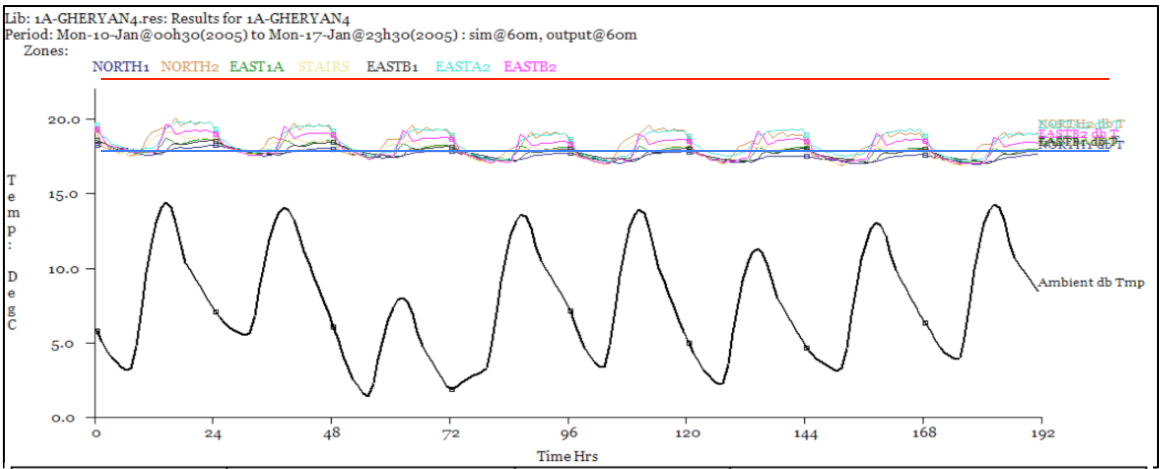


Figure (7. 97) Comparative study between the base case and the layout strategy during a day in summer

7.7.3.6 The combined strategies

From the previous strategies it can be concluded that one strategy cannot achieve indoor comfort for the model. Therefore the best results found from the previous strategies were combined into the model and a simulation was run for the model during a week in winter and summer.

During the coldest week the combined strategy was successful, and, in all zones, air temperatures were recorded as within the comfort zone,most zones reaching 19-21.5 °C.



(red line)	22.8 °C upper margin	(grey line)	Ambient temperature
(blue line)	18.8°C lower margin	Others	Indoor air temperature- dbT

Figure (7. 98) Combined strategy, the thermal performance of the zones during the coldest week in winter

The comparative study between the base case and the combined strategy shows that indoor air temperature improved by 12-14K in all zones, and this proves that the comfort indoor temperature can be achieved by passive heating methods only.

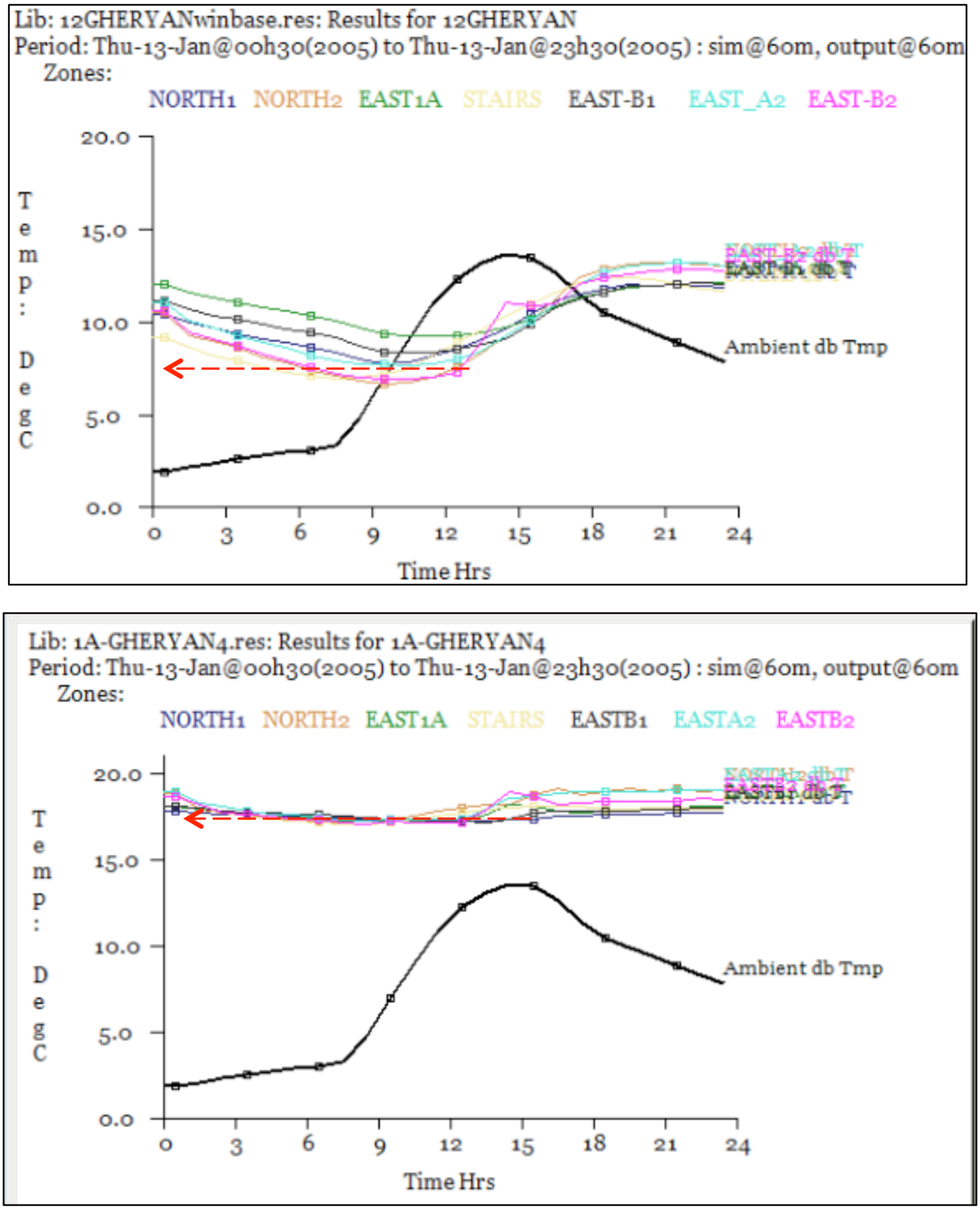
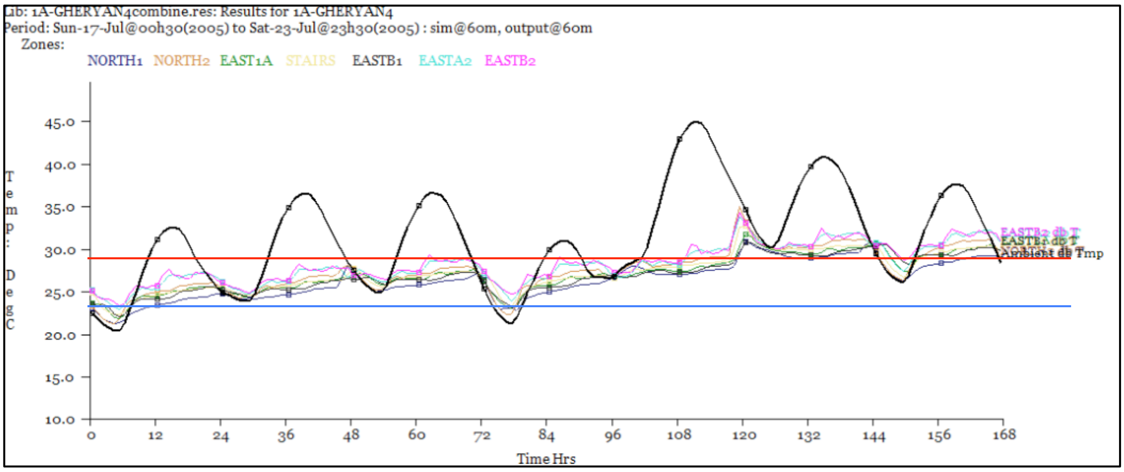


Figure (7. 99) Comparative study between the base case and the combined strategies during a day in winter



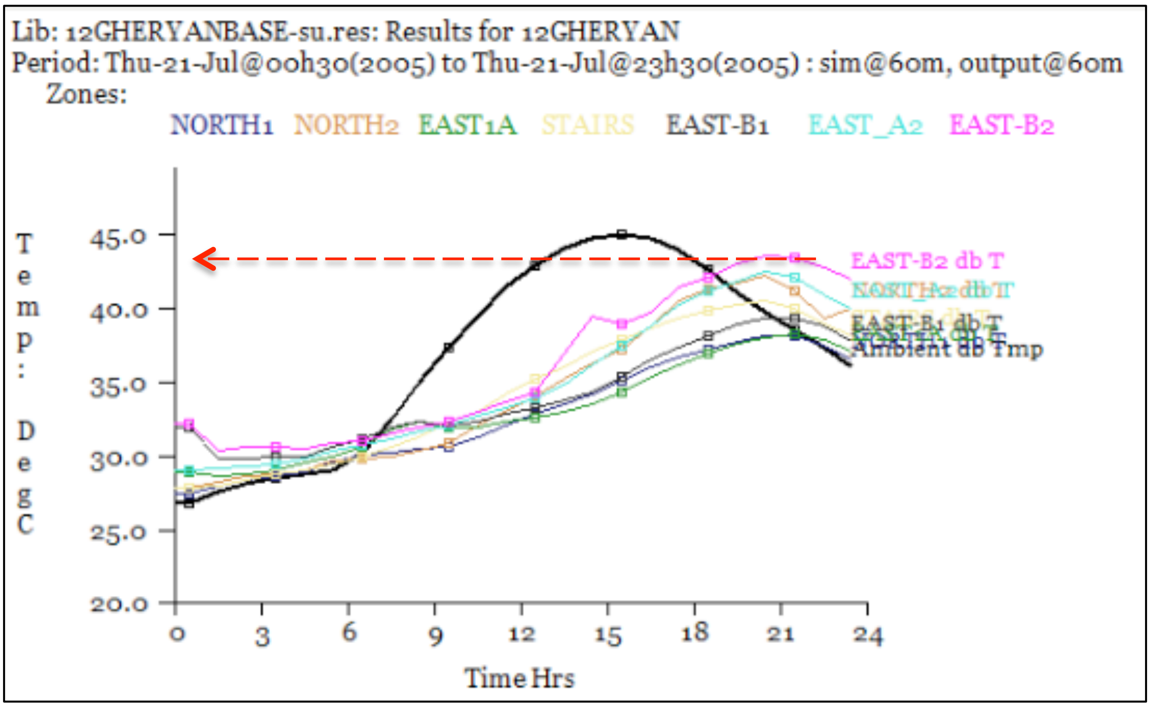
	30.5 °C upper margin		Ambient temperature
	26.5°C lower margin	Others	Indoor air temperature (zones)

Figure (7. 100) Combined strategies, the thermal performance of the zones during the hottest week in summer

The final simulation for the model including all strategies was run for the hottest week in summer. The results show improvement in the indoor air temperature in all zones; for this season the effect of the insulation, shading and earth cooling strategies on the indoor air temperature is outstanding.

The comparative study between the final model and the base case demonstrates that the indoor air temperature in all zones is lower than 30°C, with decreases of more than 14K. The insulation strategy and the air flow between the zones reduce the air temperature in the upper floors.

In conclusion, in Gheryan, passive heating and cooling can reduce heating and cooling loads in the model and therefore the energy consumption.



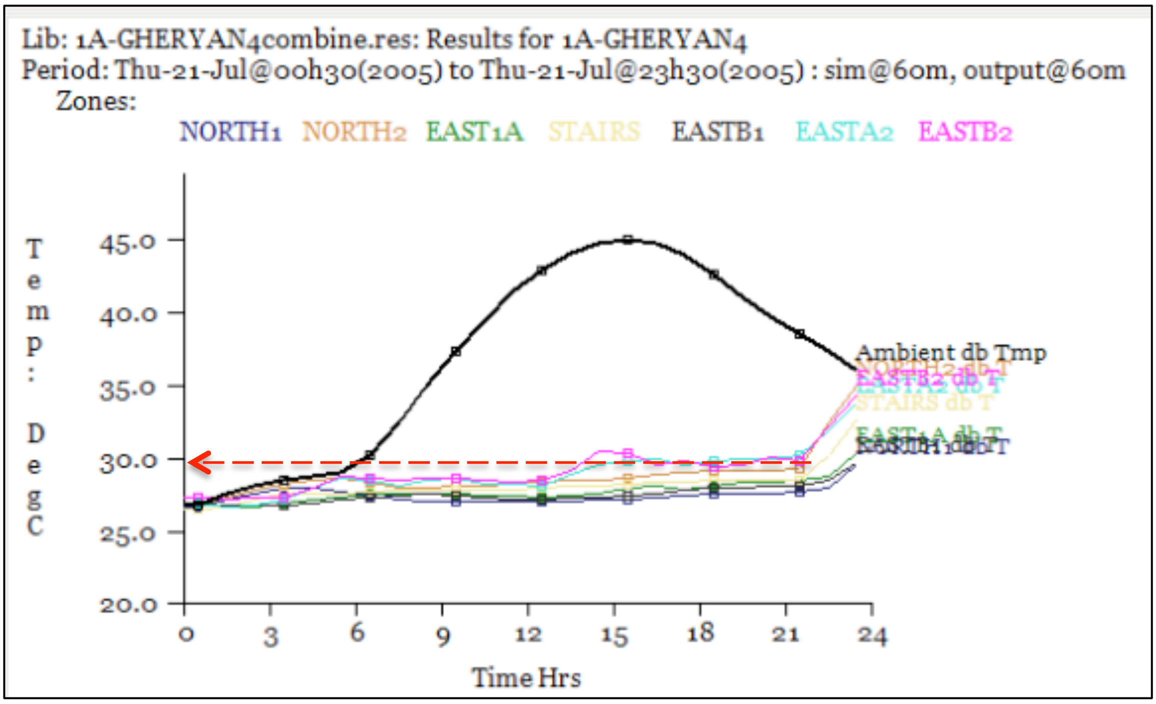


Figure (7. 101) Comparative study between the base case and the combined strategies during a day in summer

7.8. Conclusion

This doctoral research aims to examine the potential relevance of informing future low energy housing design in Libya. The energy simulation results for the three models indicate that vernacular design can enrich the future low energy housing in Libya. Modifying the base models with respect to the traditional environment solutions can establish a comfort environment that is acceptable to Libyans in the three regions.

Using the right available building material is the key issue in constructing low energy houses. Using the available materials in the three regions such as date palm insulation with limestone blocks, breeze blocks and sand blocks that have a low conductivity of 1.5, 0.44 and 1.8 W/mK respectively, reduces the U value of the wall construction to less than 0.58 W/m^2K. The final model sets the U values to less than 0.6 W/m^2K for opaque envelope elements and 2.8 W/m^2K for windows.

In Tripoli the courtyard acts as a source of natural cooling for the house, using the night cooling with insulation strategy have a great impact on the indoor environment. Shading devices such as shutters and a secondary roof are vital in the hot season; nevertheless they have to be adjustable devices so it wont has any negatively impact on the internal environment during the cold season. The layout and contextual strategy has a remarkable impact on the model in both cold and hot seasons; the row type complex reduces the area of surfaces exposed to the environment and therefore reduces heat gain/loss through the walls, especially from west walls. In Tripoli and the coastal region, indoor comfort temperature can be achieved in both winter and summer by using only passive heating and cooling strategies.

In the Ghadames model the application of the vernacular passive cooling strategy improves the thermal performance of the model in both winter and summer seasons. The model adopts the space arrangement of the vernacular houses such as design layout, shading devices, ventilation and contextual strategy. The layout of the model improves the thermal performance of the model by separating the kitchen from the rest of the zones in order to isolate the heat gain from the kitchen during the hot season, and minimizes the roof area by creating a multi-layer model. In addition, shading devices have prodigious impact on the thermal performance of the model; covering the courtyard obstructs the direct solar radiation, reducing the heat gain, and, at the same time, allowing a view to the rooms.

In the city of Gheryan, the application of vernacular passive cooling and heating is associated with the earth cooling strategy Using the ground as protector from the external environment improves the air temperature in the underground rooms, and by using a controlled airflow between the floors the upper floor air temperature is improved. Insulation and shading devices are also vital in improving enhancing the thermal performance of the houses in Gheryan.

In conclusion the use of the vernacular passive cooling and heating strategy were successful in the three regions with the use of the local materials and responding to people's needs.

8. Chapter Eight: Thermal performance Analysis –ESP-r

8.1 Thermal performance

Thermal performance analysis had been conducted for each of the three models in the three regions using the ESP-r to calculate the indoor air temperature for the three regions during the hottest and coldest months. A comparative analysis was made between the thermal performance of contemporary houses and the model in terms of hours above or below comfort temperature.

Evaluating the thermal performance of the model and compare it with the thermal performance houses in three regions by using the comfort temperature as standard threshold, in other word calculate the summation of temperature difference over time, the temperature difference is set as difference between the comfort temperature and indoor air temperature. The comfort temperature was found from the thermal comfort survey that has been conducted in the three cities. The comfort temperature varied according to the outdoor temperature.

8.1 Thermal performance - Tripoli

In Tripoli the cold season found in three month of the year January, February and December where the mean maximum ambient temperature dropped below the comfort zone, Figure (8-1). In these months the ambient temperature ranges from mean daily minimum 8, 9., 11℃ to mean maximum 19, 18 and 19℃ in January, February, and December respectively. The comfort temperatures in these months are 21, 21 and 22℃ in January, February, and December respectively; using the wider comfort band, the lower margin was set as comfort zone with $-2K$ difference from the comfort temperature. As noted in chapter six the ±2K are equivalent to one point on the thermal comfort scale, according to Humphrey's assumption for the G value where the increase in temperature for each thermal sensation scale point is 2K. (Nicol, Humphreys, and Roaf 2012, 148).

From the charts in figure (8-1), it shows that hot season started from late May to early October, while the peak requirement will be in June, July and August. In these months the ambient temperature ranges from mean minimum 19, 22and 23°C to mean maximum 33, 36 and 37°C. Furthermore, the comfort temperatures for these months are nearly 27, 29 and 29 °C for June, July and August respectively.

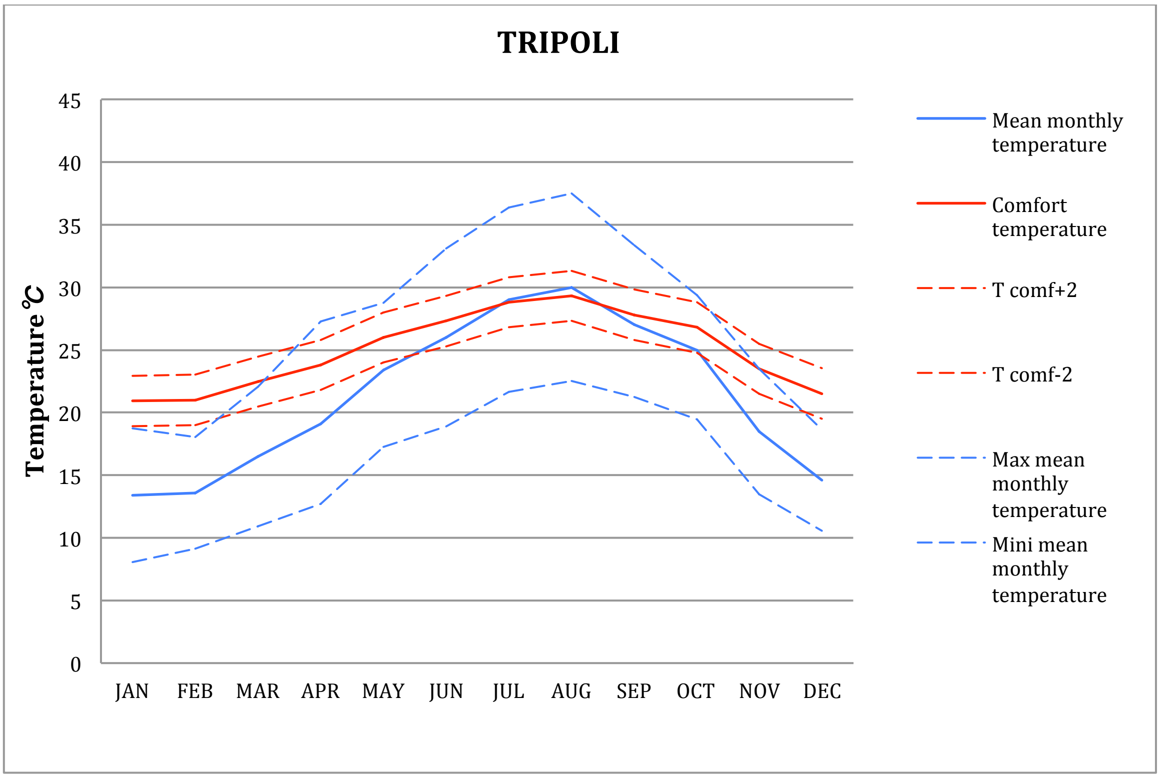
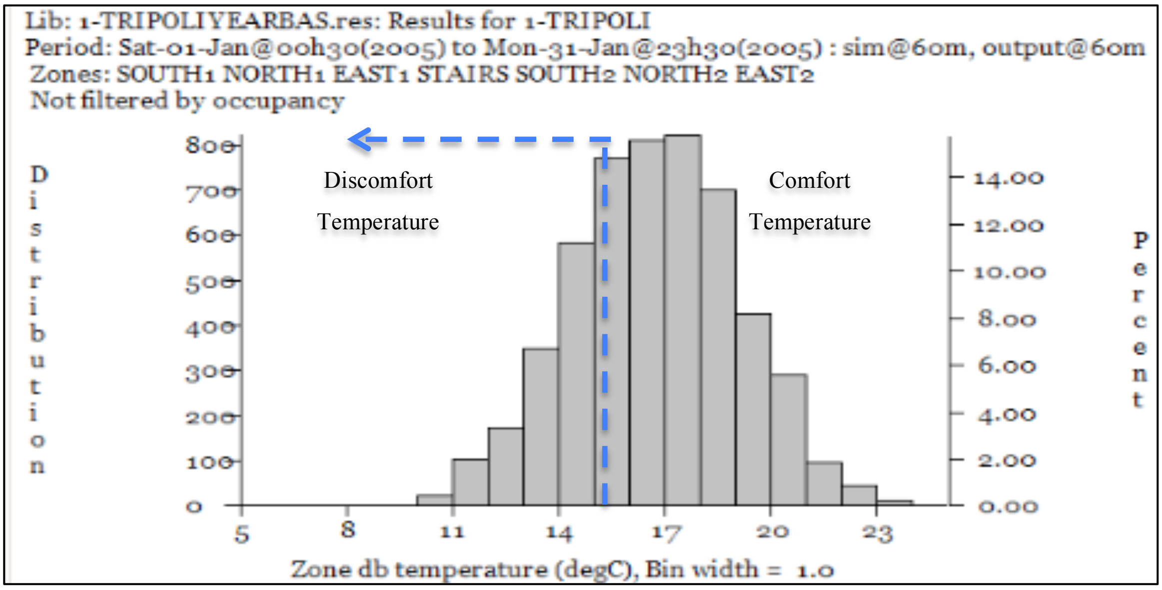


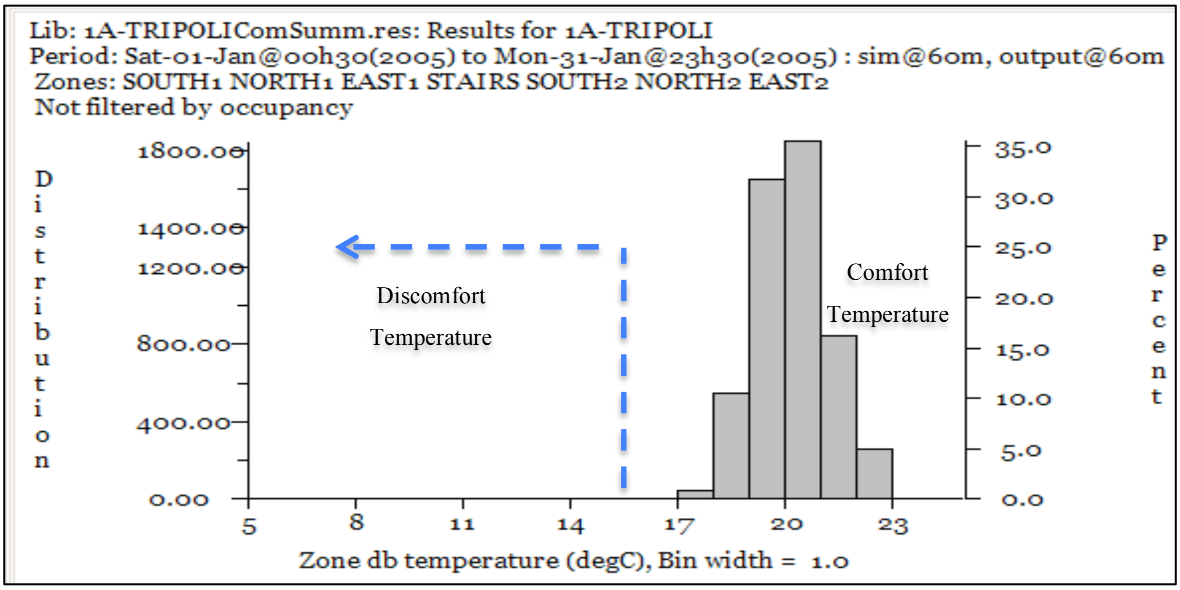
Figure (8. 1) ambient temperature and comfort Temperature - Tripoli

Using passive heating and cooling techniques, which has been discussed earlier in chapter seven, improve the indoor air temperature, the charts Figures (8-2) and (8-3) illustrated the distribution of indoor temperature in the seven zones of the contemporary and the model during January and July. From the frequency bin the number of hours the indoor temperature is above or below comfort temperature can be calculated.

The data shown in the chart Figures (8-2) and (8-3) is not filtered by occupancy, therefore adding the occupant factor to the comfort temperature is necessary. From the ESP-r energy simulation, the study found that according to the Libyan culture and activity, the internal gain contributed nearly 4*K* rise in internal temperature, therefore the base temperature is calculated by subtracting this value from wider comfort bands of the comfort temperature. Therefore, the minimum limit of comfort temperature for January is 19℃by subtracting 4K the base temperature is 15℃. And in July the maximum limit of comfort temperature is (31°C - 4K= 27 °C). Therefore, In January when indoor air temperature is below 16°C people will be uncomfortable. And in July, when inside temperature is above 28 °C, it considered uncomfortable.



Contemporary House in Tripoli

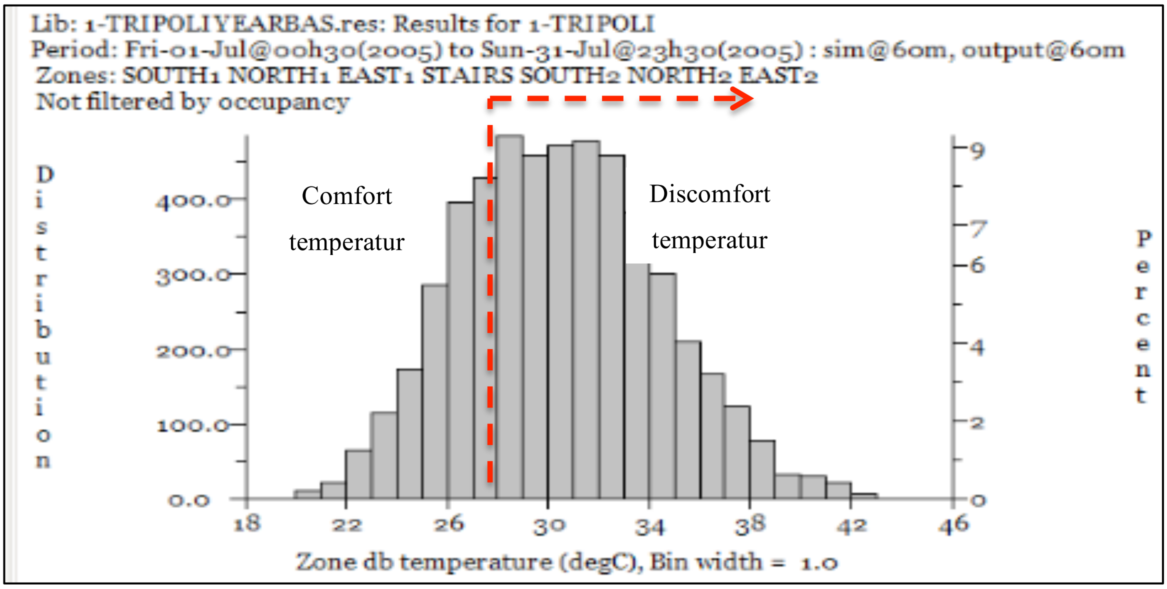


The Low Energy Model

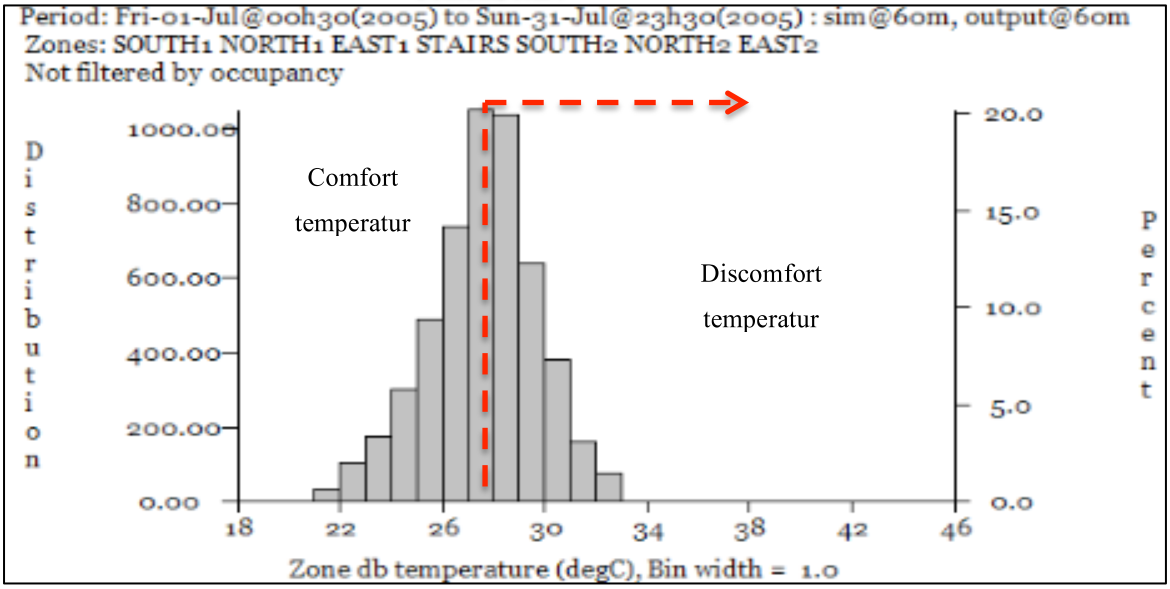
Figure (8. 2) the distribution of the indoor air temperature in the contemporary house and the model in January.

According to the chart figure (8-2) it proved that in winter thermal comfort condition could be achieved in Tripoli houses using the passive heating technique.

The chart figure (8-3) proved that summer thermal comfort condition could be improved in Tripoli houses using the passive cooling technique. (Charts for the whole year for the model see Appendix C)



Contemporary



Model

Figure (8. 3) the distribution of indoor air temperature in the contemporary house and the model in July.

The chart illustrated in Figure (8.4) shows the comparative study was made between the number of hours of discomfort temperature accrued in the model and the contemporary house during the month of January and July. The study shows improvement in the thermal performance in both January and July, in January the thermal performance of the model is improved with 100% compared to the contemporary house. While in July the thermal performance of the model is improved with 65%.

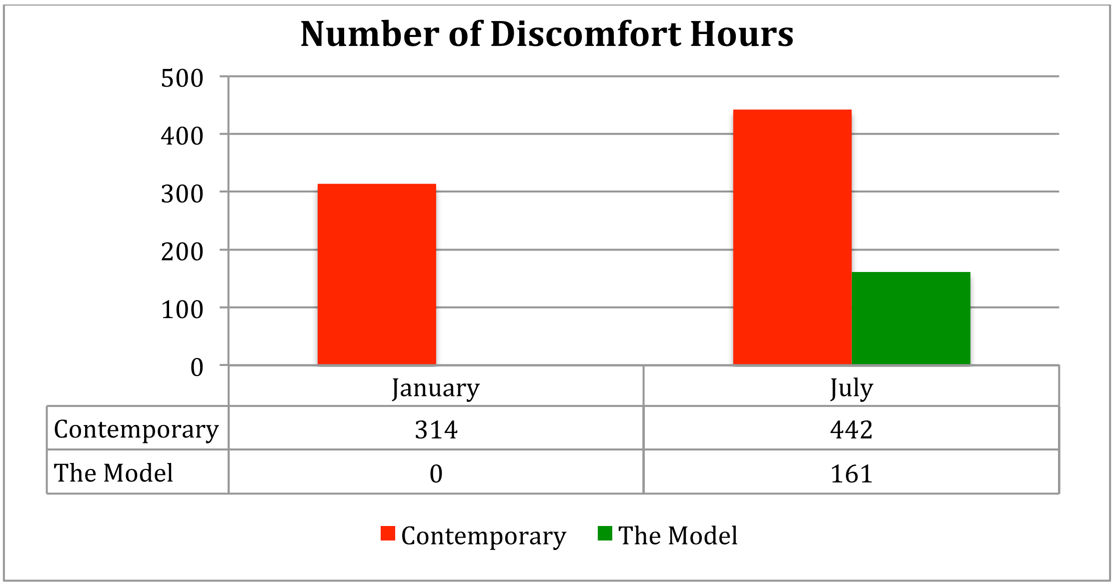


Figure (8. 4) Comparison between the hours of discomfort temperature.

8.2 Thermal performance analysis - Ghadames

The cold season occurred when the mean maximum ambient temperature dropped below the comfort zone in Ghadames, these include the month of January, February and December, as illustrated in Figure (8.5). In winter months the ambient temperature ranges from mean minimum 7, 9 and 9.2°C to mean maximum 17.2, 19.7 and 18.5°C in January, February, and December respectively. The comfort temperatures in these months are 22, 23 and 23°C respectively, the upper and lower limit of the comfort zone were set to $\pm 2K$ deference from the comfort temperature, corresponded to one point on thermal comfort scale, see the chapter six.

Charts in figure (8.5) show that hot season started from late May to early October, while the peak requirement will be in June, July and August. In these months the ambient temperature ranges from mean minimum 26.8, 29.8 and 29.7°C to mean maximum 43, 43 and 42°C. Furthermore, the comfort temperatures for these months are nearly 31, 33and 32 °Cfor June, July and August respectively.

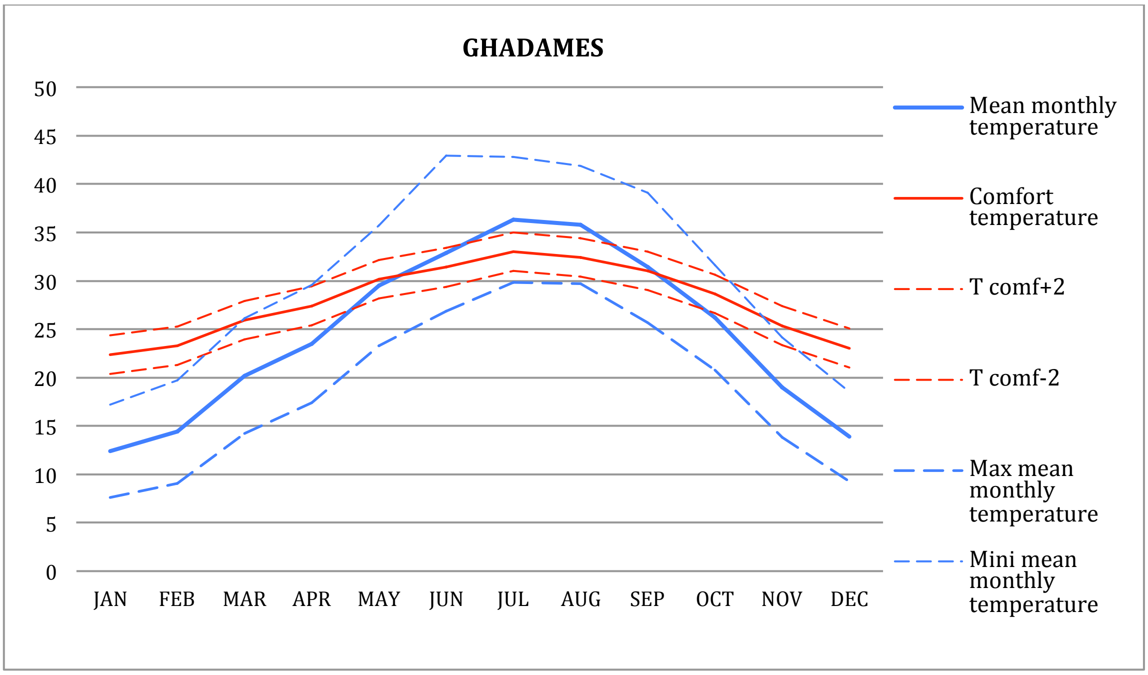
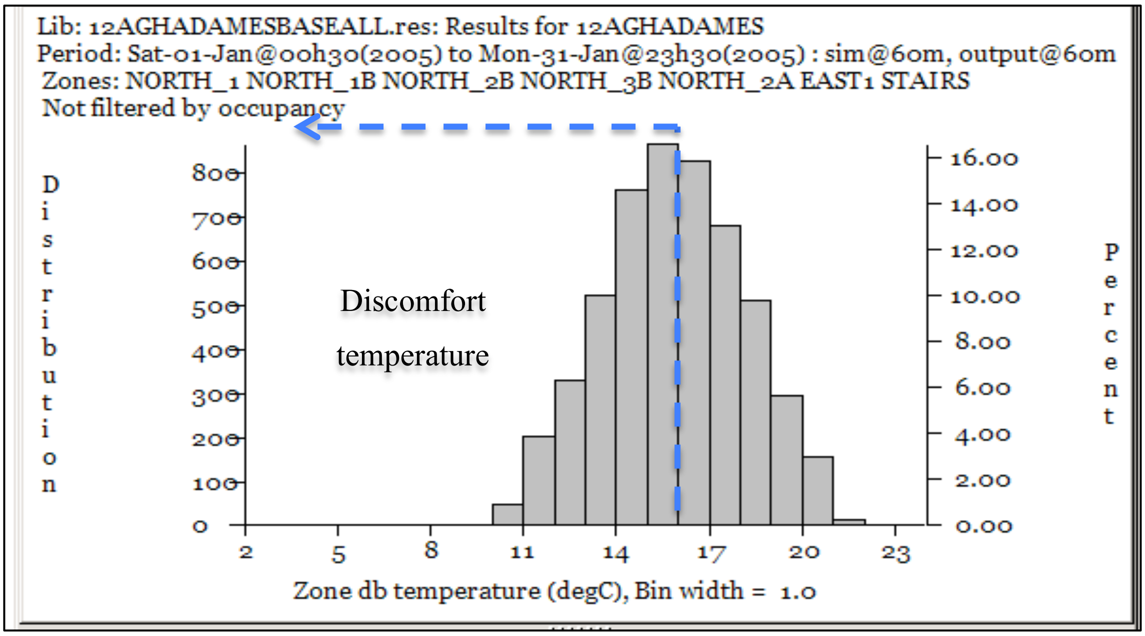


Figure (8. 5) ambient temperature and comfort temperature - Ghadames

The data shown in the chart Figures (8-6) and (8.7) illustrated the distribution of indoor temperature in the seven zones of the contemporary and the model during January and July. This is not filtered by occupancy; therefore adding the occupant factor to the comfort temperature is necessary. Taking into account the internal gain, which contributed nearly 4*K* rise in internal temperature, therefore the base temperature is calculated by subtracting this value from wider comfort bands of the comfort temperature. Therefore, the minimum limit of comfort temperature for January is 20°C by subtracting 4K the base temperature is 16°C. And in July the maximum limit of comfort temperature is (35°C - 4K= 31 °C). Therefore, In January when indoor air temperature is below 16°C people will be uncomfortable. And in July, when inside temperature is above 31 °C, it considered uncomfortable.



Contemporary

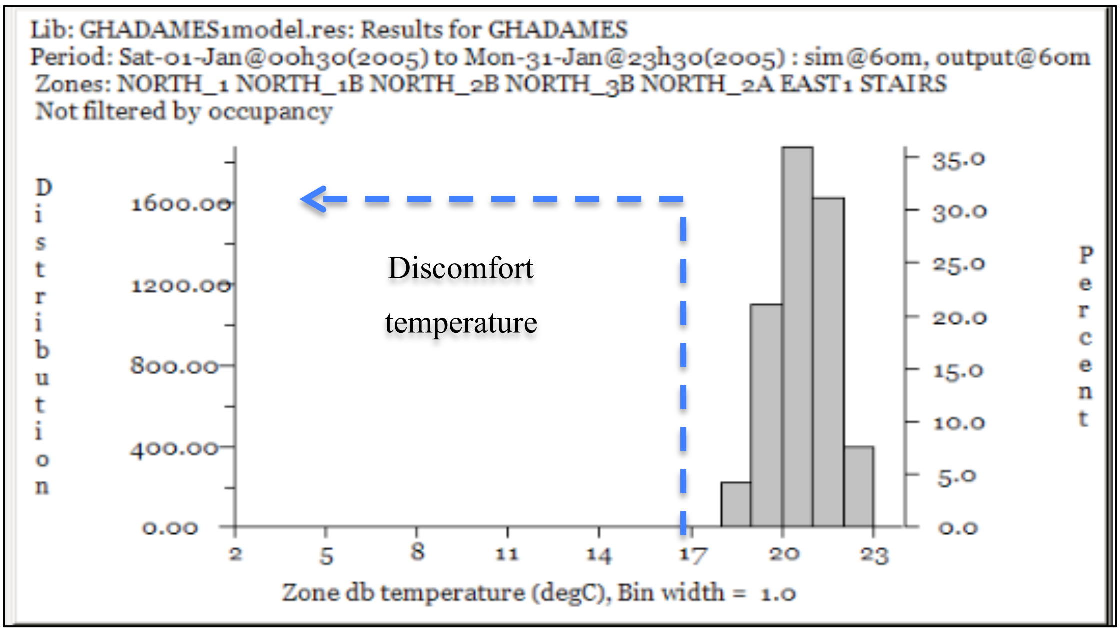
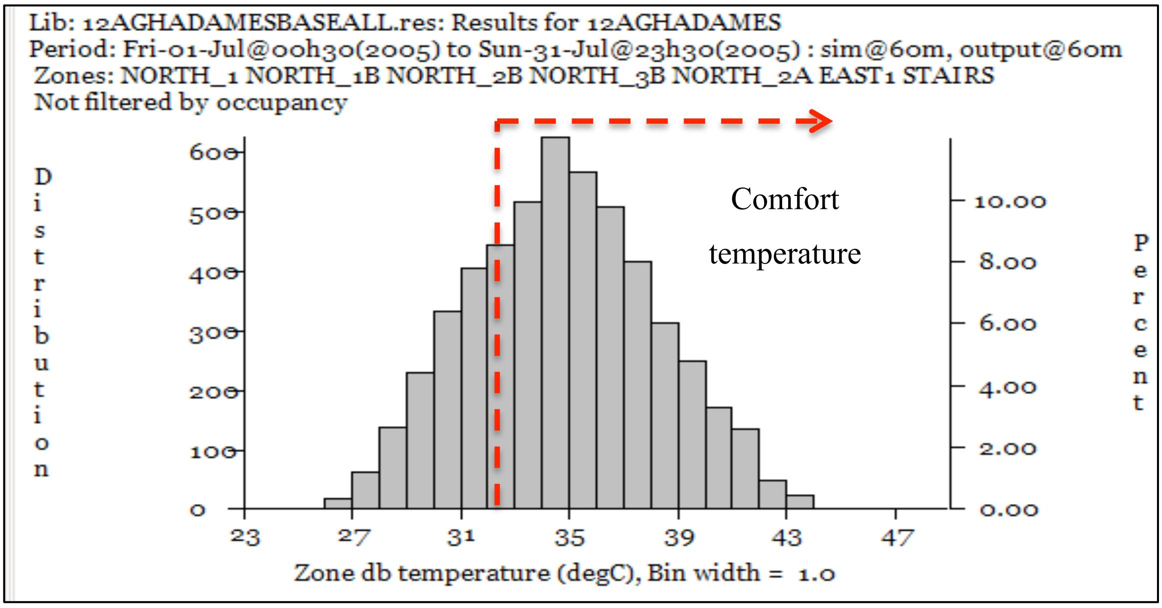
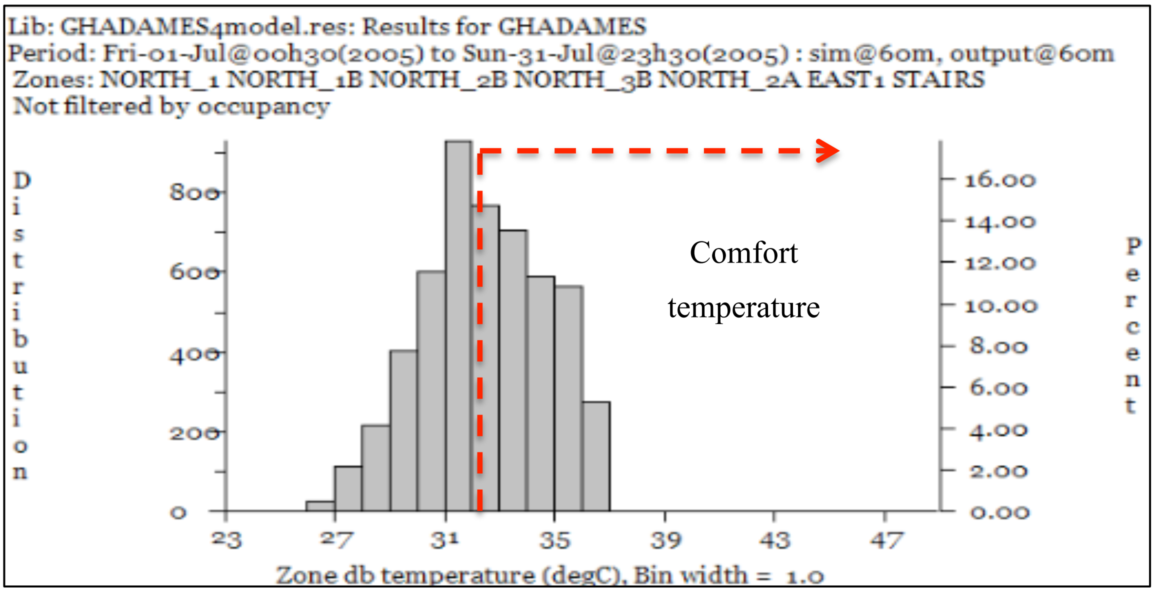


Figure (8. 6) Comparison between the number of hours below comfort temperature in the contemporary house and model for the cold month.



Contemporary



Model

Figure (8. 7) Comparison between the number of hours above comfort temperature in the contemporary house and model for hot month.

The number of hour of discomfort temperature accrue in the model was calculated for Ghadames using the ESP-r, with the base temperature was set with respect to the comfort temperature 20°C the lower margin of the comfort temperature zone Figure (8.5). The chart shows that in the contemporary house the discomfort temperature accrue 507 hours from 744 hours of the month in January, this number dropped to Zero in the model. That proved that using passive heating g techniques, discussed in chapter seven, achieved the indoor thermal comfort.

Using passive heating and cooling techniques, discussed in chapter seven, improved the indoor air temperature, the charts in both Figures (8.6) and (8.7) illustrated the improve in thermal performance in the proposed model.

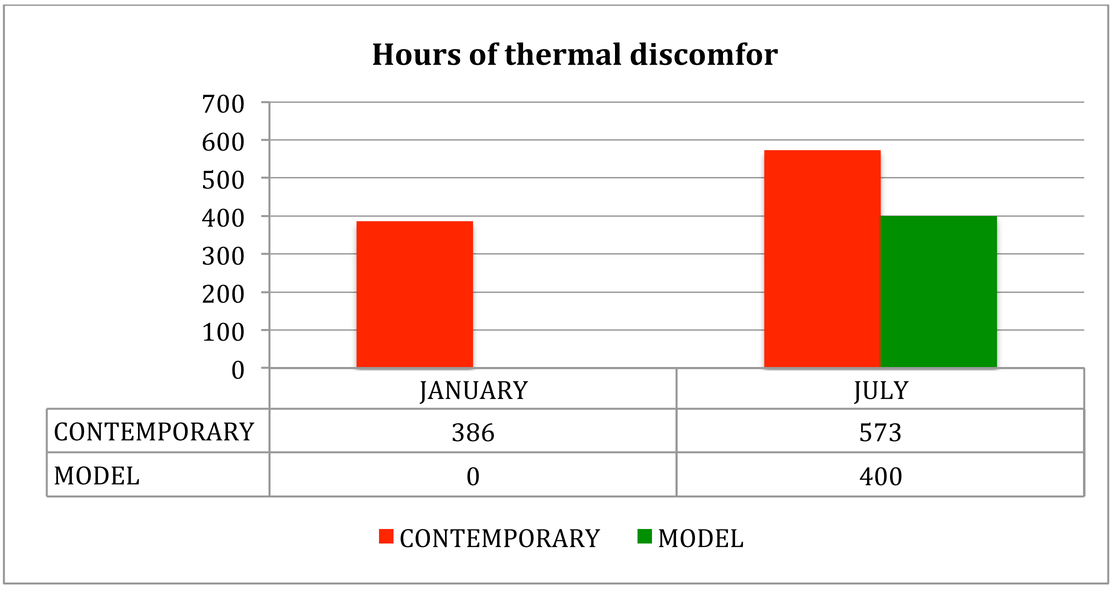


Figure (8. 8) comparison of hours of discomfort in the contemporary and in the model.

8.3 Thermal performance analysis -Gheryan

The mean minimum and maximum ambient temperature for a year in Gheryan is illustrated in the figure (8-9), the lowest temperature recorded in the three months January, February and December demonstrating the cold period of the year. In the cold season the ambient temperature ranges from mean minimum 6, 6 and 7°C to mean maximum 14, 16 and 15°C in January, February, and December respectively.

The hot season started from late May to early October, while the peak will be in June, July and August. In these months the ambient temperature ranges from mean minimum 19, 22.4 and 23.33°C to mean maximum 32.09, 34.94 and 34.2°C.

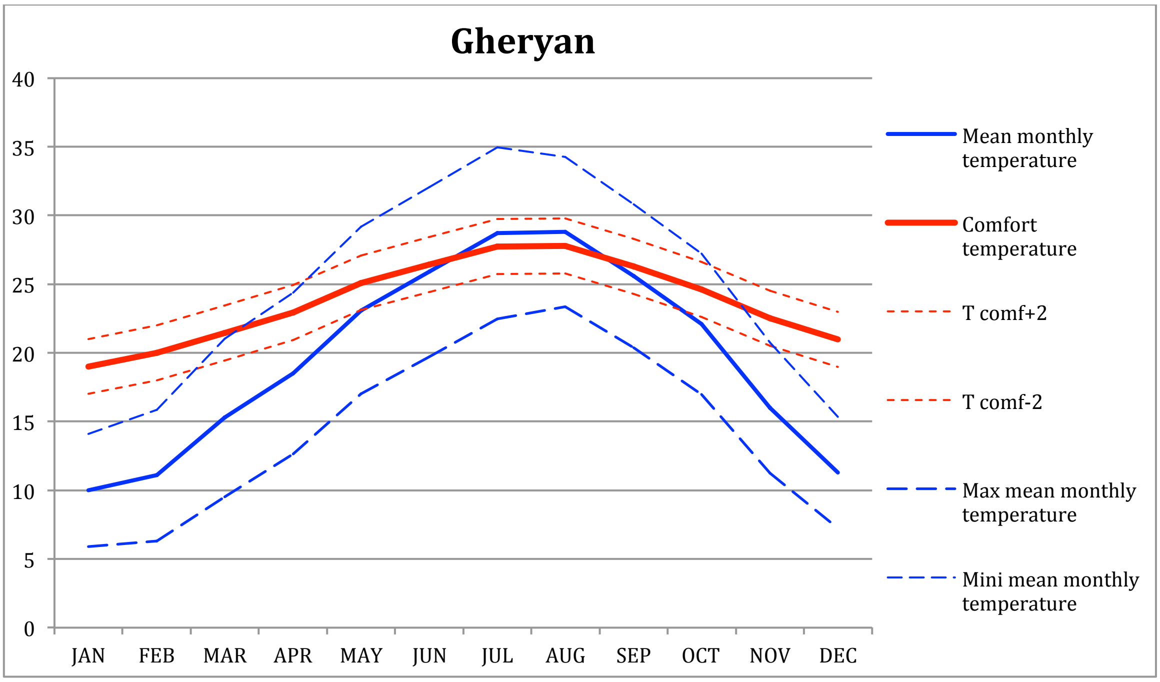
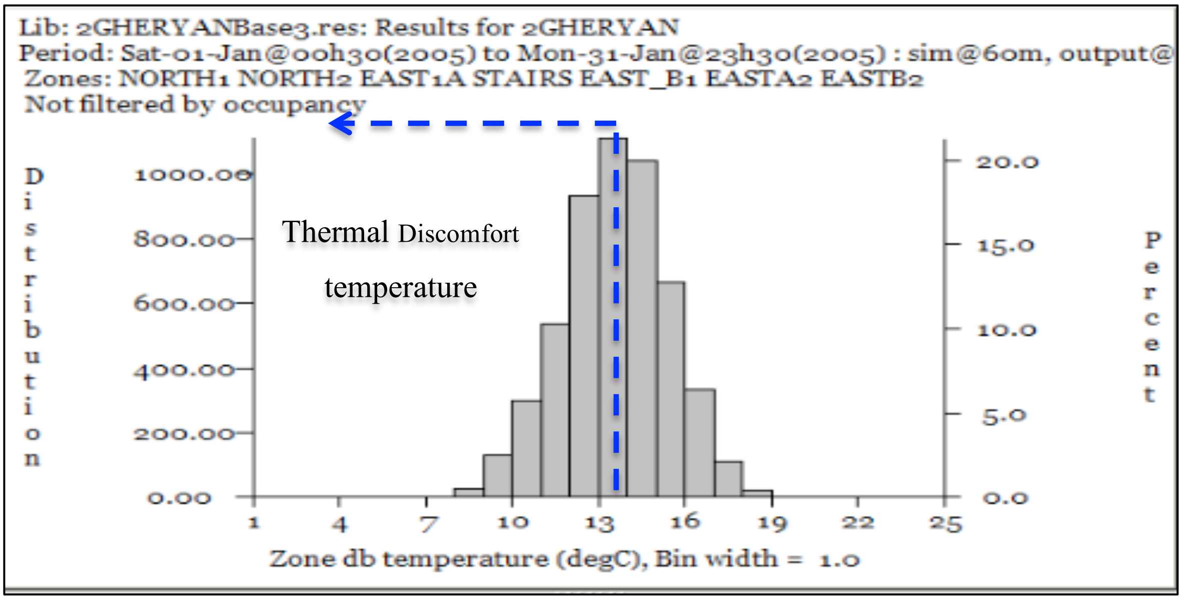


Figure (8. 9) ambient temperature and comfort temperature- Gheryan

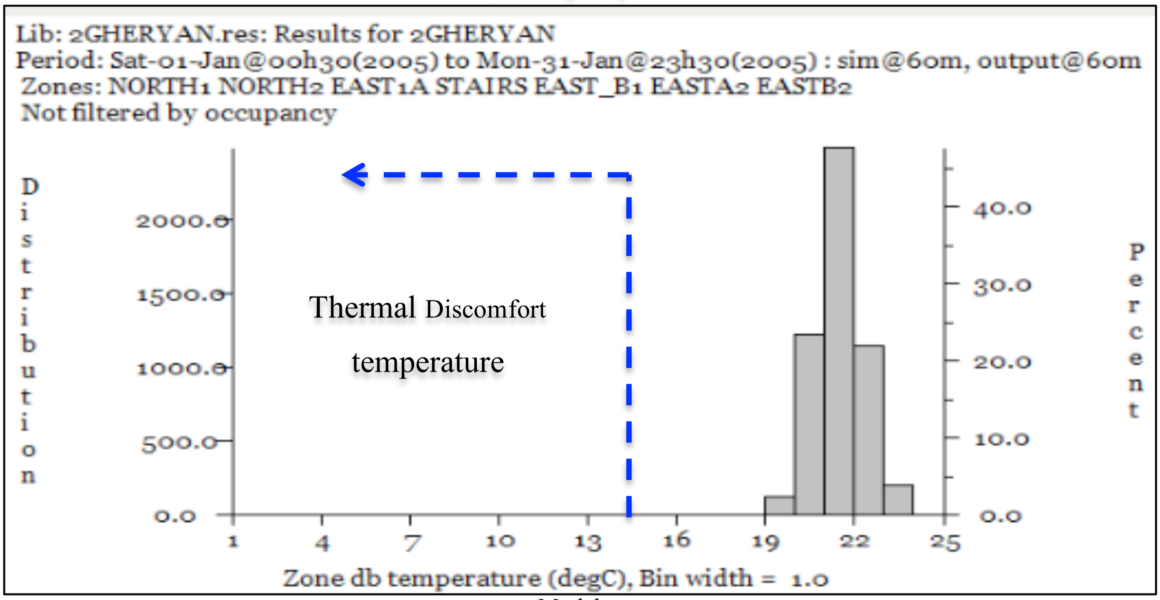
Furthermore, calculated with respect to external temperature using the thermal comfort equation for Gheryan, founded in chapter five. For the cold season the comfort temperature are 19, 20and 21°C in January, February, and December respectively, using the wider thermal comfort band, the upper and lower margin were set as comfort zone with $\pm 2K$ difference from the comfort temperature.

For the hot season the comfort temperatures for these months are 26, 28 and 28 °Cfor June, July and August respectively. The chart shows the wider thermal comfort band by with $\pm 2K$ difference from the comfort temperature, therefore the higher band of comfort in these months are 28, 230 and 30 °C for June, July and August respectively.

The charts Figures (8-10) and (8-11) illustrated the distribution of indoor temperature in the seven zones of the contemporary and the model during January and July. From the frequency bin the number of hours the indoor temperature is above or below comfort temperature can be calculated.



Contemporary

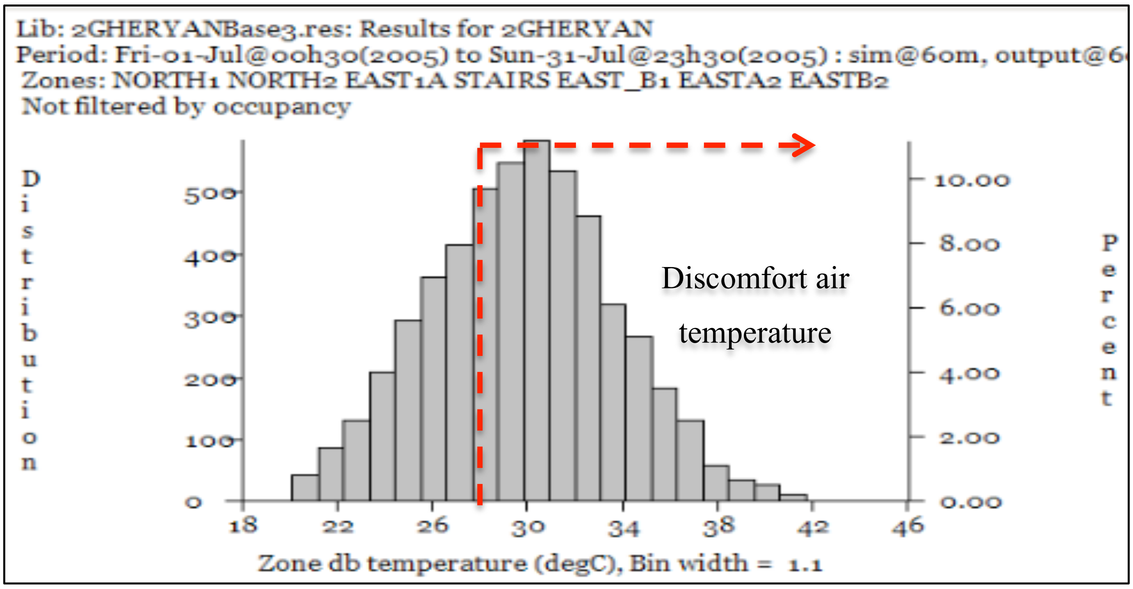


Model

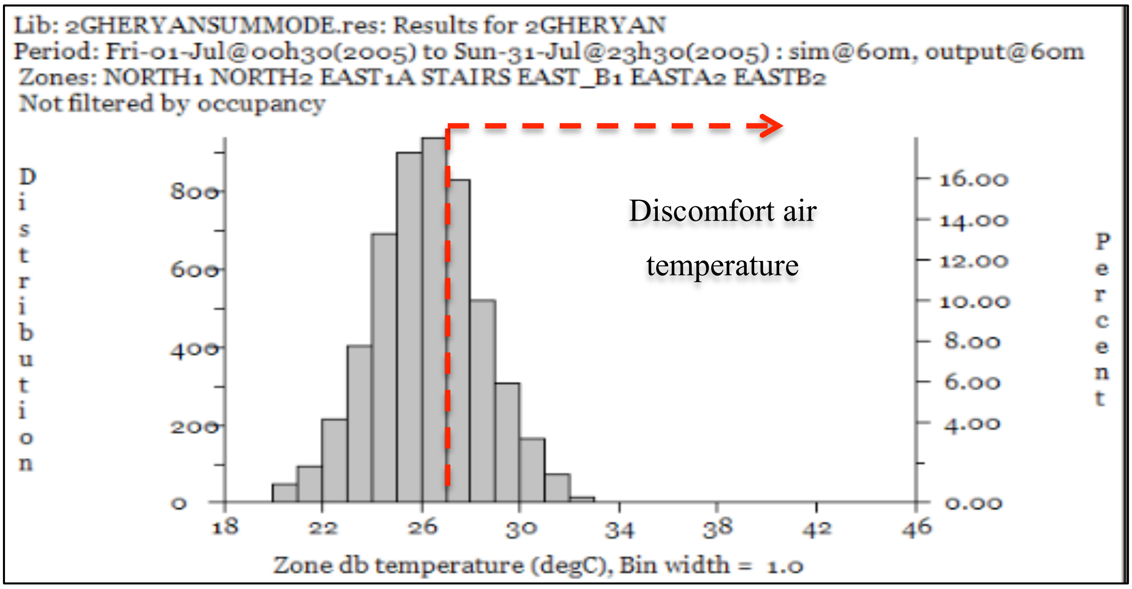
Figure (8. 10) Comparing the indoor temperature for the contemporary house and the model- in January

The chart in figure (8-10) frequency bin shows the distribution of indoor temperature in the contemporary house, with the minimum air temperature recorded is 9C and the highest is 19 number, and the mode temperature is 14 C, showing that indoor air temperature will be lower than the comfort temperature 444 hours, this is 60% of hours in January. However in model the lowest temperature recorded is 19C with no Discomfort temperature that shows the model had an outstanding thermal performance in winter as the value of hours recorded below the comfort temperature dropped to zero hours in January with reduction of nearly 100% compared to the contemporary house.

That prove by using passive heating techniques, discussed in chapter seven, achieved the indoor thermal comfort.



Contemporary



Model

Figure (8. 11) Comparing the indoor temperature in the contemporary house and the model

The frequency bin shows the distribution of indoor air temperature recorded in the contemporary house and the mode during July. The chart Figure (8.11) shows that in the contemporary houses the indoor temperature rises up to 42 C, and with mode temperature is 31C. Therefore it shows that discomfort temperature hours accrued 65% of the month. This value dropped in the model to 25% of the month. In Gheryan the study shows that using passive heating strategies in the proposed model improve the thermal performance of the house.

A comparative study between the contemporary house and the model in Gheryan illustrated in figure (8.12), shows the numbers of hours of discomfort indoor air temperature, by summing the number of indoor air temperature recorded below the comfort zone in January and above the comfort zone in July.

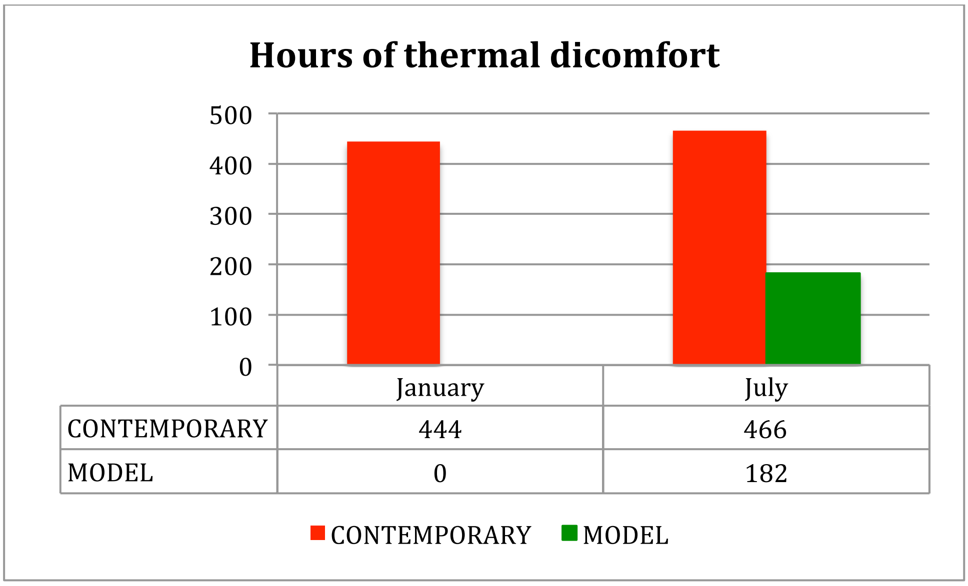


Figure (8. 12) comparison between hours of discomfort temperature in the contemporary house and the model

The chart shows that during the cold month the model had an outstanding thermal performance with reduction of nearly 100% compared to the contemporary house. And during that hot month the value and nearly 60% in the model compared to the contemporary house. That proves by using passive heating and cooling techniques in the model, improve the indoor thermal environment.

8.4 Conclusion

The application of passive heating and cooling technique in Libya's houses can improve the thermal environment compared to the contemporary dwelling. As the indoor air temperature recorded in the three models in the three cities are within the limit of the comfort temperature in winter. That shows 100% improvement from the contemporary houses. However in summer the thermal environment improved with 60%, 40% and 60% in Tripoli Ghadames and Gheryan. The following table shows the percentage of improvement in indoor temperature of the low energy houses compared to the contemporary house.

Thermal performance	Tripoli	Ghadames	Gheryan
January	100%	100%	100%
July	60%	40%	60%

Table (8. 1) Percentage of improvement in indoor temperature of the low energy houses compared to the contemporary house.

In conclusion, it confirms the improvement of the thermal performance of the model in the three cities taking into account the external environment in addition to internal heat gains, and it shows that in three cities a lower energy houses can be achieved.

9. Chapter Nine: Conclusion

9.1 Conclusion

This chapter identifies the findings and conclusions of the study and in addition it outlines potential future research on low energy technology in Libya houses. The study describes in detail the strategy and pathways follow to obtain a lower energy house in Libya using local materials and vernacular passive strategies for cooling and heating in three different region of the country. The final part of this chapter outlines potential future research on thermal comfort, building materials, zero energy houses and more lessons from vernacular houses.

The study has applied a mixed methods approach by combining quantitative data collection of site-based temperatures from iButton readings; qualitative data collection through thermal comfort field surveys; by applying the resulting adaptive thermal comfort temperatures to provide passive architectural solutions to vernacular housing design for lowering annual energy demand through computer modelling and energy simulation using dynamic thermal software.

The interruption of the civil war in Libya has resulted the collapse one of the potential case studies resulting in data collection in just three locations rather than four as was originally planned.

9.2 Key findings and conclusions

The findings from literature, field studies and computer simulation work include cultural, climate and technology that combine to achieve low energy house design in Libya.

9.2.1 The culture factors

The outcome of the literature and descriptive analysis of the three traditional vernacular house forms in Libya suggests several cultural aspects that inform the house design in Libya. Cultural aspects can be classified in to two groups of factors that govern the cultural performance of the house; main factors and secondary factors. The main factors include the basic needs and privacy. And the secondary factors include the family structure, position of women and social intercourse. In addition, these forces can be introduced as criteria derived from the lessons of traditional house form that can be utilized in the examination of the cultural performance of the contemporary and outline for the future houses in Libya.

The outcome of the survey examining three traditional vernacular house forms in Libya suggests that changes in the society are physically express in the building. The family structure, position of women and social intercourse shows a recognizable effect on the space use and its re-arrangement in the three remodelled vernacular houses. Understanding these factors and their effect on forming Libyan houses must be outlined when designing the low energy future house.

9.2.2 Environmental factors

Studying the building material, passive cooling and heating technique, in addition to monitoring the thermal performance of the vernacular houses in Libya provides us with more information in how to learn from it, as product characteristics of the building offer possibilities for learning from the vernacular in order to obtain low energy houses that not only response to the climate but also to cultural requirements. The houses have been monitored using a computer chip (iButton) installed in the houses for 10 days during summer and winter. This study provides a comparative analysis between the three traditional vernacular houses and proves the effect of climate on modifying both the vernacular house design and the perception of comfort temperature in the three regions.

The thermal performance of the courtyard house in the coastal region demonstrates a noticeable reduction in summer heat by using Lime block and date palm wood as local materials along with vernacular cooling and heating techniques such as orientations, thermal mass, opening location, shading and layout context. The compact house in the desert displays a remarkable thermal performance, using local material such as sundry sand stone and date palm wood, the cooling and heating technique in the compact vernacular houses comprises thermal mass, opening position and the urban context or architectural “massing”. Monitoring the thermal performance of earth shelter house in the mountains shows that thermal comfort may be achieved using passive techniques such as earth cooling and heating combined with shading.

Monitoring and analysis of the vernacular houses proves that local builders built with respect to their environmental contexts and available resources in order to achieve comfort environments. Moreover, from the studying the thermal performance of traditional vernacular houses a set of passive heating and cooling strategies has been outlined and used in the model in order to obtain a low energy house. The effect of these combined strategies on improving the thermal performance of the model provides the energy simulation results shown in chapter seven.

9.2.3 Thermal comfort

Field surveys have been conducted to outline the perception of thermal comfort in Libya's houses, the studies include three different climatic region in Libya, the city of Tripoli in the semi-Mediterranean climate on the coastal area, the city of Ghadames in the Desert and the city of Gheryan in the Mediterranean climate influenced by the mountainous altitude. A total of nearly 160 persons were interviewed during the surveys, where they were asked in their houses under their normal living conditions during the hottest (Summer), the coldest (Winter) and the moderate (Spring) periods of the year. The survey includes both subjective (collecting data from the subjects), and objective (measuring the environment variables) outcomes.

The study outcome provides two main findings: First it provides the thermal insulation of traditional Libyan clothing Thermal insulation of traditional Libyan clothing was tested in a climate chamber and the results show that male traditional clothing is 0.63 clo in summer and 1.95 clo in winter, while female traditional clothing is 1.17 clo in summer and 1.6 clo in winter. The field survey found that older generations tend to wear the heavier traditional Libyan clothing. In the summer women in Libya usually wear heavier clothes than men, while in winter men wear heavier clothes than women. These differences almost certainly result from both cultural and practical factors since women are expected to cover their heads and bodies yet are also responsible for household work and thus operate at a higher metabolic rate.

Secondly, the study assigns adaptive thermal comfort temperatures to the three climatic zones from which three computer models are developed using the running mean outdoor temperature as predictor of the thermal comfort to indicate the limits of the comfort zones for the three cities.

The thermal comfort readings in this research may be taken as part of a broader empirical study to set a thermal standard for the North African Countries 'Al-Maghreb Al-Arabie' which includes Libya, Tunisia, Algeria, Mauritania and Morocco.

9.2.4 Energy simulation results and low energy house guideline

The energy simulations results for the three models shows that vernacular traditional houses can enrich the future design of low energy housing in Libya. Modifying the models with respect to the traditional environment solutions can establish a comfortable environment that is acceptable by Libyans in the three regions. Using the right available building material is the key issue to constructing low energy houses. Where date palm insulation with Lime stone block, breezeblock or sand block provide the right combination of low conductivity and high thermal mass. The energy simulation results show that passive heating and cooling techniques can provide indoor thermal comfort in the three cities.

The outline of low energy houses in Tripoli found from the study indicates that optimal results are based on using insulation provided by local materials such as date palm insulation with Lime stone block and breezeblock in the form of a cavity wall. Secondly adjustable shading devices to obstruct solar radiation in the warm season and using shutter on the windows reduce heat flow through glazed surfaces. Finally urban context had a considerable impact on thermal performance of the model as shown by the building orientation and courtyard position. Indoor comfort temperature can be achieved in Tripoli and the coastal region both in winter and summer by using the passive heating and cooling strategies.

In the Ghadames model the application of the vernacular passive cooling strategy improves the thermal performance of the model in both winter and summer season. Passive cooling and heating strategies include the design layout separating the kitchen as heat source zone from the rest of the zones (to isolate the heat gain from the kitchen during the hot season) minimizing the roof area by creating a multi-layer model, in addition to ventilation and contextual strategy. Shading devices provide a passive strategy by covering the courtyard to obstruct direct solar radiation and help to reduce the heat gain, and at the same time allow view to the rooms.

In the city of Gheryan the application of vernacular passive cooling and heating is associated with the earth cooling strategy; using the ground as protector from the external environment improves the thermal performance of the houses. In addition to using shading devices, thermal mass has a noticeable effect on the thermal performance of the model. The energy simulation results show that thermal comfort can be achieved in Gheryan houses using only passive heating and cooling techniques.

In conclusion the computer energy simulation results prove that targeted vernacular construction techniques improve the thermal performance of the houses in the three regions.

9.2.5 Heating and cooling Degree day

The results of the survey to provide comfort temperatures were used to calculate heating and cooling degree-hours in the three climatic zones by setting the base temperature with respect to thermal comfort temperature and casual heat gains in houses. In Tripoli when base temperature was set at 15°C the annual HDD is nearly 494, and when the base temperature is 24°C the annual CDD is 721. In Ghadames when base temperature was set at 19°C the annual HDD is nearly 661, and when the base temperature is 28°C the annual CDD is 959. Finally In Gheryan when base temperature was set at 14°C the annual HDD is nearly 432, and when the base temperature is 23°C the annual CDD is 631.

9.2.6 Thermal Performance

The Final chapter in this research, a comparative analysis between indoor temperature of the models and contemporary house, proves that the application of passive heating and cooling techniques in Libya's houses can improve the indoor thermal environment of the houses in Libya.

In winter the study shows that the thermal performance of the proposed model can be improved by 100% compared to the contemporary houses, by using passive heating techniques. In hot season the study shows the thermal performance of the proposed model can be improved by 60%, 40% and 60% in Tripoli, Ghadames and Gheryan.

In conclusion, the study supports the argument that vernacular architecture can inform the design of low energy housing in Libya. Architecture informed by adaptive thermal design, local materials and responding to inhabitants' lifestyles are appropriate techniques for all three regions.

9.3 Potential Future Research

The research demonstrates a guide to low energy houses in Libya, however it does not present final solution for energy efficient houses. The research highlights potential future research in many areas. First in thermal comfort studies, the comfort survey was limited to only ten days in the three seasons of winter, spring and summer. However a monthly survey would provide more data to set a better estimation for the population responses. Therefore more studies in the field are required in order to define thermal comfort standards for Libyan Codes.

Secondly, the use of contemporary materials with no concern to the climate leads to houses with poor thermal performance and high-energy consumption, demanding the use of active cooling and heating. Using local building material such as palm insulation is fundamental to low energy houses. The thermo-physical properties of date palm insulation vary according to the date palm variety, and its composition, therefore, a study of Libyan date palm as insulation material and its introduction to the Libyan market could have a major impact on both the thermal performance and embedded energy of houses in Libya.

In order to enhance the level of energy performance in houses a next step should be to study the actual energy use of housing in order to reduce it. Therefore studying the use of passive solar systems in lighting, hot water supply, and heating could reduce the energy use in houses in Libya.

Finally, the research emphasizes the possibility of more lessons from vernacular houses. Vernacular architecture is not only an object of environmental design research but it also enriches future architecture and inspires the development of new ideas. For example, taking into consideration that lighting is one of the components of sustainable architecture, studying architectural lighting and its link to the climate and cultural requirements in vernacular houses can provide us with springboard and model for architecture day lighting.

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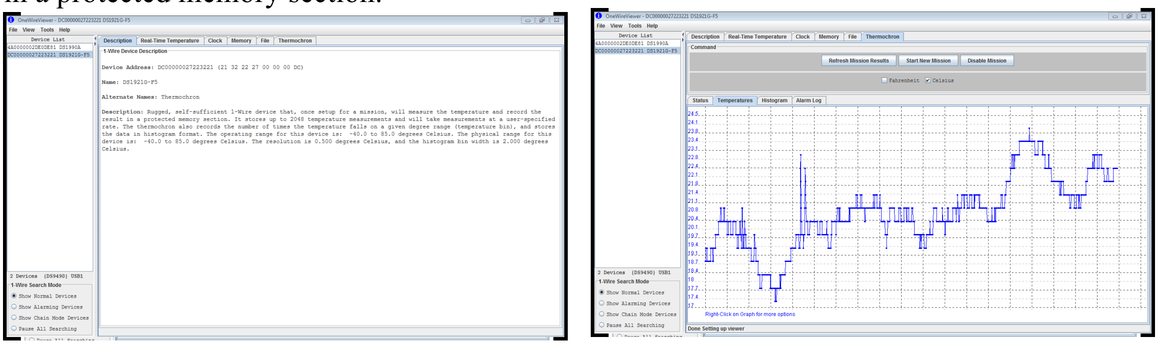
Appendixes

Appendix A- The vernacular houses thermal performance data

The following table illustrates the iButton distribution around the house according to the room's orientation, which allows the analysis the solar radiation effect as well as the air movement. the device measures the temperature and record the result every hour and save it in a protected memory section.



Appendix A 1 – iButtun – OneWireVeiwer software used for reading the iButtons

	Room	Position fixed
No1	Ground floor living room No1	Internal West wall
No2	Ground floor living room No2	Internal East wall
No3	Ground floor courtyard No3	External North wall
No4	First floor Bed room No4	External South wall
No5	First floor Kitchen No5	Internal South wall
No6	First floor livingroomNo6	External East wall

Computer chip location in the house. Tripoli

	Room	Position fixed
No1	Ground floor Storage room No1	Internal East wall
No2	First floor living room No2	External East wall
No3	First floor upper level storage room No3	Internal West wall
No4	First floor lower level Bed room No4	Internal West wall
No5	First floor upper level bed room No5	Internal North wall
No6	Second floor (roof) Kitchen No6	External west wall

Computer chip location in the house. Ghadames

	Room	Position fixed
No1	Storage room	Internal wall
No2	Under ground floor- Entrance	Internal wall
No3	West facing room	Sleeping area
No4	Court yard	Open area
No5	Kitchen	Internal wall
No6	South facing room	Sleeping area
No7	North facing room	Sleeping area
No8	East facing room	Sleeping area
No9	East facing room	Living area

Computer chip location in the house. Gheryan

Thermal performance Data of the vernacular houses

Tripoli Courtyard House thermal performance in winter

Data/ Time	No1	No2	No3	N04	No5	No6
24/12/10 17:51:00	19	19.5	19	17.5	16.5	18.5
24/12/10 18:51:00	19	19.5	19.5	17.5	16.5	18.5
24/12/10 19:51:00	19	19.5	19	17	16.5	18.5
24/12/10 20:51:00	19	19.5	18.5	17	16.5	18.5
24/12/10 21:51:00	19	19.5	18	17	16.5	18
24/12/10 22:51:00	19	19.5	18	16.5	16.5	18
24/12/10 23:51:00	19	19.5	18	16.5	16	18
25/12/10 00:51:00	18.5	19	17.5	16	16	18
25/12/10 01:51:00	18.5	19	17.5	15.5	16	18
25/12/10 02:51:00	18.5	19	17	15	16	18
25/12/10 03:51:00	18.5	18.5	17	14.5	16	17.5
25/12/10 04:51:00	18	18.5	16.5	14.5	15.5	18
25/12/10 05:51:00	18	18.5	16.5	14.5	15.5	18
25/12/10 06:51:00	18	18	16.5	14.5	15.5	18
25/12/10 07:51:00	18	18.5	16.5	14.5	15.5	18
25/12/10 08:51:00	18	18.5	16.5	15	15.5	17.5
25/12/10 09:51:00	18	18.5	17.5	16	15.5	17.5
25/12/10 10:51:00	17.5	18	17.5	16	15.5	17.5
25/12/10 11:51:00	18	18	17	16.5	16	17.5
25/12/10 12:51:00	18	18	17.5	16.5	16	17.5
25/12/10 13:51:00	18	18	19.5	16.5	16	17.5
25/12/10 14:51:00	18	18	18	16.5	16	17.5
25/12/10 15:51:00	17.5	18	18	16	16	17.5
25/12/10 16:51:00	17.5	18	18	16	16	17.5
25/12/10 17:51:00	17.5	18	18	15.5	16	17.5
25/12/10 18:51:00	17.5	18	17.5	15.5	16	17
25/12/10 19:51:00	17.5	18.5	17.5	15.5	16	17
25/12/10 20:51:00	17.5	18.5	17	15.5	16	17
25/12/10 21:51:00	17.5	18.5	16.5	15	16	17
25/12/10 22:51:00	17.5	18.5	16.5	14.5	16	17
25/12/10 23:51:00	17.5	18	16	14.5	15.5	16.5
26/12/10 00:51:00	17.5	18	16	14.5	15.5	16.5
26/12/10 01:51:00	17	18	16	13.5	15.5	16.5
26/12/10 02:51:00	17	18	15.5	13.5	15.5	16.5
26/12/10 03:51:00	17	17.5	15.5	13.5	15.5	16.5
26/12/10 04:51:00	17	17.5	15.5	13.5	15.5	17
26/12/10 05:51:00	17	17.5	16	13.5	15.5	17
26/12/10 06:51:00	16.5	17	15	13	15	17
26/12/10 07:51:00	16.5	17	15	13	15	16.5
26/12/10 08:51:00	16.5	17	15	14	15	17
26/12/10 09:51:00	16.5	17	15.5	14.5	15	16.5
26/12/10 10:51:00	16.5	17.5	15.5	15	15	16.5
26/12/10 11:51:00	17	17.5	15.5	15.5	15.5	17
26/12/10 12:51:00	17	17.5	15.5	15.5	15.5	17
26/12/10 13:51:00	17	17.5	15.5	15.5	15.5	17
26/12/10 14:51:00	16.5	17.5	15.5	15.5	15.5	16.5
26/12/10 15:51:00	17	17.5	16.5	15	15.5	16.5
26/12/10 16:51:00	16.5	17	18	15	15.5	16.5
26/12/10 17:51:00	16.5	17.5	17.5	15	15.5	16
26/12/10 18:51:00	17	17.5	17	15	15.5	16
26/12/10 19:51:00	17	17.5	17	15	15.5	16
26/12/10 20:51:00	17	17.5	16.5	15	15.5	16
26/12/10 21:51:00	16.5	17.5	16	15	15.5	15.5
26/12/10 22:51:00	16.5	17.5	15.5	14.5	15	15.5

26/12/10 23:51:00	16.5	17.5	15.5	14	15	15.5
27/12/10 00:51:00	16	17.5	15	13.5	15	15.5
27/12/10 01:51:00	16	17.5	15	13.5	15	15.5
27/12/10 02:51:00	16	17	15	13.5	15	15.5
27/12/10 03:51:00	16	17	15	14	15	15.5
27/12/10 04:51:00	15.5	17	14.5	13	14.5	15.5
27/12/10 05:51:00	15.5	17	14.5	13	15	15.5
27/12/10 06:51:00	15.5	17	14.5	13.5	14.5	15.5
27/12/10 07:51:00	15.5	17	14.5	13	14.5	15.5
27/12/10 08:51:00	15.5	17	14.5	13	14.5	15.5
27/12/10 09:51:00	15.5	17	15	13.5	14.5	15.5
27/12/10 10:51:00	15.5	16.5	15	13.5	14.5	15.5
27/12/10 11:51:00	15.5	17	15	13.5	14.5	15.5
27/12/10 12:51:00	15.5	17	15	14	15	15.5
27/12/10 13:51:00	15.5	17.5	15	14	14.5	15.5
27/12/10 14:51:00	15.5	17.5	15	14	15	15.5
27/12/10 15:51:00	15.5	17.5	15	14	15	15.5
27/12/10 16:51:00	15.5	17.5	15.5	14	15	15.5
27/12/10 17:51:00	15.5	17	15.5	14	15	15.5
27/12/10 18:51:00	15.5	17.5	15.5	14.5	15	15.5
27/12/10 19:51:00	15.5	18	15.5	14.5	15	15.5
27/12/10 20:51:00	15.5	18	15.5	14.5	15	15.5
27/12/10 21:51:00	15.5	18	15.5	14.5	15	15.5
27/12/10 22:51:00	15.5	18	15	14.5	15	15.5
27/12/10 23:51:00	15.5	18	15	14.5	15	15.5
28/12/10 00:51:00	15.5	18	14.5	14.5	15	15.5
28/12/10 01:51:00	15.5	18	14.5	14.5	15	15.5
28/12/10 02:51:00	15.5	17.5	14.5	14.5	15	15.5
28/12/10 03:51:00	15.5	17.5	14.5	14.5	15	16
28/12/10 04:51:00	15.5	17.5	14.5	14.5	15	16
28/12/10 05:51:00	15.5	18	15.5	14.5	15	15.5
28/12/10 06:51:00	15.5	17.5	15.5	14.5	15	16
28/12/10 07:51:00	15.5	17.5	15	15	15	16
28/12/10 08:51:00	15.5	17.5	15	15	15	16
28/12/10 09:51:00	15.5	17.5	15	15.5	15	16
28/12/10 10:51:00	16	17.5	15	16	15	16
28/12/10 11:51:00	16	17.5	15.5	16	15	16
28/12/10 12:51:00	15.5	17.5	15.5	15.5	15	16
28/12/10 13:51:00	16	17.5	16	15.5	15.5	16
28/12/10 14:51:00	16	17.5	16.5	15.5	15.5	16
28/12/10 15:51:00	16	17.5	16	15.5	15.5	16
28/12/10 16:51:00	16	17.5	16	15	15.5	16
28/12/10 17:51:00	16	17.5	16	15.5	15.5	16
28/12/10 18:51:00	16	18	16	15	15.5	16
28/12/10 19:51:00	16	18	16.5	15	15.5	15.5
28/12/10 20:51:00	16	17.5	16.5	15	15.5	15.5
28/12/10 21:51:00	16	18	15.5	15	15.5	15.5
28/12/10 22:51:00	16	18	15	15	15.5	15.5
28/12/10 23:51:00	16	17.5	15	15	15	15.5
29/12/10 00:51:00	16	17.5	15	15	15	15.5
29/12/10 01:51:00	16	17.5	15	14.5	15	15.5
29/12/10 02:51:00	15.5	17.5	14.5	14	15	15.5
29/12/10 03:51:00	15.5	17.5	14.5	13.5	15	15.5
29/12/10 04:51:00	15.5	17.5	14.5	13	15	15.5
29/12/10 05:51:00	15.5	17	15	13	14.5	16
29/12/10 06:51:00	15.5	16.5	15	12.5	14.5	16
29/12/10 07:51:00	15.5	16.5	15	13	14.5	16
29/12/10 08:51:00	15.5	16.5	15	13.5	14.5	16
29/12/10 09:51:00	15.5	16.5	14.5	14	14.5	16
29/12/10 10:51:00	15.5	17	14.5	14.5	14.5	15.5

29/12/10 11:51:00	15.5	17	15	15	14.5	15.5
29/12/10 12:51:00	16	17	15	15	14.5	15.5
29/12/10 13:51:00	16	17	14.5	15	15	15.5
29/12/10 14:51:00	16	17	15	15	15	15.5
29/12/10 15:51:00	16	17	15.5	14.5	15	15.5
29/12/10 16:51:00	16	16.5	16	14.5	15	15.5
29/12/10 17:51:00	15.5	17	15.5	14.5	14.5	15.5
29/12/10 18:51:00	15.5	17	15.5	14.5	14.5	15.5
29/12/10 19:51:00	15.5	17	15.5	14.5	14.5	15
29/12/10 20:51:00	15.5	17	15.5	14	14.5	15
29/12/10 21:51:00	15.5	17	15	13.5	14.5	15
29/12/10 22:51:00	15.5	17	14.5	13.5	14.5	15
29/12/10 23:51:00	15.5	17	14	13	14.5	15
30/12/10 00:51:00	15.5	17	14	13	14	14.5
30/12/10 01:51:00	15.5	16.5	14	13	14	14.5
30/12/10 02:51:00	15	16.5	13.5	12.5	14	14.5
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30/12/10 04:51:00	15	16.5	13.5	12.5	14	15
30/12/10 05:51:00	15	16.5	13.5	12	14	15
30/12/10 06:51:00	15	16.5	13.5	12	13.5	15
30/12/10 07:51:00	14.5	16	13.5	12	13.5	15
30/12/10 08:51:00	14.5	16	13.5	13	14	15
30/12/10 09:51:00	14.5	16	13.5	14	14	15
30/12/10 10:51:00	14.5	16.5	13.5	14	14	15
30/12/10 11:51:00	15	16.5	14	15	14	15
30/12/10 12:51:00	15	16.5	14	15	14	15
30/12/10 13:51:00	15	17	14.5	15	14.5	15
30/12/10 14:51:00	15	17	14.5	15	14.5	15
30/12/10 15:51:00	15	17	14.5	14.5	14.5	15
30/12/10 16:51:00	15	17	14	14.5	14.5	15
30/12/10 17:51:00	15	16.5	14	14.5	14.5	15
30/12/10 18:51:00	15	16.5	14	14.5	14.5	14.5
30/12/10 19:51:00	15	16.5	14	14	14.5	14.5
30/12/10 20:51:00	15	16.5	14.5	14	14.5	14.5
30/12/10 21:51:00	15	16.5	14	14	14.5	14.5
30/12/10 22:51:00	15	16.5	14	13.5	14.5	14.5
30/12/10 23:51:00	15	16.5	13.5	13.5	14.5	14.5
31/12/10 00:51:00	15	16	13.5	13	14.5	14
31/12/10 01:51:00	14.5	16	13.5	13	14	14.5
31/12/10 02:51:00	14.5	16	13	12.5	14	14.5
31/12/10 03:51:00	14.5	16	13	12.5	14	14.5
31/12/10 04:51:00	14.5	16	13	12.5	14	15
31/12/10 05:51:00	14.5	16	13	12.5	14	15
31/12/10 06:51:00	14.5	16	13	12.5	14	15
31/12/10 07:51:00	14	15.5	13	12.5	14	15
31/12/10 08:51:00	14.5	16	13	13.5	14	15
31/12/10 09:51:00	14.5	16	13.5	14	14	15
31/12/10 10:51:00	14.5	16	14	15	14.5	15
31/12/10 11:51:00	15	16.5	14	15	14.5	30
31/12/10 12:51:00	15	16.5	14.5	15	14.5	21
31/12/10 13:51:00	15	16.5	14.5	15.5	14.5	21
31/12/10 14:51:00	15	16.5	14.5	15.5	14.5	21
31/12/10 15:51:00	15	16.5	14.5	15	14.5	21
31/12/10 16:51:00	15	16.5	14	14.5	14.5	21
31/12/10 17:51:00	15	16.5	14.5	15	14.5	21
31/12/10 18:51:00	30	28.5	29.5	29	29.5	21
31/12/10 19:51:00	21	22.5	20.5	21	21.5	21

Ghadames Compact House thermal performance in winter

Ghadames Date/Time	No7	No1	No2	No3	No4	No5	No6
12/28/10 14:13	14	13	14.5	14	13.5	14.5	11
12/28/10 15:13	15	13	14.5	14	13.5	14.5	11
12/28/10 16:13	16	13	14.5	14	13.5	14.5	11
12/28/10 17:13	17	12.5	14.5	14	13.5	14.5	10.5
12/28/10 18:13	18	12.5	14.5	14	13.5	14.5	10.5
12/28/10 19:13	19	12.5	14	14	13.5	14.5	10
12/28/10 20:13	20	12.5	14	14	13.5	14.5	10
12/28/10 21:13	21	12	14	14	13.5	14.5	10
12/28/10 22:13	22	11	14	14	14	14.5	9.5
12/28/10 23:13	23	11	14	14	13.5	14.5	9.5
12/29/10 0:13	0	10.5	14	14	13.5	14.5	9
12/29/10 1:13	1	10.5	14	14	13.5	14.5	9
12/29/10 2:13	2	10	14	14	13.5	14.5	9
12/29/10 3:13	3	9	14	14	13.5	14.5	7.5
12/29/10 4:13	4	9	14	14	13.5	14.5	7.5
12/29/10 5:13	5	8.5	14	13.5	13.5	14.5	7
12/29/10 6:13	6	8	13.5	13.5	13.5	14.5	7
12/29/10 7:13	7	7.5	13.5	13.5	13.5	14.5	6.5
12/29/10 8:13	8	8.5	13.5	13.5	13.5	14.5	7
12/29/10 9:13	9	9.5	13.5	13.5	13	14.5	7.5
12/29/10 10:13	10	10.5	13.5	13.5	13	14.5	8
12/29/10 11:13	11	11	13.5	13.5	13	14.5	9
12/29/10 12:13	12	11.5	13.5	13.5	13	14.5	10
12/29/10 13:13	13	12	14	13.5	13	14.5	10.5
12/29/10 14:13	14	12	14	13.5	13	14.5	11
12/29/10 15:13	15	12	14	13.5	13	14.5	11
12/29/10 16:13	16	12.5	14	13.5	13	14.5	11
12/29/10 17:13	17	12	13.5	13.5	13	14.5	11
12/29/10 18:13	18	12	13.5	13.5	13	14.5	10.5
12/29/10 19:13	19	12	13.5	13.5	13.5	14.5	10
12/29/10 20:13	20	12	13.5	13.5	13.5	14	9.5
12/29/10 21:13	21	11.5	13.5	13.5	13.5	14	9
12/29/10 22:13	22	11.5	13.5	13.5	13.5	14	8.5
12/29/10 23:13	23	11.5	13.5	13	13.5	14	8.5
12/30/10 0:13	0	11.5	13.5	13	13	14	8
12/30/10 1:13	1	11	13.5	13	13	14	7.5
12/30/10 2:13	2	11	13.5	13	13	14	7
12/30/10 3:13	3	10.5	13.5	13	13	14	6.5
12/30/10 4:13	4	10.5	13.5	13	13	14	6
12/30/10 5:13	5	10.5	13	13	13	14	5.5
12/30/10 6:13	6	10	13	13	13	14	5
12/30/10 7:13	7	10.5	12.5	13	13	13	5
12/30/10 8:13	8	11	12	13	13	13	5.5
12/30/10 9:13	9	11	12.5	13	13	13	6.5
12/30/10 10:13	10	12	12.5	13	13	13.5	8
12/30/10 11:13	11	12	13	13	13	13.5	11
12/30/10 12:13	12	12.5	13	13	13	13.5	12
12/30/10 13:13	13	13	13.5	13	13	13.5	13
12/30/10 14:13	14	13	13.5	13	13	13.5	14
12/30/10 15:13	15	13	13.5	13	13	14	15
12/30/10 16:13	16	13	13.5	13	13	14	14.5
12/30/10 17:13	17	12.5	13.5	13	13	13.5	13.5
12/30/10 18:13	18	12.5	13.5	13	13	13.5	13
12/30/10 19:13	19	12	13.5	13	13	13.5	12.5
12/30/10 20:13	20	12	13.5	13	13	13.5	11.5
12/30/10 21:13	21	12	13.5	13	13	13.5	11
12/30/10 22:13	22	12	13.5	13	13	13.5	11
12/30/10 23:13	23	12	13	13	13	13.5	10.5
12/31/10 0:13	0	12	13	13	13	13.5	10.5
12/31/10 1:13	1	12	13	13	13	13.5	10
12/31/10 2:13	2	11.5	13	13	13	13.5	10
12/31/10 3:13	3	11.5	13	13	13	13.5	9.5
12/31/10 4:13	4	11.5	13	13	13	13.5	9.5
12/31/10 5:13	5	11	13	13	13	13.5	9.5
12/31/10 6:13	6	10.5	13	13	13	13.5	9.5

12/31/10 7:13	7	10.5	13	13	13	13.5	9
12/31/10 8:13	8	11	13	13	13	13.5	9.5
12/31/10 9:13	9	11.5	13	13	13	13.5	10.5
12/31/10 10:13	10	12.5	13	13	13	13.5	11.5
12/31/10 11:13	11	13	13	13	13	13.5	13
12/31/10 12:13	12	13	13	13	13	13.5	14.5
12/31/10 13:13	13	13.5	13	13	13	13.5	15
12/31/10 14:13	14	13	13	13	13	13.5	15.5
12/31/10 15:13	15	13.5	13	13	13	13.5	16
12/31/10 16:13	16	13.5	13	13	13	13.5	15.5
12/31/10 17:13	17	13.5	13	13	13	13.5	15
12/31/10 18:13	18	13	13	13	13	13.5	14
12/31/10 19:13	19	13	13	13	13	13.5	13.5
12/31/10 20:13	20	13	13	13	13	13.5	13
12/31/10 21:13	21	13	13	13	13	13.5	12.5
12/31/10 22:13	22	13	13	13	13	13.5	12
12/31/10 23:13	23	12.5	13	13	13	13.5	11.5
1/1/11 0:13	0	13	13	13	13	13.5	11
1/1/11 1:13	1	12	13	13	13	13.5	11
1/1/11 2:13	2	11.5	13	13	13	13.5	10.5
1/1/11 3:13	3	11.5	13	13	13	13.5	10
1/1/11 4:13	4	10.5	13	13	13	13.5	10
1/1/11 5:13	5	10.5	13	13	13	13.5	9.5
1/1/11 6:13	6	10.5	13	13	13	13.5	9.5
1/1/11 7:13	7	10.5	13	13	13	13.5	9.5
1/1/11 8:13	8	10.5	13	13	13	13.5	9.5
1/1/11 9:13	9	11	13	13	13	13.5	10
1/1/11 10:13	10	12	13	13	13	13.5	10.5
1/1/11 11:13	11	12.5	13	12.5	13	13.5	11.5
1/1/11 12:13	12	12.5	13	12.5	13	13.5	12.5
1/1/11 13:13	13	13	13	12.5	13	13.5	13
1/1/11 14:13	14	13	13	13	13	13.5	13
1/1/11 15:13	15	13	13	13	13	13.5	13.5
1/1/11 16:13	16	13	13	12.5	13	13.5	13.5
1/1/11 17:13	17	12.5	13	12.5	13	13.5	13
1/1/11 18:13	18	12.5	13	12.5	13	13	12.5
1/1/11 19:13	19	12.5	13	12.5	13	13.5	12
1/1/11 20:13	20	12.5	13	12.5	13	13	11.5
1/1/11 21:13	21	12	13	12.5	13	13	11
1/1/11 22:13	22	12.5	13	12.5	13	13	11
1/1/11 23:13	23	12	13	12.5	13	13	10.5
1/2/11 0:13	0	11.5	13	12.5	13	13	10.5
1/2/11 1:13	1	11.5	13	12.5	13	13	10.5
1/2/11 2:13	2	11	13	12.5	13	13	10
1/2/11 3:13	3	11	13	12.5	13	13	10
1/2/11 4:13	4	11	13	12.5	13	13	10
1/2/11 5:13	5	11	13	12.5	13	13	9.5
1/2/11 6:13	6	10.5	12.5	12.5	13	13	9
1/2/11 7:13	7	10.5	12.5	12.5	12.5	13	9
1/2/11 8:13	8	10.5	12.5	12.5	12.5	13	9
1/2/11 9:13	9	11	13	12.5	12.5	13	10
1/2/11 10:13	10	12	13	12.5	12.5	13	11
1/2/11 11:13	11	12.5	13	12.5	12.5	13	12.5
1/2/11 12:13	12	13	13	12.5	12.5	13	13
1/2/11 13:13	13	13	13	12.5	12.5	13	14
1/2/11 14:13	14	13	13	12.5	12.5	13	14.5
1/2/11 15:13	15	13	13	12.5	13	13	14.5
1/2/11 16:13	16	13	13	12.5	13	13	14.5
1/2/11 17:13	17	13	13	12.5	13	13	13.5
1/2/11 18:13	18	13	13	12.5	13	13	13
1/2/11 19:13	19	12.5	13	12.5	13	13	12.5
1/2/11 20:13	20	13	13	12.5	13	13	12.5
1/2/11 21:13	21	12.5	13	12.5	13	13	12
1/2/11 22:13	22	12.5	13	12.5	13	13	11.5
1/2/11 23:13	23	12.5	13	12.5	13	13	11.5
1/3/11 0:13	0	12	13	12.5	13	13	11
1/3/11 1:13	1	11.5	13	12.5	13	13	10.5

1/3/11 2:13	2	11.5	13	12.5	13	13	10.5
1/3/11 3:13	3	11	13	12.5	13	13	10
1/3/11 4:13	4	11	13	12.5	13	13	10
1/3/11 5:13	5	10.5	13	12.5	13	13	9.5
1/3/11 6:13	6	10.5	13	12.5	13	13	9.5
1/3/11 7:13	7	10.5	13	12.5	13	13	9.5
1/3/11 8:13	8	10.5	13	12.5	12.5	13	9.5
1/3/11 9:13	9	11	13	12.5	12.5	13	10
1/3/11 10:13	10	12	13	12.5	12.5	13	11.5
1/3/11 11:13	11	12.5	13	12.5	12.5	13	12.5
1/3/11 12:13	12	12.5	13	12.5	12.5	13	13.5
1/3/11 13:13	13	13	13	12.5	12.5	13	14
1/3/11 14:13	14	13	13	12.5	13	13	14.5
1/3/11 15:13	15	13	13	12.5	13	13	14.5
1/3/11 16:13	16	13	13	12.5	13	13	14
1/3/11 17:13	17	13	13	12.5	13	13	13.5
1/3/11 18:13	18	12.5	13	12.5	13	13	13
1/3/11 19:13	19	12.5	13	12.5	13	13	12.5
1/3/11 20:13	20	12.5	13	12.5	13	13	12.5
1/3/11 21:13	21	12.5	13	12.5	13	13	12
1/3/11 22:13	22	12.5	13.5	12.5	13	13	11.5
1/3/11 23:13	23	12.5	13.5	12.5	13	13	11.5
1/4/11 0:13	0	12	13.5	12.5	13	13	11
1/4/11 1:13	1	11.5	13.5	12.5	13	13	11
1/4/11 2:13	2	11	13.5	12.5	13	13	10.5
1/4/11 3:13	3	10	13.5	12.5	13	13	10
1/4/11 4:13	4	10	13	12.5	13	13	9
1/4/11 5:13	5	11	13	12.5	12.5	13	8.5
1/4/11 6:13	6	11	13	12.5	12.5	13	8.5
1/4/11 7:13	7	11	13	12.5	12.5	13	8.5
1/4/11 8:13	8	11	13	12.5	12.5	13	8.5
1/4/11 9:13	9	11	13	12.5	12.5	12.5	8.5
1/4/11 10:13	10	11.5	13	12.5	12.5	13	9.5
1/4/11 11:13	11	12	13	12.5	12.5	13	10.5
1/4/11 12:13	12	12.5	13	12.5	12.5	13	12
1/4/11 13:13	13	12.5	13	12.5	12.5	13	13
1/4/11 14:13	14	13	13	12.5	12.5	13	13.5
1/4/11 15:13	15	13	13	12.5	12.5	13	13.5
1/4/11 16:13	16	13	13	12.5	12.5	13	13.5
1/4/11 17:13	17	13	13	12.5	12.5	13	13
1/4/11 18:13	18	12.5	13	12.5	12.5	13	12.5
1/4/11 19:13	19	12.5	13	12.5	12.5	13	12
1/4/11 20:13	20	12.5	13	12.5	12.5	12.5	11.5
1/4/11 21:13	21	13	13	12.5	12.5	12.5	11
1/4/11 22:13	22	13	13	12.5	12.5	12.5	10.5
1/4/11 23:13	23	12.5	13	12.5	12.5	12.5	10.5
1/5/11 0:13	0	12.5	13	12.5	12.5	12.5	10
1/5/11 1:13	1	12.5	13	12.5	12.5	12.5	9.5
1/5/11 2:13	2	12.5	13	12.5	12.5	12.5	9.5
1/5/11 3:13	3	12.5	13	12.5	12.5	12.5	9.5
1/5/11 4:13	4	12.5	13	12.5	12.5	12.5	9.5
1/5/11 5:13	5	10.5	12.5	12.5	12.5	12.5	9
1/5/11 6:13	6	10	12.5	12.5	12.5	12.5	8.5
1/5/11 7:13	7	9.5	12.5	12.5	12.5	12.5	8.5
1/5/11 8:13	8	11	12.5	12.5	12.5	12.5	8.5
1/5/11 9:13	9	11	12.5	12.5	12.5	12.5	9
1/5/11 10:13	10	12	12.5	12.5	12.5	12.5	10
1/5/11 11:13	11	12.5	12.5	12.5	12.5	12.5	11
1/5/11 12:13	12	12.5	12.5	12.5	12.5	12.5	12
1/5/11 13:13	13	13	12.5	12.5	12.5	12.5	12.5
1/5/11 14:13	14	12.5	12.5	12.5	12.5	12.5	13
1/5/11 15:13	15	13	12.5	12.5	12.5	12.5	13.5
1/5/11 16:13	16	13	12.5	12.5	12.5	12.5	13
1/5/11 17:13	17	12.5	12.5	12	12.5	12.5	12.5
1/5/11 18:13	18	12.5	12.5	12	12.5	12.5	12
1/5/11 19:13	19	12.5	12.5	12	12.5	12.5	11.5
1/5/11 20:13	20	12.5	12.5	12	12.5	12.5	11

1/5/11 21:13	21	12.5	12.5	12	12.5	12.5	10.5
1/5/11 22:13	22	12.5	12.5	12	12.5	12.5	10
1/5/11 23:13	23	12.5	12.5	12	12.5	12.5	9.5
1/6/11 0:13	0	12.5	12.5	12	12.5	12.5	9
1/6/11 1:13	1	12.5	12.5	12	12.5	12.5	9
1/6/11 2:13	2	12.5	12.5	12	12.5	12.5	9
1/6/11 3:13	3	11	12.5	12	12.5	12.5	8.5
1/6/11 4:13	4	10.5	12.5	12	12.5	12.5	8.5
1/6/11 5:13	5	12	12.5	12	12.5	12.5	8
1/6/11 6:13	6	12	12.5	12	12.5	12.5	7.5
1/6/11 7:13	7	12	12.5	12	12.5	12.5	6.5
1/6/11 8:13	8	11.5	12.5	12	12	12.5	7
1/6/11 9:13	9	11.5	12.5	12	12	12.5	7.5
1/6/11 10:13	10	11.5	12.5	12	12	12.5	8.5
1/6/11 11:13	11	12	12.5	12	12	12.5	10
1/6/11 12:13	12	12.5	12.5	12	12	12.5	11.5
1/6/11 13:13	13	12.5	12.5	12	12	12.5	12.5
1/6/11 14:13	14	12.5	12.5	12	12	12.5	13
1/6/11 15:13	15	12.5	12.5	12	12	12.5	13
1/6/11 16:13	16	12.5	12.5	12	12	12.5	13
1/6/11 17:13	17	12.5	12.5	12	12	12.5	12.5
1/6/11 18:13	18	12.5	12.5	12	12	12.5	11.5
1/6/11 19:13	19	12.5	12.5	12	12	12.5	11
1/6/11 20:13	20	12	12.5	12	12	12.5	10.5
1/6/11 21:13	21	12	12.5	12	12.5	12.5	10.5
1/6/11 22:13	22	12.5	12.5	12	12.5	12.5	10
1/6/11 23:13	23	12	12.5	12	12.5	12.5	9.5
1/7/11 0:13	0	12.5	12.5	12	12	12.5	9.5
1/7/11 1:13	1	12.5	12	12	12	12.5	9
1/7/11 2:13	2	12.5	12	12	12	12.5	8.5
1/7/11 3:13	3	12	12	12	12	12	8
1/7/11 4:13	4	11.5	12	12	12	12	7.5
1/7/11 5:13	5	11	12	12	12	12	7
1/7/11 6:13	6	11.5	12	12	12	12	6.5
1/7/11 7:13	7	11.5	12	12	12	12	5.5
1/7/11 8:13	8	10.5	12	12	12	12	6.5
1/7/11 9:13	9	11	12	12	12	12	7.5
1/7/11 10:13	10	11.5	12	12	12	12	9
1/7/11 11:13	11	12	12	12	12	12	11

Gheryan Earth sheltered House thermal performance in winter

Date/Time	No1	No2	No3	No4	No5	No6	No8	N09
12/26/10 12:43	14.5	14.5	15.5	11.5	12.5	18	15.5	15
12/26/10 13:43	14.5	14.5	15.5	11.5	12.5	18	15.5	15
12/26/10 14:43	14.5	14.5	15.5	11	13	18	15.5	15
12/26/10 15:43	14.5	14.5	15	10	13	18	15.5	15
12/26/10 16:43	14.5	14.5	15	9.5	13	18	15.5	15
12/26/10 17:43	14.5	14.5	14.5	9	12.5	18	15.5	15
12/26/10 18:43	14.5	14.5	14.5	9	12.5	17.5	15.5	15
12/26/10 19:43	14.5	14.5	14.5	8.5	12	17.5	15.5	15
12/26/10 20:43	14.5	14.5	14.5	8.5	12	17.5	15	15
12/26/10 21:43	14.5	14.5	14	8.5	12	17.5	15	14.5
12/26/10 22:43	14.5	14.5	14	9	12	17.5	15	15
12/26/10 23:43	14.5	14.5	14.5	9	12	17.5	15	15
12/27/10 0:43	14.5	14.5	14.5	9.5	12	17.5	15	15
12/27/10 1:43	14.5	14.5	14.5	9.5	12	17.5	15	14.5
12/27/10 2:43	14.5	14.5	14.5	9.5	12	17.5	15	14.5
12/27/10 3:43	14	14.5	14	8.5	12	17.5	15	14.5
12/27/10 4:43	14	14.5	14	8	11.5	17.5	15	14.5
12/27/10 5:43	14	14.5	14	8.5	11.5	17.5	15	14.5
12/27/10 6:43	14	14.5	13.5	8.5	11.5	17.5	15	14.5
12/27/10 7:43	14	14.5	13.5	8.5	11.5	17.5	15	14.5
12/27/10 8:43	14	14.5	14	9	11.5	17.5	15	14.5
12/27/10 9:43	13.5	14	14	9.5	11.5	17	15	14
12/27/10 10:43	13.5	14	14	9.5	11.5	17	15	14
12/27/10 11:43	14	14	14	9.5	11.5	17.5	15	14.5
12/27/10 12:43	14	14	14.5	11.5	12	17.5	15	14.5
12/27/10 13:43	14	14	14.5	9	12.5	17.5	15	14.5

12/27/10 14:43	14	14	14.5	8.5	13	17.5	15	14.5
12/27/10 15:43	14	14	14.5	8	12.5	17.5	15	14
12/27/10 16:43	14	14	14.5	7.5	12	17.5	15	14
12/27/10 17:43	14	14	14.5	7.5	12	17.5	15	14
12/27/10 18:43	14	14	14.5	7.5	12	17.5	15	14
12/27/10 19:43	14	14	14	7	12	17.5	15	14
12/27/10 20:43	14	14	14	7.5	11.5	17.5	15	14
12/27/10 21:43	14	14	14.5	7.5	11.5	17.5	15	14
12/27/10 22:43	14	14	14	7.5	11.5	17.5	14.5	14
12/27/10 23:43	14	14	14	6.5	11.5	17.5	14.5	14
12/28/10 0:43	14	14	14	7	11.5	17.5	14.5	14
12/28/10 1:43	14	14	14	7	11.5	17.5	14.5	14
12/28/10 2:43	14	14	14	6.5	11	17.5	14.5	13.5
12/28/10 3:43	14	14	14	6.5	11	17.5	14.5	14
12/28/10 4:43	14	14	14	6.5	11	17.5	14.5	13.5
12/28/10 5:43	14	14	14	6.5	11	17.5	14.5	14
12/28/10 6:43	13.5	14	14	7	11	17.5	14.5	14
12/28/10 7:43	14	14	14	7.5	11.5	17	14.5	14
12/28/10 8:43	13.5	14	14	7.5	15	17.5	14.5	14
12/28/10 9:43	13.5	13.5	14	7.5	15.5	17.5	14.5	14
12/28/10 10:43	13.5	13.5	14	8.5	18.5	17.5	14.5	14
12/28/10 11:43	14	13.5	14	8	14	17.5	15	14
12/28/10 12:43	14	13.5	14.5	9	14	17.5	15.5	14
12/28/10 13:43	14.5	13.5	14.5	8.5	14.5	17.5	15	14
12/28/10 14:43	14	13.5	14.5	8.5	14	17.5	15	14
12/28/10 15:43	14	13.5	14.5	8	13.5	17.5	15	14
12/28/10 16:43	14	13.5	14.5	8	13	17.5	15	14
12/28/10 17:43	14	13.5	14.5	8	13	17	15	14
12/28/10 18:43	14	14	14.5	8	12.5	17	15	14
12/28/10 19:43	14	14	14.5	8	12.5	17	15	14
12/28/10 20:43	14	14	14.5	8	12.5	17	15	14
12/28/10 21:43	14	14	14.5	7.5	12	17	15	14
12/28/10 22:43	14	14	14.5	7.5	12	16.5	15	14
12/28/10 23:43	14	14	14.5	7.5	12	16.5	14.5	14
12/29/10 0:43	14	14	14.5	7	12	16.5	14.5	14
12/29/10 1:43	14	14	14.5	6.5	11.5	16.5	14.5	14
12/29/10 2:43	13.5	14	14	6.5	11.5	16.5	14.5	13.5
12/29/10 3:43	13.5	13.5	14	6	11.5	16	14.5	13.5
12/29/10 4:43	13.5	13.5	14	6	11.5	16	14.5	13.5
12/29/10 5:43	13.5	13.5	14	6	11	16	14.5	13.5
12/29/10 6:43	13.5	13.5	14	6.5	11	15.5	14.5	13.5
12/29/10 7:43	13.5	13.5	14	7	11	15.5	14.5	13.5
12/29/10 8:43	13.5	13.5	14	8	11.5	15.5	14.5	14
12/29/10 9:43	13.5	13.5	14.5	9	12	16	14.5	14
12/29/10 10:43	14	13.5	14.5	9.5	12	16	14.5	14
12/29/10 11:43	14	13.5	14.5	10	12	16.5	14.5	14
12/29/10 12:43	14	13.5	14.5	10.5	12	16.5	14.5	14
12/29/10 13:43	14	13.5	14.5	10.5	13	16.5	14.5	14
12/29/10 14:43	14	13.5	14.5	10	13	16.5	14.5	14
12/29/10 15:43	14	13.5	14.5	9	13	16.5	14.5	14
12/29/10 16:43	14	13.5	14.5	8	12.5	16	14.5	14
12/29/10 17:43	14	13.5	14.5	7.5	12	16	14.5	14
12/29/10 18:43	14	13.5	14	7.5	12	16	14.5	14
12/29/10 19:43	13.5	14	14.5	7.5	12	16	14.5	14
12/29/10 20:43	13.5	13.5	14.5	7	12	16	14.5	14
12/29/10 21:43	13.5	13.5	14	7	11.5	15.5	14.5	14
12/29/10 22:43	13.5	13.5	14	7	11.5	15.5	14.5	14
12/29/10 23:43	13.5	13.5	14	7	11.5	15.5	14.5	14
12/30/10 0:43	13.5	13.5	14	6.5	11.5	15.5	14.5	14
12/30/10 1:43	13.5	13.5	14	6.5	11.5	15.5	14	13.5
12/30/10 2:43	13.5	13.5	14	6	11	15.5	14	13.5
12/30/10 3:43	13.5	13.5	14	6	11	15.5	14	13.5
12/30/10 4:43	13.5	13.5	14	6	11	15.5	14	13.5
12/30/10 5:43	13.5	13.5	13.5	6	11	15.5	14	13.5
12/30/10 6:43	13.5	13.5	14	6.5	11	15	14	13.5
12/30/10 7:43	13.5	13.5	14	7.5	11	15	14	13.5
12/30/10 8:43	13.5	13.5	14	8.5	11	15.5	14	14

12/30/10 9:43	13.5	13.5	14.5	10	11.5	15.5	14	14
12/30/10 10:43	14	13.5	14.5	11.5	11.5	16	14.5	14
12/30/10 11:43	14	14	15	12.5	12	16	14.5	14
12/30/10 12:43	14	14	15	13	13	16	14.5	14
12/30/10 13:43	14	14	15	12.5	13	16	14.5	14.5
12/30/10 14:43	14	14	15	11.5	13	16	14.5	14.5
12/30/10 15:43	14	14	15	10.5	13	16	14.5	14.5
12/30/10 16:43	14	14	15	10	13	16	14.5	14.5
12/30/10 17:43	14	14	15	9.5	13	16	14.5	14.5
12/30/10 18:43	14	14	14.5	9	12.5	16	14.5	14.5
12/30/10 19:43	14	14	14.5	9	12.5	16	14.5	14.5
12/30/10 20:43	14	14	14.5	9	12.5	16	14.5	14.5
12/30/10 21:43	14	14	14.5	9	12	16	14.5	14.5
12/30/10 22:43	14	14	15	8.5	12	16	14.5	14.5
12/30/10 23:43	14	14	15	8.5	12	16	14.5	14.5
12/31/10 0:43	14	14	15	8.5	12	16	14.5	14.5
12/31/10 1:43	14	14	14.5	8	12	16	14.5	14.5
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12/31/10 4:43	14	14.5	15	8.5	12	16	14.5	14.5
12/31/10 5:43	14	14	15	8.5	11.5	16	14.5	14.5
12/31/10 6:43	14	14.5	15	9	11.5	16	14.5	14.5
12/31/10 7:43	14	14.5	15	9.5	12	16	14.5	14.5
12/31/10 8:43	14	14.5	15	11	12	16	14.5	14.5
12/31/10 9:43	14.5	14.5	15	11.5	12.5	16	14.5	14.5
12/31/10 10:43	14.5	14.5	15.5	13.5	13	16	15	14.5
12/31/10 11:43	14.5	14.5	15.5	14.5	13	16.5	15	15
12/31/10 12:43	14.5	14.5	15.5	15.5	13.5	16.5	15	15
12/31/10 13:43	15	15	15.5	14.5	13.5	16.5	15	15
12/31/10 14:43	15	15	15.5	14	13.5	16.5	15	15
12/31/10 15:43	15	15	15.5	13	13.5	16.5	15	15
12/31/10 16:43	14.5	15	15.5	12.5	13.5	16.5	15	15
12/31/10 17:43	14.5	15	15.5	11.5	13	16.5	15	15
12/31/10 18:43	14.5	15	15.5	11.5	13	16.5	15	15
12/31/10 19:43	14.5	15	15	11	13	16.5	15	15
12/31/10 20:43	14.5	15	15	10.5	13	16.5	15	15
12/31/10 21:43	14.5	15	15	10.5	13	16.5	15	15
12/31/10 22:43	14.5	15	15	10	12.5	16.5	15	15
12/31/10 23:43	14.5	15	14.5	9.5	12.5	16.5	15	15
1/1/11 0:43	14.5	15	14.5	9.5	12.5	16	15	14.5
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1/1/11 3:43	14	14.5	14.5	8	12	16	15	14.5
1/1/11 4:43	14	14.5	14	7.5	12	16	14.5	14
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1/1/11 7:43	14	14.5	14	8.5	12	16	14.5	14
1/1/11 8:43	14	14.5	14	9.5	12	16	14.5	14.5
1/1/11 9:43	14	14.5	14.5	10.5	12	16	14.5	14.5
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1/1/11 11:43	14	14.5	14.5	11.5	12.5	16.5	15	14.5
1/1/11 12:43	14.5	14.5	14.5	12	12.5	17	15	14.5
1/1/11 13:43	14.5	14.5	14.5	12	13	17	15	14.5
1/1/11 14:43	14.5	14.5	14.5	11.5	13	16.5	15	14.5
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1/1/11 16:43	14	14.5	14.5	9.5	13	16.5	15	14.5
1/1/11 17:43	14	14.5	14	9	12.5	16.5	15	14.5
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1/1/11 19:43	14	14.5	14	8.5	12	16	14.5	14.5
1/1/11 20:43	14	14.5	14	8.5	12	16	14.5	14.5
1/1/11 21:43	14	14.5	14	8	12	16	14.5	14.5
1/1/11 22:43	14	14.5	14	8	12	16	14.5	14.5
1/1/11 23:43	14	14.5	14	8	12	16	14.5	14
1/2/11 0:43	14	14	14	7.5	11.5	15.5	14.5	14
1/2/11 1:43	14	14	13.5	7.5	11.5	15.5	14.5	14
1/2/11 2:43	13.5	14	13.5	7.5	11.5	15.5	14.5	14
1/2/11 3:43	13.5	14	13.5	7	11	15.5	14.5	14

1/2/11 4:43	13.5	14	13.5	7	11	15.5	14.5	14
1/2/11 5:43	13.5	14	13.5	6.5	11	15.5	14	14
1/2/11 6:43	13.5	14	13.5	7	11	15	14	14
1/2/11 7:43	13.5	14	13.5	8	11	15	14	14
1/2/11 8:43	13.5	14	14	9	11.5	15.5	14	14
1/2/11 9:43	14	14	14	10	11.5	15.5	14.5	14
1/2/11 10:43	14	14	14	11	11.5	15.5	14.5	14
1/2/11 11:43	14	14	14	12	13.5	16	14.5	14.5
1/2/11 12:43	14	14	14.5	12.5	13.5	16	14.5	14.5
1/2/11 13:43	14	14	14.5	12.5	14	16	14.5	14.5
1/2/11 14:43	14	14	14.5	12	13.5	16	14.5	14.5
1/2/11 15:43	14	14.5	14.5	11	13.5	16	14.5	14.5
1/2/11 16:43	14	14.5	14	10	13	16	14.5	14.5
1/2/11 17:43	14	14.5	14	9.5	13	16	14.5	14
1/2/11 18:43	14	14.5	14.5	9.5	13	16	14.5	14
1/2/11 19:43	14	14.5	14	9.5	12.5	15.5	14.5	14
1/2/11 20:43	14	14.5	14.5	10	12.5	15.5	14.5	14
1/2/11 21:43	14	14.5	14.5	10	12.5	15.5	14.5	14.5
1/2/11 22:43	14	14.5	14.5	10	12.5	16	14.5	14.5
1/2/11 23:43	14	14.5	14.5	10	12.5	16	14.5	14.5
1/3/11 0:43	14	14.5	14.5	10	12.5	16	14.5	14.5
1/3/11 1:43	14	14.5	14.5	9.5	12.5	16	14.5	14
1/3/11 2:43	14	14.5	14.5	9	12	16	14.5	14
1/3/11 3:43	14	14	14.5	8.5	12	16	14.5	14
1/3/11 4:43	14	14	14	8.5	12	15.5	14.5	14
1/3/11 5:43	13.5	14	14	8	11.5	15.5	14.5	14
1/3/11 6:43	13.5	14	14	7.5	11.5	15.5	14.5	14
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1/3/11 11:43	14	14	14.5	11.5	13.5	16	14.5	14.5
1/3/11 12:43	14	14	14.5	10	13	16	14.5	14.5
1/3/11 13:43	14	14	14.5	10.5	13	16	14.5	14.5
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1/3/11 15:43	14	14	14.5	9.5	12.5	16	14.5	14.5
1/3/11 16:43	14	14	14	8.5	12.5	16	14.5	14
1/3/11 17:43	14	14	14	9	12	16	14.5	14
1/3/11 18:43	14	14	14	8.5	12	16	14.5	14
1/3/11 19:43	14	14	14	8.5	12	16	14.5	14
1/3/11 20:43	14	14	14	8.5	12	16	14.5	14
1/3/11 21:43	14	14	13.5	8.5	12	16	14.5	14
1/3/11 22:43	14	14	13.5	8	12	15.5	14.5	14
1/3/11 23:43	14	14	13.5	7.5	11.5	15.5	14.5	14
1/4/11 0:43	13.5	14	14	7.5	11.5	15.5	14.5	14
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1/4/11 4:43	13.5	14	13.5	7	11	15.5	14	14
1/4/11 5:43	13.5	14	13.5	7	11	15	14	13.5
1/4/11 6:43	13.5	13.5	13.5	6.5	11	15	14	13.5
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1/4/11 11:43	14	13.5	14	11	15.5	16	14.5	14
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1/4/11 14:43	14	14	14.5	11	14.5	16	14.5	14
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1/4/11 16:43	14	14	14	9	13.5	16	14.5	14
1/4/11 17:43	14	14	14	8.5	13	16	14.5	14
1/4/11 18:43	14	14	13.5	8	12.5	15.5	14.5	14
1/4/11 19:43	14	14	13.5	7.5	12.5	15.5	14.5	14
1/4/11 20:43	14	14	13.5	7.5	12	15.5	14.5	14
1/4/11 21:43	14	14	13.5	7.5	12	15.5	14	14
1/4/11 22:43	14	14	13.5	8	12	15.5	14	14

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1/5/11 0:43	14	14	13.5	7.5	11.5	15	14	14
1/5/11 1:43	13.5	14	13.5	7.5	11.5	15	14	14
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1/6/11 14:43	14	14	14.5	12	12.5	16	14.5	14
1/6/11 15:43	14	14	14.5	11	12.5	16	14.5	14
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1/6/11 17:43	14	14	14	9.5	12	15.5	14	14
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1/6/11 21:43	14	14	14	8.5	12	15.5	14	14
1/6/11 22:43	14	14	14	8.5	12	15.5	14	14
1/6/11 23:43	14	14	14	8.5	12	15.5	14	14
1/7/11 0:43	14	14	14	8.5	11.5	15.5	14	14
1/7/11 1:43	14	14	14	8.5	11.5	15.5	14	14
1/7/11 2:43	14	14	14	8	11.5	15.5	14	14
1/7/11 3:43	14	14	14	8	11.5	15.5	14	14
1/7/11 4:43	14	14	14	8	11.5	15.5	14	14
1/7/11 5:43	14	14	13.5	7.5	11.5	15.5	14	14
1/7/11 6:43	13.5	14	13.5	7.5	11	15	14	14
1/7/11 7:43	14	14	14	9	11.5	15	14	14
1/7/11 8:43	14	14	14	10	12	15.5	14	14
1/7/11 9:43	14	14	14.5	11.5	12	15.5	14	14
1/7/11 10:43	14	14	14.5	12.5	12.5	15.5	14.5	14.5
1/7/11 11:43	14.5	14.5	14.5	13.5	12.5	15.5	14.5	14.5
1/7/11 12:43	14.5	14.5	15	14	12.5	15.5	14.5	14.5
1/7/11 13:43	14.5	14.5	15	14.5	13	16	14.5	14.5
1/7/11 14:43	14.5	14.5	15	14	13	16	14.5	14.5
1/7/11 15:43	14.5	14.5	15	12.5	13	16	14.5	14.5
1/7/11 16:43	14.5	14.5	15	11.5	12.5	16	14.5	14.5
1/7/11 17:43	14.5	14.5	14.5	10.5	12.5	16	14.5	14.5

1/7/11 18:43	14.5	14.5	14.5	10.5	12.5	16	15	14.5
1/7/11 19:43	14.5	14.5	14.5	10.5	12.5	16	15	14.5
1/7/11 20:43	14.5	14.5	14.5	10	12.5	16	15	14.5
1/7/11 21:43	14.5	14.5	14.5	10	12.5	16	15	14.5
1/7/11 22:43	14.5	14.5	14.5	10	12.5	16	15	14.5
1/7/11 23:43	14.5	14.5	14.5	9.5	12.5	16	15	14.5
1/8/11 0:43	14	14.5	14.5	9.5	12	16	15	14.5
1/8/11 1:43	14	14.5	14.5	9.5	12	16	15	14.5
1/8/11 2:43	14.5	14.5	14.5	9.5	12	16	15	14.5
1/8/11 3:43	14	14.5	14.5	9.5	12	16	15	14.5
1/8/11 4:43	14	14.5	14.5	9	12	16	15	14.5
1/8/11 5:43	14	14.5	14.5	9	12	16	15	14.5
1/8/11 6:43	14	14.5	14	9	12	16	14.5	14.5
1/8/11 7:43	14.5	14.5	14.5	10	12	16	15	14.5
1/8/11 8:43	14.5	14.5	14.5	11.5	12.5	16	15	15
1/8/11 9:43	14.5	14.5	15	13	13	16	15	15
1/8/11 10:43	14.5	14.5	15	14	13	16	15	15
1/8/11 11:43	14.5	15	15	15	13.5	16	15	15
1/8/11 12:43	15	15	15.5	16	13.5	16	15	15
1/8/11 13:43	15	15	15.5	15.5	13.5	16.5	15	15
1/8/11 14:43	15	15	15.5	15	13.5	16.5	15	15
1/8/11 15:43	15	15	15.5	14	13.5	16.5	15	15
1/8/11 16:43	14.5	15	15	13	13.5	16.5	15	15
1/8/11 17:43	14.5	15	15	12	13	16.5	15	15
1/8/11 18:43	14.5	15	15	11.5	13	16	15	15
1/8/11 19:43	14.5	15	15	11.5	13	16	15	15
1/8/11 20:43	14.5	15	15	11	13	16	15	15
1/8/11 21:43	14.5	15	15	11.5	13	16	15	15
1/8/11 22:43	14.5	15	15	11.5	13	16	15	15
1/8/11 23:43	14.5	15	15	11.5	13	16	15	15
1/9/11 0:43	14.5	15	15	11	13	16	15	15
1/9/11 1:43	14.5	15	15	10.5	13	16	15	15
1/9/11 2:43	14.5	15	15	10.5	13	16	15	15
1/9/11 3:43	14.5	15	15	10.5	13	16	15	15
1/9/11 4:43	14.5	15	15	10.5	13	16	15	15
1/9/11 5:43	14.5	15	15	10.5	13	16	15	15
1/9/11 6:43	14.5	15	15	10.5	13	16	15	15
1/9/11 7:43	14.5	15	15	11.5	13	16	15	15
1/9/11 8:43	14.5	15	15	12.5	13	16	15	15
1/9/11 9:43	14.5	15	15	13	13	16.5	15	15
1/9/11 10:43	14.5	15	15.5	13.5	15	16.5	15	15
1/9/11 11:43	15	15	15.5	14	14.5	17	15	15
1/9/11 12:43	15	15	15.5	14.5	15	17	15	15
1/9/11 13:43	15	15.5	15.5	14.5	15.5	17	15	15
1/9/11 14:43	15	15.5	15.5	14	15.5	17	15	15
1/9/11 15:43	15	15.5	15.5	14	15	16.5	15	15
1/9/11 16:43	15	15.5	15.5	13	14.5	16.5	15	15
1/9/11 17:43	15	15.5	15.5	12.5	14.5	16.5	15	15
1/9/11 18:43	14.5	15.5	15.5	12.5	14.5	16.5	15	15
1/9/11 19:43	14.5	15.5	15.5	12	14	16.5	15	15
1/9/11 20:43	14.5	15	15	12	14	16.5	15	15
1/9/11 21:43	14.5	15	15	12	13.5	16.5	15	15
1/9/11 22:43	14.5	15	15	11.5	13.5	16.5	15	15
1/9/11 23:43	14.5	15	15	11	13.5	16.5	15	15
1/10/11 0:43	14.5	15	15	11.5	13.5	16.5	15	15
1/10/11 1:43	14.5	15	15	11	13	16	15	15
1/10/11 2:43	14.5	15	15	10.5	13	16	15	15
1/10/11 3:43	14.5	15	15	10	12.5	16	15	15
1/10/11 4:43	14.5	15	15	10	12.5	16	15	15
1/10/11 5:43	14.5	15	14.5	10	12.5	16	14.5	15
1/10/11 6:43	14.5	15	14.5	9.5	12.5	16	14.5	14.5
1/10/11 7:43	14.5	15	14.5	10.5	12.5	16	14.5	14.5
1/10/11 8:43	14.5	15	15	11.5	13	16	14.5	15
1/10/11 9:43	14.5	15	15	12	13	16.5	15	15
1/10/11 10:43	14.5	14.5	15	13	13.5	16.5	15	15
1/10/11 11:43	14.5	15	15.5	13	13.5	17	15	15
1/10/11 12:43	14.5	15	15.5	13.5	13.5	17	15	15

1/10/11 13:43	14.5	15	15.5	13.5	14	17	15	15
1/10/11 14:43	14.5	15	15.5	13.5	14	17	15	15
1/10/11 15:43	14.5	15	15.5	12.5	14	17	15	15
1/10/11 16:43	14.5	15	15.5	12	14	16.5	15	15
1/10/11 17:43	14.5	15	15	11.5	13.5	16.5	15	15
1/10/11 18:43	14.5	15	15	11.5	13.5	16.5	15	15
1/10/11 19:43	14.5	15	15	11	13.5	16.5	15	15
1/10/11 20:43	14.5	15	15	11	13	16.5	15	15
1/10/11 21:43	14.5	15	15	11	13	16.5	15	15
1/10/11 22:43	14.5	15	15	11	13	16	15	15
1/10/11 23:43	14.5	15	15	10.5	13	16	15	15
1/11/11 0:43	14.5	15	15	10.5	12.5	16	14.5	15
1/11/11 1:43	14.5	15	14.5	10	12.5	16	14.5	14.5
1/11/11 2:43	14.5	15	15	10.5	12.5	16	14.5	14.5
1/11/11 3:43	14.5	15	15	10	12.5	16	14.5	14.5
1/11/11 4:43	14	14.5	14.5	9.5	12.5	16	14.5	14.5
1/11/11 5:43	14	14.5	14.5	9.5	12.5	16	14.5	14.5
1/11/11 6:43	14	14.5	14	9.5	12	15.5	14.5	14.5
1/11/11 7:43	14	14.5	14.5	10	12.5	16	14.5	14.5
1/11/11 8:43	14	14.5	14.5	10.5	12.5	16	14.5	14.5
1/11/11 9:43	14	14.5	14.5	11	13	16	14.5	14.5
1/11/11 10:43	14.5	14.5	15	12	14	16.5	15	15
1/11/11 11:43	14.5	15	15	12	14.5	16.5	15	15
1/11/11 12:43	14.5	15	15	12.5	14	17	15	15
1/11/11 13:43	14.5	15	15	12.5	14.5	16.5	15	15
1/11/11 14:43	14.5	15	15	12	14.5	16.5	15	15
1/11/11 15:43	14.5	15	15	11.5	14	16.5	15	15
1/11/11 16:43	14.5	15	15	11	14	16.5	15	15
1/11/11 17:43	14.5	15	15	10.5	14	16.5	15	15
1/11/11 18:43	14.5	15	15	10	13.5	16.5	15	15
1/11/11 19:43	14.5	15	14.5	10	13.5	16.5	15	15
1/11/11 20:43	14.5	15	14.5	9.5	13	16.5	15	14.5
1/11/11 21:43	14.5	15	14.5	9.5	13	16.5	15	14.5
1/11/11 22:43	14.5	15	14.5	9.5	13	16	15	14.5
1/11/11 23:43	14.5	15	14.5	9.5	13	16	15	14.5
1/12/11 0:43	14.5	15	14.5	9.5	13	16	15	14.5
1/12/11 1:43	14.5	15	14.5	9.5	12.5	16	15	14.5
1/12/11 2:43	14.5	15	14.5	9	12.5	16	15	14.5
1/12/11 3:43	14.5	14.5	14.5	9	12.5	16	14.5	14.5
1/12/11 4:43	14.5	14.5	14.5	9	12.5	16	14.5	14.5
1/12/11 5:43	14	14.5	14	8.5	12.5	16	14.5	14.5
1/12/11 6:43	14.5	14.5	14	9	12.5	16	14.5	14.5
1/12/11 7:43	14	14.5	14.5	9	12.5	16	14.5	14.5
1/12/11 8:43	14	14.5	14.5	9.5	12.5	16	14.5	14.5
1/12/11 9:43	14	14.5	14.5	10	12.5	16	15	14.5
1/12/11 10:43	14.5	14.5	14.5	11	12.5	16.5	14.5	14.5
1/12/11 11:43	14.5	14.5	14.5	11	12.5	16.5	14.5	14.5
1/12/11 12:43	14.5	14	15	11.5	12.5	16.5	14.5	14.5
1/12/11 13:43	14.5	14	15	11.5	13	16.5	14.5	14.5
1/12/11 14:43	14.5	14	15	11.5	13	16.5	14.5	14.5
1/12/11 15:43	14.5	14	14.5	9	12.5	16.5	14.5	14.5
1/12/11 16:43	14	14	14.5	9	12.5	16.5	14.5	14
1/12/11 17:43	14	14	14.5	8.5	12	16	14.5	14
1/12/11 18:43	14	14	14.5	8	11.5	16	14.5	14
1/12/11 19:43	14	14	14	7.5	11.5	16	14.5	14
1/12/11 20:43	14	14	14	7.5	11	16	14.5	13.5
1/12/11 21:43	13.5	14	14	7.5	11	16	14.5	13.5
1/12/11 22:43	13.5	14	14	7	11	15.5	14	13.5
1/12/11 23:43	13.5	14	13.5	6.5	11	15.5	14	13.5
1/13/11 0:43	13.5	13.5	13.5	6	10.5	15.5	14	13.5
1/13/11 1:43	13.5	13.5	13.5	6.5	10.5	15.5	14	13.5
1/13/11 2:43	13.5	13.5	14	6.5	10.5	15.5	14	13.5
1/13/11 3:43	13.5	13.5	13.5	6.5	10.5	15.5	14	13.5
1/13/11 4:43	13.5	13.5	13.5	6.5	10.5	15.5	14	13.5
1/13/11 5:43	13.5	13.5	13.5	7	10.5	15.5	14	13.5
1/13/11 6:43	13.5	13.5	13.5	7	10.5	15.5	14	13.5
1/13/11 7:43	13.5	13.5	13.5	7	10.5	15.5	14	13.5

1/13/11 8:43	13.5	13.5	13.5	7.5	11	15.5	14	13.5
1/13/11 9:43	14	13.5	13.5	8	11	15.5	14	13.5
1/13/11 10:43	14	13.5	13.5	8	11	15.5	14	13.5
1/13/11 11:43	14	14	13.5	8.5	11	15.5	14	13.5
1/13/11 12:43	14	14	14	8.5	11.5	15.5	14	13.5
1/13/11 13:43	14	13.5	14	8.5	11.5	15.5	14	13.5
1/13/11 14:43	14	14	14	8.5	11.5	15.5	14	14
1/13/11 15:43	14	13.5	13.5	8	11	15.5	14	13.5
1/13/11 16:43	14	13.5	13.5	8	11	15.5	14	13.5
1/13/11 17:43	14	13.5	13.5	7.5	11	15.5	14	13.5
1/13/11 18:43	14	13.5	13.5	7.5	11	15.5	14	13.5
1/13/11 19:43	13.5	13.5	13.5	7.5	11	15	14	13.5
1/13/11 20:43	13.5	13.5	13.5	7.5	11	15	14	13.5
1/13/11 21:43	13.5	13.5	13.5	7.5	11	15	14	13.5
1/13/11 22:43	13.5	13.5	13.5	7.5	11	15	14	13.5
1/13/11 23:43	13.5	13.5	13	7	11	15	14	13.5
1/14/11 0:43	13.5	13.5	13	7	10.5	15	14	13.5
1/14/11 1:43	13.5	13.5	13	7	10.5	15	14	13.5
1/14/11 2:43	13.5	13.5	13	7	10.5	15	14	13.5
1/14/11 3:43	13.5	13.5	13	7	10.5	15	14	13.5
1/14/11 4:43	13.5	13.5	13	7	10.5	15	13.5	13.5
1/14/11 5:43	13.5	13.5	13	6.5	10.5	15	13.5	13.5
1/14/11 6:43	13.5	13.5	13	6.5	10.5	15	13.5	13
1/14/11 7:43	13.5	13.5	13	7	10.5	15	13.5	13.5
1/14/11 8:43	13.5	13.5	13	7.5	10.5	15	13.5	13.5
1/14/11 9:43	13.5	13.5	13.5	8	10.5	15	14	13.5
1/14/11 10:43	13.5	13.5	13.5	8	10.5	15	14	13.5
1/14/11 11:43	13.5	13.5	13.5	8	10.5	15	14	13.5
1/14/11 12:43	13.5	13.5	13.5	8	10.5	15	14	13.5
1/14/11 13:43	13.5	13.5	14	8.5	11	15	14	13.5
1/14/11 14:43	20	20.5	20	20	20	20	19.5	20

Tripoli Courtyard House thermal performance in summer

Date/Time	No1	No2	No3	No4	No5	No6
7/25/10 10:02	28.5	29	28	30.5	29	29
7/25/10 11:02	28.5	29	28	30.5	29	29
7/25/10 12:02	28.5	29	28	30.5	29	29
7/25/10 13:02	28.5	29	28	30.5	29	29
7/25/10 14:02	28.5	29	28	30.5	29	28.5
7/25/10 15:02	28.5	29	28	30.5	29	28.5
7/25/10 16:02	28.5	29	27.5	30	29	28.5
7/25/10 17:02	28.5	29	28	30	29	28.5
7/25/10 18:02	28.5	29	28	30	29	28.5
7/25/10 19:02	28.5	29	29	30	29	28.5
7/25/10 20:02	28.5	29	30.5	30	29	28.5
7/25/10 21:02	28.5	29	32.5	30	29	28.5
7/25/10 22:02	28.5	29	31.5	30	29	28.5
7/25/10 23:02	28.5	29	31.5	30	29.5	28.5
7/26/10 0:02	28.5	29.5	31.5	30	29	28.5
7/26/10 1:02	28.5	29.5	31	30.5	29	28.5
7/26/10 2:02	28.5	29.5	30	30.5	29	28.5
7/26/10 3:02	28.5	29	29.5	30.5	29	29
7/26/10 4:02	28.5	29	29	30.5	29	29
7/26/10 5:02	28.5	29	28.5	30.5	29	29
7/26/10 6:02	28	29	28	30.5	29	29
7/26/10 7:02	28	29	28	30.5	28.5	29
7/26/10 8:02	28	29	28	30.5	28.5	28.5
7/26/10 9:02	28.5	29	28	30.5	28.5	28.5
7/26/10 10:02	28.5	29	28	30.5	28.5	28.5
7/26/10 11:02	28.5	29	28	30.5	28.5	28.5
7/26/10 12:02	28.5	29	27.5	30.5	28.5	28.5
7/26/10 13:02	28.5	29	27.5	30.5	28.5	28.5
7/26/10 14:02	28.5	28.5	27.5	30	28.5	28.5

7/26/10 15:02	28.5	28.5	27.5	30	28.5	28
7/26/10 16:02	28.5	28.5	27.5	30	28.5	28
7/26/10 17:02	28.5	28.5	27.5	30	28.5	28
7/26/10 18:02	28	28.5	28	29.5	28.5	28
7/26/10 19:02	28	28.5	29	29.5	28.5	28
7/26/10 20:02	28	29	31	29.5	29	28
7/26/10 21:02	28.5	29	32	29.5	29	28
7/26/10 22:02	28.5	29	32.5	30	29	28.5
7/26/10 23:02	28.5	29	31.5	30	29	28.5
7/27/10 0:02	28.5	29	31	30	29	28
7/27/10 1:02	28.5	29	30.5	30.5	29	28
7/27/10 2:02	28.5	29	30	30.5	29	28.5
7/27/10 3:02	28.5	29	29.5	30.5	29.5	28.5
7/27/10 4:02	28.5	29	29	30.5	29.5	28.5
7/27/10 5:02	28.5	29	28.5	30.5	29	29
7/27/10 6:02	28	29	28.5	30.5	29.5	29
7/27/10 7:02	28	29	28	30.5	29	29
7/27/10 8:02	28	29	28	30.5	29	29
7/27/10 9:02	28	29	28	30.5	29	29
7/27/10 10:02	28	29	28	30	29	28.5
7/27/10 11:02	28	28.5	27.5	30	28.5	28.5
7/27/10 12:02	28	28.5	27.5	30	28.5	28.5
7/27/10 13:02	28	28.5	27.5	30	28.5	28.5
7/27/10 14:02	28	28.5	27	30	28.5	28
7/27/10 15:02	28	28.5	27	30	28.5	28
7/27/10 16:02	28	28.5	27	29.5	28	28
7/27/10 17:02	28	28.5	27.5	29.5	28.5	28
7/27/10 18:02	28	28.5	27.5	29.5	28.5	28
7/27/10 19:02	28	28.5	29	29.5	28.5	28
7/27/10 20:02	28	28.5	31	29.5	28.5	28
7/27/10 21:02	28	28.5	32.5	29.5	29	28
7/27/10 22:02	28	29	32.5	29.5	28.5	28
7/27/10 23:02	28	29	31.5	29.5	28.5	28
7/28/10 0:02	28.5	29	31	30	29	28
7/28/10 1:02	28.5	29	30.5	30	29	28.5
7/28/10 2:02	28.5	29	30	30	29	29
7/28/10 3:02	28.5	29	29.5	30	28.5	29
7/28/10 4:02	28	29	28.5	30	29	29
7/28/10 5:02	28	29	28	30	30	29
7/28/10 6:02	28	29	28	30	29.5	29
7/28/10 7:02	28	28.5	28	30	29	29
7/28/10 8:02	28	28.5	28	30	29	29
7/28/10 9:02	28	28.5	27.5	30	28.5	29
7/28/10 10:02	28	28.5	27.5	29.5	28.5	29
7/28/10 11:02	28	28.5	27	29.5	28.5	29
7/28/10 12:02	28	28.5	27	29.5	28.5	29
7/28/10 13:02	28	28.5	27	29.5	28	29
7/28/10 14:02	28	28.5	27	29.5	28	29
7/28/10 15:02	28	28.5	27	29.5	28	29
7/28/10 16:02	28	28.5	27	29	28	29
7/28/10 17:02	28	28.5	27	29	28	28.5
7/28/10 18:02	28	28.5	28	29	28.5	29
7/28/10 19:02	28	28.5	29	29	28.5	28.5
7/28/10 20:02	28	28.5	31.5	29	28.5	29
7/28/10 21:02	28	28.5	32	29	28.5	29
7/28/10 22:02	28	28.5	32	29.5	29	29
7/28/10 23:02	28	29	31.5	29.5	29	29
7/29/10 0:02	28	29	30.5	29.5	30.5	29
7/29/10 1:02	28	29	30	30	29.5	29
7/29/10 2:02	28	29	29.5	30	29	29

7/29/10 3:02	28	29	29	30	29	29
7/29/10 4:02	28	28.5	28.5	30	28.5	29.5
7/29/10 5:02	28	28.5	28	29.5	28.5	29.5
7/29/10 6:02	28	28.5	28	29.5	28.5	29
7/29/10 7:02	28	28.5	28	29.5	28.5	29
7/29/10 8:02	28	28.5	27.5	29.5	28.5	29
7/29/10 9:02	28	28.5	27.5	29.5	28.5	29.5
7/29/10 10:02	28	28.5	27	29.5	28	29.5
7/29/10 11:02	28	28.5	27	29.5	28	29.5
7/29/10 12:02	28	28.5	27	29.5	28	29
7/29/10 13:02	28	28.5	26.5	29	28	29
7/29/10 14:02	28	28.5	26.5	29	28	29
7/29/10 15:02	28	28.5	26.5	29	28	29
7/29/10 16:02	27.5	28	26.5	29	27.5	29
7/29/10 17:02	27.5	28	27	29	28	29
7/29/10 18:02	27.5	28.5	27.5	29	28	29
7/29/10 19:02	28	28.5	28.5	29	28	29
7/29/10 20:02	28	28.5	30.5	29	28.5	29
7/29/10 21:02	28	28.5	32	29	28.5	29
7/29/10 22:02	28	28.5	32	29	28.5	29
7/29/10 23:02	28	29	31.5	29.5	29.5	29
7/30/10 0:02	28	29	31	29.5	29	29
7/30/10 1:02	28	29	30	29.5	29	29.5
7/30/10 2:02	28	29	29.5	30	29	29.5
7/30/10 3:02	28	29	29	29.5	29	29.5
7/30/10 4:02	28	29	28.5	29.5	29	29.5
7/30/10 5:02	28	29	28.5	29.5	29	29
7/30/10 6:02	28	29	28	29.5	29	29.5
7/30/10 7:02	27.5	29	28	30	29	29.5
7/30/10 8:02	27.5	29	28	29.5	29	29.5
7/30/10 9:02	27.5	28.5	28	29.5	28.5	29.5
7/30/10 10:02	28	28.5	27.5	29.5	28.5	29
7/30/10 11:02	28	28.5	27.5	29.5	28.5	29
7/30/10 12:02	28	28.5	27.5	29.5	28.5	29
7/30/10 13:02	28	28.5	27	29.5	28	29
7/30/10 14:02	28	28.5	27	29	28	29
7/30/10 15:02	28	28.5	27	29	28	29
7/30/10 16:02	28	28.5	27	29	28	29
7/30/10 17:02	28	28.5	27.5	29	28	29
7/30/10 18:02	28	28.5	28	29	28	29
7/30/10 19:02	28	28.5	29	29	28.5	29
7/30/10 20:02	28	28.5	31	29	28.5	29
7/30/10 21:02	28	28.5	32.5	29	29	29
7/30/10 22:02	28	29	32.5	29.5	29	29
7/30/10 23:02	28	29	31.5	29.5	29	29
7/31/10 0:02	28	29	31	29.5	30	29
7/31/10 1:02	28	29	30.5	30	29.5	29.5
7/31/10 2:02	28	29	30	30	29	29.5
7/31/10 3:02	28	29	29.5	30	29	29.5
7/31/10 4:02	28	29	29	30	29	29.5
7/31/10 5:02	28	29	28.5	30	29	29.5
7/31/10 6:02	28	29	28.5	30	29	29.5
7/31/10 7:02	28	29	28	30	29	29.5
7/31/10 8:02	28	29	28	29.5	29	29.5
7/31/10 9:02	28	28.5	28	29.5	28.5	29.5
7/31/10 10:02	28	28.5	28	29.5	28.5	29.5
7/31/10 11:02	28	28.5	27.5	29.5	28.5	29.5
7/31/10 12:02	28	28.5	27.5	29.5	28.5	29.5
7/31/10 13:02	28	28.5	27.5	29.5	28.5	29.5
7/31/10 14:02	28	28.5	27.5	29.5	28.5	29.5

7/31/10 15:02	28	28.5	27.5	29.5	28.5	29.5
7/31/10 16:02	27.5	28.5	27.5	29	28.5	29
7/31/10 17:02	27.5	28.5	27.5	29	28.5	29
7/31/10 18:02	27.5	28.5	28	29	28.5	29
7/31/10 19:02	28	28.5	29	29	28.5	29
7/31/10 20:02	28	28.5	30.5	29	28.5	29
7/31/10 21:02	28	28.5	32	29.5	28.5	29
7/31/10 22:02	28	28.5	32	29.5	28.5	29
7/31/10 23:02	28	29	31	29.5	28.5	29
8/1/10 0:02	28	29	31	29.5	29	29
8/1/10 1:02	28	29	30	30	29	29
8/1/10 2:02	28	29	29.5	30	28.5	29
8/1/10 3:02	28	28.5	29	30	28.5	29
8/1/10 4:02	28	28.5	28.5	30	28.5	29
8/1/10 5:02	28	28.5	28.5	30	28.5	29
8/1/10 6:02	28	28.5	28.5	30	28.5	29
8/1/10 7:02	27.5	28.5	28	30	28.5	29
8/1/10 8:02	27.5	28.5	28	30	28.5	29
8/1/10 9:02	27.5	28.5	27.5	29.5	28.5	29.5
8/1/10 10:02	28	28.5	27.5	29.5	28.5	29.5
8/1/10 11:02	28	28.5	27.5	29.5	28.5	29.5
8/1/10 12:02	28	28.5	27	29.5	28.5	29.5
8/1/10 13:02	28	28.5	27	29.5	28	29.5
8/1/10 14:02	28	28.5	26.5	29	28	29.5
8/1/10 15:02	28	28	26.5	29	28	29
8/1/10 16:02	28	28	26	29	27.5	29
8/1/10 17:02	28	28	26.5	29	27.5	29
8/1/10 18:02	28	28	27	28.5	27.5	29
8/1/10 19:02	28	28	29	29	28	29
8/1/10 20:02	28	28	30.5	29	28.5	29
8/1/10 21:02	28	28.5	32	29	28.5	29
8/1/10 22:02	28	28.5	32.5	29	28.5	29
8/1/10 23:02	28	31	30.5	31	31	31
8/2/10 0:02	28	33.5	31.5	32.5	32	31.5
8/2/10 1:02	28	28.5	27	28	27.5	27.5
8/2/10 2:02	28	27	25.5	26.5	26.5	26
8/2/10 3:02	28	26	25	25.5	25.5	25.5
8/2/10 4:02	28	25.5	24.5	25	25	25
8/2/10 5:02	28	24.5	24	24.5	24.5	24.5
8/2/10 6:02	28	24.5	24	24.5	24.5	24.5
8/2/10 7:02	28	24.5	24	24	24	24.5
8/2/10 8:02	28	24.5	24	24	24	24.5
8/2/10 9:02	28	24.5	24	24	24.5	24.5

Ghadames Compact House thermal performance in summer

Date /Time	No1	No2	No3	No4	No5	No6
00:29:00	30.5	33.5	34	33	34	32.5
01:29:00	30.5	33.5	34	33	34	32.5
02:29:00	30	33.5	34	33	34	31.5
03:29:00	30	33.5	34	33	34	31
04:29:00	30	33.5	34	33	34	30
05:29:00	30	33.5	34	32.5	34	30
06:29:00	29.5	33	34	32.5	34	30
07:29:00	29.5	33	33.5	32.5	33.5	30
08:29:00	29.5	33	33.5	32.5	33.5	30.5
09:29:00	30	33	33.5	32.5	33.5	31
10:29:00	30	33.5	33.5	32.5	33.5	32
11:29:00	30.5	33.5	33.5	32.5	33.5	33
12:29:00	30.5	33.5	33.5	32.5	33.5	34
13:29:00	30.5	33.5	33.5	32.5	34	35
14:29:00	30.5	33.5	33.5	32.5	34	35.5

15:29:00	30.5	33.5	33.5	32.5	34	36
16:29:00	30.5	33.5	33.5	32.5	34	36
17:29:00	30.5	33	33.5	32.5	34	36
18:29:00	30.5	33	33.5	32.5	34	35.5
19:29:00	30.5	33	33.5	32.5	34	35
20:29:00	30.5	33	33.5	32.5	34	34.5
21:29:00	30.5	33	33.5	32.5	34	33.5
22:29:00	30.5	33	33.5	32.5	34	33
23:29:00	30.5	33	33.5	32.5	33.5	32.5
00:29:00	30	33	33.5	32.5	33.5	32
01:29:00	30	33	33.5	32.5	33.5	31.5
02:29:00	29.5	33	33.5	32.5	33.5	31
03:29:00	29.5	32.5	33.5	32.5	33.5	30.5
04:29:00	29	32.5	33.5	32.5	33.5	30.5
05:29:00	28.5	32.5	33.5	32	33.5	29.5
06:29:00	28.5	32.5	33.5	32	33.5	29.5
07:29:00	28.5	32.5	33.5	32	33.5	29.5
08:29:00	29	32.5	33.5	32	33.5	30
09:29:00	29.5	32.5	33.5	32	33.5	30.5
10:29:00	30	33	33.5	32	33.5	31.5
11:29:00	30	33	33.5	32	33.5	32
12:29:00	30	33	33	32	33.5	33
13:29:00	30	33	33	32	33.5	34
14:29:00	30.5	33	33	32	33.5	35
15:29:00	30	32.5	33	32	33.5	35.5
16:29:00	30.5	32.5	33	32	33.5	36
17:29:00	30.5	32.5	33	32	33.5	36
18:29:00	30	32.5	33	32	33.5	35.5
19:29:00	30	32.5	33	32	33.5	35
20:29:00	30	32.5	33	32	33.5	34
21:29:00	30	32.5	33	32	33.5	33.5
22:29:00	30	32.5	33	32	33	33
23:29:00	29.5	32.5	33	32	33	32.5
00:29:00	29.5	32	33	32	33	32
01:29:00	29	32	33	31.5	33	31.5
02:29:00	29	32	33	31.5	33	31
03:29:00	28.5	32	33	31.5	33	30.5
04:29:00	28.5	32	32.5	31.5	32.5	30
05:29:00	28	32	32.5	31.5	32.5	29.5
06:29:00	28	31.5	32.5	31.5	33	29.5
07:29:00	28	31.5	32.5	31.5	32.5	29.5
08:29:00	29	32	32.5	31.5	32.5	30.5
09:29:00	29.5	32	32.5	31.5	33	31.5
10:29:00	30	32.5	32.5	31.5	33	33
11:29:00	30	32.5	32.5	31.5	33	34.5
12:29:00	30	32.5	32.5	31.5	33	35.5
13:29:00	30	32.5	33	31.5	33.5	36.5
14:29:00	30	32.5	33	31.5	33	37
15:29:00	30	32.5	33	31.5	33.5	37.5
16:29:00	30	32.5	33	31.5	33.5	38
17:29:00	30	32.5	33	31.5	33.5	37.5
18:29:00	30	32.5	33	31.5	33.5	37
19:29:00	30	32.5	33	31.5	33.5	36.5
20:29:00	30	32.5	33	31.5	33.5	35.5
21:29:00	30	32.5	33	31.5	33.5	35
22:29:00	30	32.5	33	31.5	33	34.5
23:29:00	30	32.5	33	31.5	33	34
00:29:00	30	32.5	33	31.5	33	33.5
01:29:00	30	32.5	33	31.5	33	33
02:29:00	29.5	32.5	33	31.5	33	33
03:29:00	29.5	32	33	31.5	33	32.5
04:29:00	29	32	32.5	31.5	33	32
05:29:00	29	32	32.5	31.5	33	32
06:29:00	29	32	32.5	31.5	33	31.5
07:29:00	29	32	32.5	31.5	33	31.5
08:29:00	30	32	32.5	31.5	33	32
09:29:00	30	32	32.5	31.5	33	33

10:29:00	30.5	33	32.5	31.5	33	34
11:29:00	30.5	32.5	33	31.5	33.5	35.5
12:29:00	30.5	32.5	33	31.5	33.5	36.5
13:29:00	30	32.5	33	31.5	33.5	37
14:29:00	30	32.5	33	31.5	34	37.5
15:29:00	30	32.5	33	31.5	34.5	38.5
16:29:00	30	32.5	33	31.5	34.5	39
17:29:00	30	32.5	33	31.5	35	38.5
18:29:00	30	32.5	33	31.5	34.5	38
19:29:00	30	32.5	33	31.5	34	37.5
20:29:00	30	32.5	33	31.5	34	37
21:29:00	30	32.5	33	32	33.5	36
22:29:00	30	32.5	33	32	33.5	36
23:29:00	30	32.5	33	32	33.5	35
00:29:00	30	32.5	33	32	33.5	34.5
01:29:00	30	32.5	33	32	33.5	33.5
02:29:00	30	32.5	33	32	33.5	33
03:29:00	29.5	32.5	33	32	33	32.5
04:29:00	29.5	32.5	33	31.5	33	31.5
05:29:00	29	32.5	33	31.5	33	31.5
06:29:00	29	32	33	31.5	33	31
07:29:00	29	32	33	31.5	33	31
08:29:00	29.5	32	32.5	31.5	33	31.5
09:29:00	29.5	32.5	33	31.5	33	32
10:29:00	29.5	33	33	31.5	33	33
11:29:00	29.5	33	33	31.5	33	34
12:29:00	30	33	33	31.5	33.5	35
13:29:00	30	32.5	33	31.5	34.5	36.5
14:29:00	30	32.5	33	31.5	34.5	37.5
15:29:00	30	32.5	33	31.5	35	38
16:29:00	30	32.5	33	31.5	35	38
17:29:00	30	32.5	33	31.5	34.5	38
18:29:00	30	32.5	33	31.5	34.5	37
19:29:00	30	32.5	33	31.5	34	36
20:29:00	30	32.5	33	31.5	33.5	35
21:29:00	30	32.5	33	31.5	33.5	34.5
22:29:00	30	32.5	33	31.5	33.5	33.5
23:29:00	30	32.5	33	31.5	33.5	33
00:29:00	29.5	32.5	32.5	31.5	33	32.5
01:29:00	29.5	32	32.5	31.5	33	32
02:29:00	29.5	32	32.5	31.5	33	31.5
03:29:00	29	32	32.5	31.5	33	32
04:29:00	29	32	32.5	31.5	33	31.5
05:29:00	29	32	32.5	31.5	33	31
06:29:00	28.5	32	32.5	31.5	33	30
07:29:00	28.5	32	32.5	31.5	33	29.5
08:29:00	29	32	32.5	31.5	33	30
09:29:00	29.5	32	32.5	31.5	33	31.5
10:29:00	29.5	33	32.5	31.5	33	32.5
11:29:00	29.5	32.5	32.5	31.5	33	34
12:29:00	30	32.5	32.5	31.5	33	35
13:29:00	30	32.5	33	31.5	33.5	35.5
14:29:00	30	32.5	33	31.5	33.5	36
15:29:00	30	32.5	33	31.5	33.5	36.5
16:29:00	30	32.5	32.5	31.5	34	37
17:29:00	30	32.5	32.5	31.5	33.5	36.5
18:29:00	30	32.5	32.5	31.5	33.5	36
19:29:00	30	32.5	32.5	31.5	33.5	35.5
20:29:00	30	32.5	32.5	31.5	33.5	34.5
21:29:00	30	32.5	32.5	31.5	33	34
22:29:00	30	32.5	32.5	31.5	33	33.5
23:29:00	30	32	32.5	31.5	33	32.5
00:29:00	29.5	32	32.5	31.5	33	32
01:29:00	29.5	32	32.5	31.5	33	31.5
02:29:00	29	32	32.5	31.5	33	31
03:29:00	29	32	32.5	31.5	33	31
04:29:00	29	32	32.5	31.5	33	30.5

05:29:00	28.5	32	32.5	31.5	33	30
06:29:00	28.5	32	32.5	31.5	33	30
07:29:00	28.5	32	32.5	31.5	33	30
08:29:00	29	32	32.5	31	33	30
09:29:00	29	32	32.5	31	32.5	31
10:29:00	29.5	33	32.5	31	33	32
11:29:00	29.5	32.5	32.5	31	33	33
12:29:00	29.5	32.5	32.5	31	33	34
13:29:00	29.5	32.5	32.5	31	33.5	35
14:29:00	30	32.5	32.5	31	33.5	36
15:29:00	30	32.5	32.5	31	33.5	36.5
16:29:00	30	32.5	32.5	31	33.5	36.5
17:29:00	30	32.5	32.5	31	33.5	36.5
18:29:00	29.5	32.5	32.5	31	33.5	36
19:29:00	29.5	32.5	32.5	31	33	35
20:29:00	29.5	32.5	32.5	31	33	34.5
21:29:00	29.5	32.5	32.5	31.5	33	34
22:29:00	29.5	32	32.5	31	33	33.5
23:29:00	29.5	32	32.5	31.5	33	32.5

Gheryan Earth sheltered House thermal performance in summer

Date/ Time	No1	No2	No3	No4	No5	No6	No7	No8
7/2/10 0:13	23.5	25.5	20.5	25	27.5	24	20	21
7/3/10 0:13	23	25.5	20.5	24.5	27.5	24	20	21
7/4/10 0:13	23	25.5	20.5	23.5	27.5	24	20	21
7/5/10 0:13	23	25	20.5	24	27.5	24	20	21
7/6/10 0:13	22.5	25	20.5	23	27.5	24	20	21
7/7/10 0:13	22.5	25	20.5	22.5	27.5	23.5	20	21
7/8/10 0:13	22.5	25	20.5	23.5	27.5	23.5	20	21
7/9/10 0:13	22.5	25	20.5	26	27.5	23.5	20	21
7/10/10 0:13	23	25	20.5	37.5	27.5	23.5	20	21
7/11/10 0:13	23	25	20.5	40	27.5	23.5	20	21
7/12/10 0:13	23.5	25	20.5	40	27.5	23.5	20	21
7/13/10 0:13	23.5	25	20.5	39.5	27.5	23.5	20	21
7/14/10 0:13	24	25	20.5	37	27.5	24	20	21
7/15/10 0:13	24	25.5	20.5	34.5	27.5	24	20	21
7/16/10 0:13	24	25.5	20.5	34	27.5	24	20	21
7/17/10 0:13	24	25.5	20.5	33	27	24	20	21.5
7/18/10 0:13	24	25.5	20.5	29	26.5	24	20	21.5
7/19/10 0:13	23.5	25	20.5	28	26	24	20	21.5
7/20/10 0:13	23.5	25	20.5	25	26	24	20	21.5
7/21/10 0:13	23	25	20.5	24	26	24	20	21.5
7/22/10 0:13	23	25	20.5	23	26	24	20	21
7/23/10 0:13	23	24.5	20.5	22	25.5	23.5	20	21
7/24/10 0:13	22.5	24.5	20.5	22	25.5	23.5	20	21
7/25/10 0:13	22.5	24.5	20.5	22	25.5	23.5	20	21
7/26/10 0:13	22.5	24.5	20.5	22	25.5	23.5	20	21
7/26/10 1:13	22	24	20.5	21.5	25.5	23.5	20	21
7/26/10 2:13	22	24	20.5	21.5	26	23.5	20	21
7/26/10 3:13	22	24	20.5	21	26	23.5	20	21
7/26/10 4:13	22	24	20.5	21	26	23	20	21
7/26/10 5:13	22	24	20.5	21	26	23	20	21
7/26/10 6:13	22	24	20.5	21	26	23	20	21
7/26/10 7:13	22	24	20.5	22.5	26	23	20	21
7/26/10 8:13	22	24	20.5	37.5	26	23	20	21
7/26/10 9:13	22.5	24	20.5	40	26	23	20	21
7/26/10 10:13	22.5	24	20.5	40	26	23	20	21
7/26/10 11:13	23	24	20.5	39.5	26	23.5	20	21
7/26/10 12:13	23	24.5	20.5	37	26	23.5	20	21
7/26/10 13:13	23	24.5	20.5	34.5	26	23.5	20	21
7/26/10 14:13	23.5	24.5	20.5	31.5	26	23.5	20	21
7/26/10 15:13	23.5	24.5	20.5	31	25.5	23.5	20	21
7/26/10 16:13	23.5	24.5	20.5	29.5	25.5	23.5	20	21

7/26/10 17:13	23.5	24.5	20.5	28.5	25	23.5	20	21
7/26/10 18:13	23	24.5	20.5	26	25	23.5	20	21
7/26/10 19:13	23	24	20.5	24	25	23.5	20	21
7/26/10 20:13	22.5	24	20.5	23	25	23.5	20	21
7/26/10 21:13	22.5	24	20.5	23	25	23.5	20	21
7/26/10 22:13	22	24	20.5	22.5	25	23.5	20	21
7/26/10 23:13	22	24	20.5	21.5	25	23.5	20	21
7/27/10 0:13	22	24	20.5	21.5	25.5	23	20	21
7/27/10 1:13	22	23.5	20.5	22	26	23	20	21
7/27/10 2:13	22	23.5	20.5	21.5	26.5	23	20	21
7/27/10 3:13	22	23.5	20.5	21.5	27	23	20	21
7/27/10 4:13	22	23.5	20.5	21	27.5	23	20	21
7/27/10 5:13	21.5	23.5	20.5	21	28	23	20	21
7/27/10 6:13	21.5	23.5	20.5	21.5	28	22.5	20	21
7/27/10 7:13	21.5	23.5	20.5	23.5	27.5	22.5	20	21
7/27/10 8:13	21.5	23.5	20.5	37.5	27	22.5	20	21
7/27/10 9:13	22	23.5	20.5	40	27	22.5	20	21
7/27/10 10:13	22	24	20.5	40	26.5	22.5	20	21
7/27/10 11:13	22.5	24	20.5	39.5	26.5	23	20	21
7/27/10 12:13	23	24.5	20	37	26	23	20	21
7/27/10 13:13	23	24.5	20.5	34.5	26	23	20	21
7/27/10 14:13	23	24.5	20.5	32.5	26	23	20	21
7/27/10 15:13	23.5	25	20.5	31.5	26	23	20	21
7/27/10 16:13	23.5	25	20.5	30.5	26	23	20	21
7/27/10 17:13	23.5	25	20.5	29	25.5	23	20	21
7/27/10 18:13	23	24.5	20.5	26.5	25.5	23	20	21
7/27/10 19:13	23	24.5	20.5	24.5	25.5	23	20	21
7/27/10 20:13	22.5	24.5	20.5	23.5	25.5	23	20	21
7/27/10 21:13	22.5	24	20.5	22.5	25.5	23	20	21
7/27/10 22:13	22.5	24	20.5	21.5	25.5	23	20	21
7/27/10 23:13	22.5	24	20.5	21.5	25.5	23	20	21
7/28/10 0:13	22.5	24	20.5	21	25.5	23	20	21
7/28/10 1:13	22	24	20.5	21.5	26.5	23	20	21
7/28/10 2:13	22	24	20.5	21.5	27	23	20	21
7/28/10 3:13	22	24	20.5	21	27.5	23	20	21
7/28/10 4:13	22	24	20.5	21	29.5	23	20	21
7/28/10 5:13	22	23.5	20.5	21	29.5	23	20	21
7/28/10 6:13	21.5	23.5	20.5	21	29	22.5	20	21
7/28/10 7:13	21.5	23.5	20.5	22.5	28.5	22.5	20	21
7/28/10 8:13	22	23.5	20.5	37.5	28.5	22.5	20	21
7/28/10 9:13	22	23.5	20.5	40	28	22.5	20	21
7/28/10 10:13	22.5	24	20.5	40	28	22.5	20	21
7/28/10 11:13	22.5	24	20.5	39.5	27.5	22.5	20	20.5
7/28/10 12:13	23	24.5	20.5	37	27.5	23	20	21
7/28/10 13:13	23	24.5	20.5	34.5	27.5	23	20	21
7/28/10 14:13	23.5	25	20.5	32	27.5	23	20	21
7/28/10 15:13	23.5	25	20.5	31	27.5	23.5	20	21
7/28/10 16:13	23.5	25	20.5	31	27.5	23.5	20	21
7/28/10 17:13	23.5	25	20.5	29.5	27	23.5	20	21
7/28/10 18:13	23	25	20.5	28	27	23.5	20	21
7/28/10 19:13	23	24.5	20.5	26	27	23.5	20	21
7/28/10 20:13	23	24.5	20.5	24.5	27	23.5	20	21
7/28/10 21:13	23	24.5	20.5	23.5	27	23	20	21
7/28/10 22:13	22.5	24.5	20.5	23	27	23.5	20	21
7/28/10 23:13	22.5	24	20.5	23	27	23	20	21
7/29/10 0:13	22	24	20.5	22.5	27	23	20	21
7/29/10 1:13	22	24	20.5	22	27.5	23	20	21
7/29/10 2:13	22	24	20.5	22	27.5	23	20	21
7/29/10 3:13	22	24	20.5	21	28	23	20	21
7/29/10 4:13	22	23.5	20.5	21	28	23	20	21
7/29/10 5:13	22	23.5	20.5	21	28	23	20	21
7/29/10 6:13	21.5	23.5	20.5	21.5	28	23	20	21
7/29/10 7:13	22	23.5	20.5	24	28	23	20	21
7/29/10 8:13	22	23.5	20.5	37.5	28	23	20	21
7/29/10 9:13	22.5	24	20.5	40	28	23	20	21
7/29/10 10:13	22.5	24	20.5	40	28	23	20	21
7/29/10 11:13	23	24	20.5	39.5	27.5	23	20	21

7/29/10 12:13	23	24.5	20.5	37	27.5	23	20	21
7/29/10 13:13	23	25	20.5	34.5	27.5	23	20	21
7/29/10 14:13	23.5	25	20.5	32.5	27.5	23	20	21
7/29/10 15:13	23.5	25	20.5	32.5	27.5	23	20	21
7/29/10 16:13	23.5	25	20.5	31.5	27.5	23	20	21
7/29/10 17:13	23.5	25	20.5	30	27.5	23	20	21
7/29/10 18:13	23.5	25	20.5	28.5	27.5	23	20	21
7/29/10 19:13	23	25	20.5	27	27.5	23	20	21
7/29/10 20:13	23	24.5	20.5	25.5	27.5	23	20	21
7/29/10 21:13	22.5	24.5	20.5	25	27	23	20	21
7/29/10 22:13	22.5	24.5	20.5	24.5	27	23	20	21
7/29/10 23:13	22.5	24	20.5	24	27	23	20	21
7/30/10 0:13	22.5	24	20.5	23.5	27	23	20	21
7/30/10 1:13	22.5	24	20.5	23	27	23	20	21
7/30/10 2:13	22.5	24	20.5	22.5	27	23	20	21
7/30/10 3:13	22	24	20.5	22.5	27	23	20	21
7/30/10 4:13	22	24	20.5	23	27.5	23	20	21
7/30/10 5:13	22	24	20.5	22.5	27.5	23	20	21
7/30/10 6:13	22	24	20.5	23.5	27.5	23	20	21
7/30/10 7:13	22	24	20.5	25.5	28	23	20	21
7/30/10 8:13	22.5	24	20.5	37.5	28	23	20	21
7/30/10 9:13	22.5	24	20.5	40	28	23	20	21
7/30/10 10:13	23	24	20.5	40	28	23	20	21
7/30/10 11:13	23	24	20.5	39.5	28.5	23	20	21
7/30/10 12:13	23	24	20.5	37	28.5	23	20	21
7/30/10 13:13	23	24.5	20.5	34.5	29	23	20	21
7/30/10 14:13	23.5	25	20.5	34	29	23	20	21
7/30/10 15:13	23.5	25.5	20.5	33.5	29	23	20	21
7/30/10 16:13	23.5	25.5	20.5	33	28.5	23	20	21
7/30/10 17:13	24	25	20.5	31.5	28	23	20	21
7/30/10 18:13	24	25.5	20.5	29.5	28	23.5	20	21
7/30/10 19:13	23.5	25	20.5	28	27.5	23.5	20	21
7/30/10 20:13	23.5	25	20.5	26	27.5	23.5	20	21
7/30/10 21:13	23	25	20.5	26	27	23.5	20	21
7/30/10 22:13	23	24.5	20.5	25.5	27	23.5	20	21
7/30/10 23:13	23	24.5	20.5	24.5	27	23.5	20	21
7/31/10 0:13	23	24.5	20.5	24.5	26.5	23.5	20	21
7/31/10 1:13	23	24.5	20.5	24	27	23.5	20	21
7/31/10 2:13	22.5	24.5	20.5	24	27	23.5	20	21
7/31/10 3:13	22.5	24	20.5	23	27	23.5	20	21
7/31/10 4:13	22.5	24	20.5	22.5	27.5	23.5	20	21
7/31/10 5:13	22.5	24	20.5	22	29	23	20	21
7/31/10 6:13	22	24	20.5	22.5	28	23	20	21
7/31/10 7:13	22.5	24	20.5	25	27.5	23	20	21
7/31/10 8:13	22.5	24	20.5	35.5	27	23	20	21
7/31/10 9:13	23	24.5	20.5	35	28	23	20	21
7/31/10 10:13	35	32	20.5	30.5	28.5	35	34.5	31.5
7/31/10 11:13	27.5	28.5	20.5	28	28	28.5	28	27.5
7/31/10 12:13	27.5	28.5	20.5	28	27	28	28	27.5
7/31/10 13:13	27.5	28.5	20.5	28	26.5	28	28	27.5
7/31/10 14:13	27.5	28.5	20.5	28	26	28.5	28	28
7/31/10 15:13	27.5	28.5	20.5	28	26	28.5	28	28
7/31/10 16:13	27.5	28.5	20.5	28	25.5	28	28	27.5
7/31/10 17:13	27.5	28.5	20.5	28	25.5	28	28	27.5
7/31/10 18:13	27.5	28.5	20.5	28	25.5	28	28	27.5
7/31/10 19:13	27.5	28.5	32.5	29	25.5	28	28	28
7/31/10 20:13	31.5	32	32	32	25.5	32	32	31.5
7/31/10 21:13	30	30.5	31	30.5	25.5	31	31	30
7/31/10 22:13	28.5	29	29	29	25.5	29.5	29.5	28.5
7/31/10 23:13	28	28.5	28.5	28.5	25.5	28.5	28.5	28
8/1/10 0:13	28.5	29.5	28.5	29	25.5	28.5	28.5	28.5
8/1/10 1:13	29	29.5	29	29.5	25.5	29.5	29.5	29
8/1/10 2:13	27.5	28	28	28	25.5	28.5	28.5	27.5
8/1/10 3:13	26	26.5	26.5	26.5	26	27	26.5	26
8/1/10 4:13	24.5	25	25	25	26	25.5	25	24.5
8/1/10 5:13	24	24.5	24	24	26	24.5	24.5	24
8/1/10 6:13	23.5	24	23.5	24	26	24	24	23.5

8/1/10 7:13	24	25.5	24	24.5	26.5	24	24	24.5
8/1/10 8:13	26.5	28.5	26.5	27.5	27.5	26.5	26.5	27
8/1/10 9:13	31.5	34.5	31	33	28	30.5	31	32
8/1/10 10:13	33	34.5	34	34	28.5	35	34	33.5
8/1/10 11:13	35	35.5	35	35.5	28	35	35	35
8/1/10 12:13	40	41.5	39.5	41	27	38.5	39	40.5
8/1/10 13:13	37.5	38	37.5	37.5	27	39	38.5	37.5
8/1/10 14:13	43	45.5	42.5	45	27.5	41	42	44
8/1/10 15:13	50.5	53	51	52	27.5	50.5	50.5	52
8/1/10 16:13	51	52.5	52	51.5	27.5	53	52.5	51.5
8/1/10 17:13	45	46	46.5	45.5	27.5	47.5	47	45.5
8/1/10 18:13	38.5	39	39	38.5	27.5	41	40.5	38.5
8/1/10 19:13	33	33	33.5	33	27.5	34	34	33
8/1/10 20:13	32	32.5	32.5	32.5	27.5	32.5	32.5	32
8/1/10 21:13	30.5	31	31.5	31	27.5	31.5	31.5	30.5
8/1/10 22:13	29.5	30	30.5	30	27.5	30.5	30	29.5
8/1/10 23:13	28.5	29	29.5	29	27.5	29.5	29	28.5
8/2/10 0:13	27.5	28	28.5	27.5	27.5	28.5	28	27.5
8/2/10 1:13	25.5	26	26.5	26	28	26.5	26.5	25.5
8/2/10 2:13	24	24.5	25	24.5	28.5	25	24.5	24
8/2/10 3:13	23	23.5	23.5	23	27	23.5	23.5	23
8/2/10 4:13	22	22.5	22.5	22.5	26	22.5	22.5	22
8/2/10 5:13	21.5	22	22	22	29.5	22	22	21.5
8/2/10 6:13	21	21.5	21.5	21.5	32	21.5	21.5	21
8/2/10 7:13	22.5	23.5	23	23.5	30.5	22.5	22.5	22.5
8/2/10 8:13	26.5	27.5	26.5	27	29.5	25.5	26	26.5
8/2/10 9:13	31	33	31.5	33	28.5	31	31.5	32
8/2/10 10:13	36.5	37.5	36.5	37	26.5	36.5	36.5	36.5
8/2/10 11:13	39	40	39	40	25.5	39	39	39.5
8/2/10 12:13	40.5	42	40.5	41.5	25	40.5	40.5	41
8/2/10 13:13	41	42	41.5	42	24.5	42.5	42	41.5
8/2/10 14:13	43	44	43.5	43.5	24.5	44	43.5	43
8/2/10 15:13	40	40.5	40.5	40.5	24	41.5	41	40
8/2/10 16:13	37	37.5	37.5	37.5	24	38.5	38	37
8/2/10 17:13	35	36	35.5	35.5	24.5	36	35.5	35
8/2/10 18:13	35.5	36.5	35.5	36	25	36	36	35.5
8/2/10 19:13	35.5	36	36	36	25	36.5	36.5	35.5
8/2/10 20:13	33	33.5	33.5	33.5	24.5	34	34	33
8/2/10 21:13	32	32.5	32.5	32	24	33	32.5	32
8/2/10 22:13	30.5	31	31	30.5	24.5	31	31	30.5
8/2/10 23:13	30.5	30.5	31	30.5	25	30	30	30
8/3/10 0:13	28.5	29	29.5	29	25	30.5	30	28.5
8/3/10 1:13	27	27.5	27	27	25	28	27.5	27
8/3/10 2:13	25.5	26	26	26	25.5	26.5	26	25.5
8/3/10 3:13	24	25	24.5	24.5	26	25	25	24
8/3/10 4:13	23	24	23.5	23.5	26	24	24	23
8/3/10 5:13	22.5	23	22.5	23	26	23	23	22.5
8/3/10 6:13	22	22.5	22	22.5	25.5	22.5	22.5	22
8/3/10 7:13	23.5	24.5	24	24.5	25	23.5	23.5	24
8/3/10 8:13	26	27	26.5	27	25	26	26	26.5
8/3/10 9:13	33.5	35	33.5	35	24.5	31.5	32	35
8/3/10 10:13	37	38.5	38	38	24	37.5	37.5	38
8/3/10 11:13	36.5	37.5	37.5	37.5	23.5	37.5	37.5	37
8/3/10 12:13	37	38.5	37.5	38.5	23.5	37.5	37.5	38
8/3/10 13:13	40.5	42	41.5	41.5	23	41	41	41.5
8/3/10 14:13	42.5	43.5	42.5	43.5	23	42.5	42.5	43.5
8/3/10 15:13	44	45	44.5	45	23.5	44.5	44.5	44.5
8/3/10 16:13	35	35	44	33	23	44.5	44.5	33.5
8/3/10 17:13	26	27.5	25.5	27	23	26	26.5	27
8/3/10 18:13	29	30	29	30	23.5	30	29.5	29.5
8/3/10 19:13	29	30	29.5	29.5	23.5	30	29.5	29
8/3/10 20:13	29	29.5	29.5	29.5	23.5	29.5	29.5	29
8/3/10 21:13	29	29.5	29.5	29.5	23.5	29.5	29.5	29
8/3/10 22:13	29	29.5	29.5	29.5	23.5	29.5	29.5	29
8/3/10 23:13	29	29.5	29.5	29.5	24	29.5	29.5	29
8/4/10 0:13	28.5	29.5	29	29.5	25	29.5	29.5	29
8/4/10 1:13	29	30	29.5	29.5	26	29.5	29.5	29

8/4/10 2:13	29	30	29.5	29.5	26.5	29.5	29.5	29
8/4/10 3:13	29	30	29.5	29.5	27	30	29.5	29
8/4/10 4:13	29	30	29.5	29.5	27.5	30	29.5	29
8/4/10 5:13	29	30	29.5	29.5	28	30	29.5	29.5
8/4/10 6:13	29	30	29.5	29.5	28	30	29.5	29
8/4/10 7:13	29	30	29.5	29.5	28	30	29.5	29.5
8/4/10 8:13	29	30	29.5	29.5	28.5	30	29.5	29.5
8/4/10 9:13	22.5	24	24	23.5	28.5	28	24	22.5
8/4/10 10:13	23.5	24	24	24	28.5	23.5	24	23.5
8/4/10 11:13	23	23.5	23.5	23.5	28.5	24	23.5	23
8/4/10 12:13	23	23.5	23.5	23.5	29	23.5	23.5	23
8/4/10 13:13	23	23.5	23	23.5	29	23.5	23.5	23
8/4/10 14:13	22.5	23	22.5	23	29	23	23	22.5
8/4/10 15:13	22.5	23.5	23	23	28.5	23	23	22.5
8/4/10 16:13	22.5	23.5	23	23.5	28.5	23.5	23	23
8/4/10 17:13	23	23.5	23	23.5	28.5	23.5	23.5	23
8/4/10 18:13	23	24	23.5	23.5	28	23.5	23.5	23
8/4/10 19:13	23	24	23.5	23.5	27.5	23.5	23.5	23.5
8/4/10 20:13	23	24	23.5	23.5	27.5	23.5	23.5	23
8/4/10 21:13	23	24	23.5	23.5	27	23.5	23.5	23
8/4/10 22:13	23	23.5	23.5	23.5	27	23.5	23.5	23
8/4/10 23:13	23	23.5	23.5	23.5	27.5	23.5	23.5	23
8/5/10 0:13	23	23.5	23	23.5	27.5	23.5	23.5	23
8/5/10 1:13	23	23.5	23	23.5	27	23.5	23.5	23
8/5/10 2:13	23	23.5	23	23.5	27.5	23.5	23.5	23
8/5/10 3:13	23	23.5	23	23.5	28.5	23.5	23.5	23
8/5/10 4:13	23	23.5	23	23.5	28.5	23.5	23.5	23
8/5/10 5:13	22.5	23.5	23	23	27	23.5	23	23
8/5/10 6:13	22.5	23.5	23	23	25.5	23.5	23	23
8/5/10 7:13	22.5	23.5	23	23	24.5	23.5	23	22.5
8/5/10 8:13	22.5	23.5	23	23	24	23.5	23	23
8/5/10 9:13	22.5	23.5	23	23	24	23	23	22.5
8/5/10 10:13	22.5	23	22.5	23	23.5	23	23	22.5
8/5/10 11:13	22.5	23	22.5	23	23	23	23	22.5
8/5/10 12:13	22.5	23	22.5	23	23	23	23	22.5
8/5/10 13:13	22.5	23	22.5	23	23	23	23	22.5
8/5/10 14:13	22.5	23.5	23	23	23	23	23	22.5
8/5/10 15:13	22.5	23.5	23	23	23.5	23.5	23	23
8/5/10 16:13	23	23.5	23	23.5	23.5	23.5	23.5	23
8/5/10 17:13	23	23.5	23.5	23.5	23	23.5	23.5	23
8/5/10 18:13	23	24	23.5	23.5	23	23.5	23.5	23.5
8/5/10 19:13	23	24	23.5	23.5	23	24	23.5	23.5
8/5/10 20:13	23	24	23.5	23.5	23	24	23.5	23.5
8/5/10 21:13	23	24	23.5	23.5	23	24	23.5	23
8/5/10 22:13	23	23.5	23.5	23.5	23	23.5	23.5	23
8/5/10 23:13	23	23.5	23.5	23.5	23	23.5	23.5	23
8/6/10 0:13	23	23.5	23	23.5	23	23.5	23.5	23
8/6/10 1:13	23	23.5	23	23.5	23	23.5	23.5	23
8/6/10 2:13	23	23.5	23	23.5	23	23.5	23.5	23
8/6/10 3:13	22.5	23.5	23	23	23	23.5	23	23
8/6/10 4:13	22.5	23.5	23	23	22.5	23.5	23	23
8/6/10 5:13	22.5	23.5	23	23	23	23.5	23	23
8/6/10 6:13	22.5	23.5	23	23	23	23	23	22.5
8/6/10 7:13	22.5	23.5	23	23	23	23	23	22.5
8/6/10 8:13	22.5	23.5	23	23	23	23	23	22.5
8/6/10 9:13	22.5	23.5	23	23	23	23	23	22.5
8/6/10 10:13	22.5	23.5	23	23	23	23	23	22.5
8/6/10 11:13	22.5	23.5	23	23	23	23.5	23	23
8/6/10 12:13	22.5	23.5	23	23	23	23.5	23	23
8/6/10 13:13	22.5	23.5	23	23	23.5	23.5	23	23
8/6/10 14:13	22.5	23.5	23	23	23.5	23.5	23	23
8/6/10 15:13	22.5	23.5	23	23.5	23.5	23.5	23.5	23
8/6/10 16:13	23	23.5	23	23.5	23.5	23.5	23.5	23
8/6/10 17:13	23	23.5	23	23.5	23.5	23.5	23.5	23
8/6/10 18:13	23	24	23.5	23.5	23.5	23.5	23.5	23
8/6/10 19:13	23	24	23.5	23.5	23.5	24	23.5	23.5
8/6/10 20:13	23	24	23.5	23.5	23	24	23.5	23.5

8/6/10 21:13	23	24	23.5	23.5	23	23.5	23.5	23
8/6/10 22:13	23	23.5	23.5	23.5	23	23.5	23.5	23
8/6/10 23:13	23	23.5	23	23.5	23.5	23.5	23.5	23
8/7/10 0:13	23	23.5	23	23.5	24	23.5	23.5	23
8/7/10 1:13	22.5	23.5	23	23	24.5	23.5	23	23
8/7/10 2:13	22.5	23.5	23	23	24.5	23	23	22.5
8/7/10 3:13	22.5	23.5	23	23	25	23	23	22.5
8/7/10 4:13	22.5	23	23	23	24.5	23	23	22.5
8/7/10 5:13	22.5	23	22.5	23	24.5	23	23	22.5
8/7/10 6:13	22.5	23	22.5	23	24.5	23	23	22.5
8/7/10 7:13	22.5	23	22.5	23	24	23	23	22.5
8/7/10 8:13	22	23	22.5	22.5	24	23	22.5	22.5
8/7/10 9:13	22	23	22.5	22.5	23.5	23	22.5	22.5
8/7/10 10:13	22	23	22.5	22.5	23.5	23	22.5	22.5
8/7/10 11:13	22	23	22.5	22.5	23	23	22.5	22.5
8/7/10 12:13	22	23	22.5	22.5	23	23	22.5	22.5
8/7/10 13:13	22	23	22.5	22.5	23	23	23	22.5
8/7/10 14:13	22.5	23	22.5	23	23	23	22.5	22.5
8/7/10 15:13	22.5	23	22.5	23	23	23	23	22.5
8/7/10 16:13	22.5	23	22.5	23	23.5	23	23	22.5
8/7/10 17:13	22.5	23	23	23	24	23	23	22.5
8/7/10 18:13	22.5	23.5	23	23	24.5	23.5	23	22.5
8/7/10 19:13	22.5	23.5	23	23	24	23.5	23	23
8/7/10 20:13	22.5	23.5	23	23.5	23.5	23.5	23.5	23
8/7/10 21:13	22.5	23.5	23	23	23.5	23.5	23	23
8/7/10 22:13	22.5	23.5	23	23	23	23.5	23	22.5
8/7/10 23:13	22.5	23.5	23	23	23	23	23	22.5
8/8/10 0:13	22.5	23	23	23	23	23	23	22.5
8/8/10 1:13	22.5	23	23	23	23	23	23	22.5
8/8/10 2:13	22.5	23	22.5	23	23	23	23	22.5
8/8/10 3:13	22.5	23	22.5	23	23	23	23	22.5
8/8/10 4:13	22.5	23	22.5	23	23	23	23	22.5
8/8/10 5:13	22	23	22.5	22.5	23.5	23	22.5	22.5
8/8/10 6:13	22	23	22.5	22.5	23.5	23	22.5	22
8/8/10 7:13	22	23	22.5	22.5	23.5	22.5	22.5	22
8/8/10 8:13	22	22.5	22.5	22.5	23.5	22.5	22.5	22
8/8/10 9:13	22	22.5	22.5	22.5	23.5	22.5	22.5	22
8/8/10 10:13	30	28.5	37	27.5	23.5	26.5	32.5	28.5
8/8/10 11:13	30.5	30.5	29.5	31	23.5	24.5	28	30.5
8/8/10 12:13	36	36	35.5	36	23	34.5	35.5	35.5
8/8/10 13:13	25.5	26	27	25	23	34.5	30	25

Appendix B: Thermal comfort investigation data

Date: ____________________ City: ____________________
Day: ____________________ House: ____________________
Time: ____________________ Interview No: ____________________

Comfort has become increasingly costly in terms of energy use in buildings with the use of more sophisticated systems such as air conditioning. Buildings are in any case responsible for 40-50% of the overall energy budget. In the other hand there is no temperature at which everyone will feel comfortable, comfort is a psychological state defined by climate, culture and economics (Nicol, 2008). Therefore, this survey aims to investigate thermal comfort level in Libyan Traditional vernacular houses, Data to be obtained will be statistically analysed in order to set a criteria for Libyan Low energy Houses.

To answer the survey Please ring the number opposite the appropriate answer (like this 1)

Part1:Personal questions

Gender:	Male Female	**1** **2**
Age:	10-20 20-40 40-60 60-80	**1** **2** **3** **4**

Part2: Thermal comfort questions

1. How do you feel at the time?	• Cold • Cool • Slightly Cool • Neutral • Slightly Warm • Warm • Hot	**1** **2** **3** **4** **5** **6** **7**
2. you would prefer to be-	• Much warmer • A bit warmer • No change • A bit Cooler • Much cooler	**1** **2** **3** **4** **5**
3. How do you feel about humidity of the air at the present time?	• Very humid • Humid • Slightly humid • Neither humid nor dry • Slightly dry • Dry • Very dry	**1** **2** **3** **4** **5** **6** **7**
4. you would prefer the air to be-	• Much drier • A bit drier • No change • A bit more humid • Much more humid	**1** **2** **3** **4** **5**
5. How do you feel about the air movement?	• Very high • High • Slightly high • Neither high nor low • Slightly low	**1** **2** **3** **4** **5** **6**

		• Low • very low	7
6. you would prefer to have -		• Much less air movement • A bit less air movement • No change • A bit more air movement • Much more air movement	1 2 3 4 5 6
7. How would you rate your overall comfort in the area?		• Very comfortable • Moderately comfortable • Slightly comfortable • Slightly uncomfortable • Moderately uncomfortable • Very uncomfortable	1 2 3 4 5 6
Part 3: Activities &clothing questions			
1. What have you been doing in the last hour?		• Sitting - Passive • Sitting – Active • Standing – Relaxed • Standing – Working • Walking - Indoors • Walking – Outdoors	1 2 3 4 5 6
2. What type of clothing are you wearing at the present time?			
1. Foot wear:		• Shoes • Boots Sandals • Others	1 2 3
2. Socks		• Short socks • Long socks • Thin nylon tights • Thick nylon or woolen tights • Others	1 2 3 4 5
3. Outerwear			
	a) Short sleeved shirt or blouse	• Thin • Average • Thick	1 2 3
	b) Long sleeved shirt or blouse	• Thin • Average • Thick	1 2 3
	c) sweater	• Thin • Average • Thick	1 2 3
	d) Jacket	• Thin • Average • Thick	1 2 3
	e) Trousers	• Thin • Average • Thick	1 2 3
	f) Skirt	• Thin • Average • Thick	1 2 3

	g) Long sleeved dress	• Thin • Average • Thick	**1** **2** **3**
	h) Short sleeved dress	• Thin • Average • Thick	**1** **2** **3**
	i) Tie or scarf	• Yes • NO	**1** **2**
	j) Veil or Hat	• Yes • No	**1** **2**
	k) Traditional vest	• Thin • Average • Thick	**1** **2** **3**
	l) Women Traditional cloth (Re' da)*	• Thin • Average • Thick	**1** **2** **3**
	m) Men Traditional cloth (Ja' red)*	• Thin • Average • Thick	**1** **2** **3**
	* These should be over traditional trousers, traditional shirt and traditional vest		
3. Do You feel comfort in what are you wearing		Yes	No
4. You prefer to wear		• Less clothing • Slightly less clothing • About the same • More clothing • Don't know	**1** **2** **3** **4** **5**

Part 3: House location and description.

City:		
Dwelling type :		
Number of stories:		
Number of rooms:		
Number of occupants:		
Do you have Air conditioner units	Yes	No
Do you have Fans	Yes	No
Do you have radiators	Yes	No

Part 4: Weather reading:

	Indoor Temperature:	Outdoor Temperature:
Air Temperature.		
Global Temperature.		
Air movement.		
Humidity.		

دراسة لتحقيق الراحة الحرارية للانسان

تاريخ:		المدينة:	
اليوم:		المنزل:	
الوقت:		مقابلة رقم:	

الراحة الحرارية للانسان اصبحت مكلفة من حيث الطاقة المستنفذة في استخدام الاجهزة الكهربائية كالمكيفات في المنازل . وحيث أن المنازل مسوؤلة عن هدر 50% من ميزانية الكلية للطاقة.بالاضافة لايوجد درجة حرارة موحدة لراحة الانسان حيث ان الراحة الحرارية للانسان تعرف بانها حالة سيكيلوجية محددة بالمناخ.(نيكول 2008).

لذا هذه الدراسة تهدف لتحديد مستوى الراحة الحرارية للانسان في المنازل المحلية في ليبيا, وذلك لوضع محددات وخصائص لمنزل المستقبل ذو طاقة منخفضة.

للاجابة على الاسئلة الرجاء حدد الاجابتك برسم دائرة حول الاجابة كالاتي 1.

الجزء الاول: اسئلة شخصية.

الجنس:	ذكر أنثى	1 2
العمر:	10 20 20 40 40 60 60 80	1 2 3 4

لجزء الثاني:اسئلة لدراسة الراحة الحرارية.

1. كيف تشعر بالحرارة حاليا	باردجدا بارد بارد نوعا ما طبيعي حار نوعا ما حار حار جدا	1 2 3 4 5 6 7
2. كيف تفضل الجو ان يكون	اكثر دفئا ادفئ نوعا ما لا تغيير ابرد نوعا ما اكثر برودة	1 2 3 4 5
3. كيف تشعر بالرطوبة حاليا	رطوبة عالية رطب رطب نوعا ما لا رطب و لا جاف جاف نوعا ما جاف كثير الجفاف	1 2 3 4 5 6 7
4. هل تفضل الجو ان يكون	اكثر جفاف اكثرجفافا نوعا ما لا تغيير اكثر رطوبة نوعا ما اكثر رطوبة	1 2 3 4 5
5. كيف تشعر بحركة الهواء حاليا	عالي جدا عالي عالي نوعا ما طبيعي منخفض نوعا ما منخفضا منخفض جدا	1 2 3 4 5 6 7
6. هل تفضل ان يكون الهواء	اقل حركة للتيارالهواء نوعا ما اقل حركة للتيارالهواء لا تغيير نوعا ما اكثر حركة للتيارالهواء اكثر حركة للتيارالهواء	1 2 3 4 5
7. كيف تقييم راحتك في البيت	مرتاحا جدا مرتاحا نوعا ما مرتاحا	1 2 3

4 5 6	نوعا ما غيرمرتاحا غيرمرتاحا غير مرتاحا ابدا	

الجزءالثالث: الانشطة و الملابس.

1 2 3 4 5 6	جالس فقط(سلبيا) جالس ناشط واقف براحة واقف ناشط تتحرك داخل المنزل تتحرك خارج المنزل	1. ماذا تفعل في الوقت الحالي .
		2. ما نوع الملابس التي تلبسها
1 2 3	حذاء صندال شبشب	1. أحذية
		2. ملابس خارجية.

1 2 3	• رقيق • وسط • سميك	1. قميص ذو كم قصير
1 2 3	• رقيق • وسط • سميك	2. قميص ذو كم طويل
1 2 3	• رقيق • وسط • سميك	3. سترة
1 2 3	• رقيق • وسط • سميك	4. سترة (جاكيت)
1 2 3	• رقيق • وسط • سميك	5. بنطال
1 2 3	• رقيق • وسط • سميك	6. تنورة
1 2 3	• رقيق • وسط • سميك	7. ثوب ذو كم قصير
1 2 3	• رقيق • وسط • سميك	8. ثوب ذو كم طويل
1 2	• نعم • كلا	9. ربطة عنق او وشاح
1 2	• نعم • كلا	10. حجاب او قبعة
1 2 3	• رقيق • وسط • سميك	11. فرملة
1 2	• رقيق • وسط	12. رداء

	• سميك	3
13. جرد	• رقيق • وسط • سميك	1 2 3

3. هل انت مرتاح لما ترتديه	• نعم • كلا	
4. هل تفضل ان تلبس	• أقل ملابس • اقل ملابس نوعا ما • لا تغيير • اكثر ملابس نوعا ما • اكثر ملابس	1 2 3 4 5

الجزء الثالث:مواصفات المنزل و موقعه.

المدينة	
نوع المنزل	
عدد الطوابق	
عدد الغرف	
عدد السكان	
هل تستخدم مكيف هواء	• نعم • كلا
هل تستخدم مروحة كهربائية	• نعم • كلا
هل تستخدم مدفئة	• نعم • كلا

الجزء الرابع: قراءة الطقس

درجة الحرارة الداخلية	
درجة الحرارة الخارجية	
درجة حرارة الكرة	
الرطوبة	
حركة الهواء	

وشكرا للمساعدة

Tripoli - Thermal comfort Field Survey Data

Tripoli	To	Ti	Tg	Air.V	RH%	Clo	Met	Gen der	Age:	1.	2.	3.	4.	5.	6.	7	AMV
22-Dec	15	17	16.7	0.5	60	1.25	2	2	1	4	4	5	3	5	4	2	2
22-Dec	15.5	17.5	17.2	0.1	66	1.5	1.6	2	4	4	3	4	3	4	4	1	3
22-Dec	15.5	17.5	17.2	0.4	67	1.62	3	1	3	4	3	4	3	4	4	2	3
22-Dec	16	18	17.6	0.2	65	1.5	2	1	3	4	3	4	3	4	4	2	3
22-Dec	15.5	17.5	17.1	0.4	66	1.96	1.6	2	3	4	4	5	3	7	4	3	3
22-Dec	15.5	17.5	17.2	0.1	66	1.5	3	2	3	4	3	5	4	4	4	2	2
22-Dec	15.5	17.5	16.9	0.12	66	1.25	1.6	2	3	4	3	4	3	4	4	2	2
22-Dec	15.5	17.5	17.1	0.1	66	1.96	3	2	1	4	3	4	3	4	4	2	2
22-Dec	15.5	17.5	17.1	0.1	80	1.5	2	1	3	4	3	4	3	4	4	2	3
23-Dec	14.5	16.5	16.1	0.12	75	1.34	1.6	1	2	4	3	4	3	4	4	2	2
23-Dec	14.5	16.5	16.1	0.1	55	1.34	1.6	2	2	3	2	4	3	3	3	2	1
23-Dec	14.5	16.5	16.1	0.1	50	1.5	1	2	3	4	3	4	3	3	3	2	1
23-Dec	14.5	16.5	16.1	0.1	50	1.34	3	2	4	4	3	4	3	4	3	2	2
23-Dec	14.5	16.5	15.9	0.1	57	1.5	3	2	3	4	3	4	3	4	3	2	2
23-Dec	14.5	16.5	16.2	0.1	58	1.5	3	2	3	4	3	4	3	4	3	3	1
23-Dec	14.5	16.5	16.2	0.11	60	1.62	2	1	3	4	3	4	3	4	3	3	1
23-Dec	14.5	16.5	16.2	0.11	55	1.25	1	1	3	4	4	4	3	3	3	2	2
23-Dec	14.5	16.5	16.1	0.1	66	1.25	1	1	2	4	4	4	3	4	3	2	2
23-Dec	14.5	16.5	16.1	0.5	60	1.5	1	2	1	4	3	4	3	4	3	2	2
23-Dec	14.5	16.5	16.1	0.11	66	1.62	1	2	3	4	3	4	3	4	3	2	2
23-Dec	14.5	16.5	16.1	0.1	55	1.34	2	1	3	4	3	4	3	7	4	2	2
23-Dec	14.5	16.5	16.2	0.1	55	1.96	1.6	1	1	4	3	4	3	4	4	2	2
23-Dec	14.5	16.5	16.2	0.1	55	1.34	2	2	3	4	3	4	3	4	4	2	2
24-Dec	15	17	16.7	0.5	55	1.34	1	1	3	4	3	4	3	4	3	1	3
24-Dec	15	17	16.6	0.1	60	1.62	2	1	4	4	3	4	3	4	3	2	3
24-Dec	15	17	16.6	0.5	60	1.34	3	2	4	4	3	4	3	4	3	2	3
24-Dec	15	17	16.6	0.5	60	1.34	2	2	4	4	3	4	3	4	3	1	2
24-Dec	15	17	16.7	0.1	60	1.5	2	2	4	4	3	4	3	4	3	2	3
24-Dec	15	17	16.7	0.2	60	1.34	3	1	4	4	3	4	3	4	3	2	3
24-Dec	15	17	16.7	0.11	60	1.62	2	2	2	4	3	4	3	4	3	2	2
24-Dec	14.5	16.5	16.2	0.2	60	1.34	2	1	3	5	4	3	2	4	4	4	2
24-Dec	15	17	16.7	0.2	60	1.5	2	2	2	5	5	2	2	5	4	5	2
24-Dec	15.5	17.5	17.1	0.15	67	1.5	2	1	3	4	3	4	3	4	3	2	3
24-Dec	15.8	17.8	17.4	0.12	68	1.5	1	1	2	4	3	4	3	4	4	2	3
24-Dec	15.5	17.5	17.1	0.12	64	1.34	1	2	2	6	4	3	2	5	4	5	4
24-Dec	15.6	17.6	17.2	0.12	66	1.34	1	2	2	4	3	4	3	4	3	2	3
24-Dec	15.5	17.5	17.2	0.12	65	1.5	3	1	2	4	3	4	3	4	3	2	2
24-Dec	15.6	17.6	17.3	0.12	65	1.25	3	2	2	4	4	4	3	4	3	2	2
24-Dec	15.5	17.5	17.2	0.12	65	1.26	2	2	2	4	3	4	2	4	3	3	4
24-Dec	15.5	17.5	17.2	0.12	65	1.96	1	1	3	5	4	4	3	4	3	3	2
24-Dec	15.6	17.6	17.3	0.1	66	1.5	1	2	1	3	2	4	3	3	4	2	1
24-Dec	15.5	17.5	17.1	0.12	64	1.5	1	2	1	3	2	4	3	3	3	2	1
24-Dec	15.5	17.5	17.1	0.2	63	1.34	1	1	3	4	3	3	2	4	3	2	2
24-Dec	15	17	16.6	0.1	60	1.34	1	2	2	4	3	2	3	4	3	2	1
24-Dec	15	17	16.6	0.1	60	1.25	2	2	3	4	3	3	2	4	3	2	2
26-Dec	16.5	18.5	18.2	0.1	55	1.34	3	2	3	4	3	4	3	4	3	2	3
26-Dec	16.5	18.5	18.2	0.1	60	1.5	3	1	1	4	3	4	3	4	3	3	4
26-Dec	16.5	18.5	18.2	0.1	55	1.62	3	1	2	4	3	4	3	4	4	3	4
26-Dec	16.5	18.5	18.2	0.1	60	1.62	2	2	1	4	5	4	3	4	5	3	3
26-Dec	16.5	18.5	18.1	0.1	55	1.96	3	1	3	5	4	3	3	4	3	2	4
26-Dec	16.7	18.7	18.3	0.5	60	1.21	3	2	3	4	3	4	3	4	3	3	2
26-Dec	17	19	18.6	0.5	55	1.5	1	1	3	4	3	4	3	5	5	3	2
26-Dec	16.5	18.5	18.1	0.1	60	1.34	1	2	2	2	2	4	4	4	5	2	2
26-Dec	16.7	18.7	18.3	0.1	60	1.4	1	2	2	2	2	4	4	4	5	3	2
26-Dec	16.5	18.5	18.1	0.1	60	1.25	2	2	3	3	3	4	4	4	5	3	1
26-Dec	17.2	19.2	18.9	0.1	55	1.4	3	1	2	2	2	4	4	4	5	2	2
26-Dec	16.5	18.5	18.2	0.1	60	1.4	1	1	3	2	2	4	4	4	5	2	2
26-Dec	16.5	18.5	18.1	0.1	60	1.2	2	1	2	4	3	4	4	4	5	2	2
30-Dec	16.5	18.5	18.1	0.1	55	1.4	1.6	2	2	4	3	4	4	4	5	2	5
30-Dec	16.5	18.5	18.1	0.1	60	1.4	1.6	1	3	3	3	4	4	4	5	3	5
30-Dec	16.5	18.5	18.2	0.1	55	1.2	1.6	2	3	3	2	4	4	4	5	3	3
30-Dec	16.5	18.5	18.2	0.1	60	1.4	1.6	2	2	3	2	4	4	4	5	3	3

30-Dec	16.5	18.5	18.2	0.1	55	1.4	1.6	2	2	4	3	4	4	4	5	2	3
30-Dec	16.5	18.5	18.2	0.1	60	1.4	1.6	1	2	2	3	4	4	4	5	2	3
30-Dec	16.5	18.5	18.1	0.1	60	1.62	1.6	2	2	2	2	4	4	4	5	2	3
30-Dec	16.4	18.4	18	0.5	66	1.4	1.6	1	2	4	3	4	4	4	5	2	3
30-Dec	16.5	18.5	18.1	0.5	66	1.2	1.6	1	2	3	2	4	4	4	5	2	2
30-Dec	16.4	18.4	18	0.6	66	1.2	1.6	2	3	4	3	4	4	4	5	3	2
30-Dec	16.4	18.4	18	0.1	55	1.2	1.6	2	2	2	3	4	4	4	5	2	2
30-Dec	16.8	18.8	18.4	0.1	66	1.2	3	2	2	3	2	4	4	4	5	3	2
30-Dec	18	20	19.6	0.1	66	1.2	3	1	3	2	2	4	4	4	5	2	3
30-Dec	16.5	18.5	18.2	0.7	66	1.1	3	2	3	4	3	4	4	4	5	3	2
30-Dec	16.5	18.5	18.2	0.7	66	1.2	3	2	2	4	3	4	4	4	5	4	2
30-Dec	16.5	18.5	18.2	0.1	45	1.4	1.6	1	4	2	2	4	4	4	5	2	2
30-Dec	16.4	18.4	18.1	0.2	40	1.96	1.6	2	2	4	3	4	4	4	5	4	2
26-Jul	32.5	35	35.8	0.2	55	0.4	3	2	3	2	2	4	4	4	5	2	6
26-Jul	32.5	35	35.4	0.11	60	0.4	1.6	2	2	2	4	4	4	4	5	2	7
26-Jul	32.5	33	35.6	0.2	60	0.4	3	2	2	4	4	4	4	4	5	2	7
26-Jul	28	33.5	33	0.16	55	0.42	3	2	2	4	4	4	4	4	5	2	5
26-Jul	32.5	33.5	33	0.15	56	0.4	1.6	1	1	2	2	4	4	4	5	2	5
26-Jul	27	33.5	33	0.15	64	0.4	3	2	3	3	2	4	4	4	5	3	5
26-Jul	32.5	33.5	33	0.15	55	0.4	1.6	2	4	4	4	4	4	4	5	2	4
26-Jul	32.5	33.5	33.2	0.15	55	0.4	3	2	3	3	2	4	4	4	5	1	4
26-Jul	32.5	33.5	33	0.15	55	0.4	2	1	3	4	4	4	4	4	5	3	5
27-Jul	32.5	32.5	32	0.15	46	0.38	1.6	1	2	3	4	4	4	4	5	3	5
27-Jul	32.5	32.5	32	0.15	46	0.38	1.6	1	2	3	2	4	4	4	5	3	4
27-Jul	32.5	32.5	32.4	0.15	46	0.38	1	2	2	3	2	4	4	4	5	2	4
27-Jul	27	28	27.5	0.15	46	0.38	1	2	3	3	1	4	4	4	5	3	4
27-Jul	32.5	32.5	32	0.15	46	0.38	1	1	2	3	1	4	4	4	5	3	4
27-Jul	33	27	26.6	0.15	46	0.38	2	2	2	3	2	4	4	4	5	2	4
27-Jul	33	32.5	32	0.15	47	0.38	1.6	2	3	3	2	4	4	4	5	2	5
27-Jul	27	32.5	32	0.15	50	0.38	2	1	3	2	4	4	4	4	5	2	4
27-Jul	33	32.5	32	0.15	46.5	0.4	2	1	2	2	4	4	4	4	5	2	5
27-Jul	33	32.5	32	0.15	46.5	0.4	1	1	2	3	2	4	4	4	5	3	5
27-Jul	33	32.5	32	0.15	46.5	0.4	3	2	2	4	4	4	4	4	5	4	4
27-Jul	33	32.5	32	0.15	46.5	0.4	2	2	3	1	3	4	4	4	5	1	4
27-Jul	32.5	27	26.8	0.15	46.5	0.4	1.6	2	2	2	2	4	4	4	5	2	4
27-Jul	33	32.5	32	0.15	46.5	0.4	3	2	2	3	4	4	4	4	5	3	4
28-Jul	33.5	33	32.6	0.16	46	0.36	1	2	3	3	2	4	4	4	5	3	5
28-Jul	27	33	32.6	0.16	46	0.36	2	2	4	3	3	4	4	4	5	3	5
28-Jul	27	27	26.8	0.16	46.5	0.5	3	2	3	3	3	4	4	4	5	3	4
28-Jul	33.6	33	32.6	0.16	46.5	0.5	2	1	3	4	3	4	4	4	5	4	5
28-Jul	33.5	33	32.4	0.16	46.5	0.5	2	1	2	2	3	4	4	4	5	2	5
28-Jul	33.6	33	32.4	0.16	60	0.36	3	1	2	3	3	4	4	4	5	3	5
28-Jul	27	33	32.4	0.16	60	0.37	2	2	2	3	2	4	4	4	5	3	5
28-Jul	27	32.5	32	0.16	60	0.36	2	2	3	2	1	4	4	4	5	3	5
28-Jul	33.6	33	32.6	0.16	60	0.36	2	1	2	3	3	4	4	4	5	3	5
28-Jul	33.5	33.5	33.2	0.16	55	0.36	2	2	2	4	3	4	4	4	5	4	5
28-Jul	33.5	27	26.4	0.16	55	0.37	1	2	3	4	4	4	4	4	5	4	4
28-Jul	33	27	26.4	0.16	46	0.36	1	1	3	3	3	4	4	4	5	3	4
28-Jul	33	33.6	33	0.16	46	0.37	1	2	2	4	3	4	4	4	5	4	5
28-Jul	34.5	33.5	33	0.16	46	0.37	3	2	3	3	3	4	4	4	5	3	5
28-Jul	34.5	33.6	33	0.16	47	0.4	2	1	2	3	3	4	4	4	5	3	5
28-Jul	34.5	27	26.8	0.16	47	0.4	2	2	2	3	2	4	4	4	5	3	4
28-Jul	34.5	27	26.4	0.16	46	0.44	1	2	3	3	2	4	4	4	5	3	4
28-Jul	34.5	33.6	33.2	0.16	45	0.37	1	1	3	3	2	4	4	4	5	3	5
28-Jul	28	33.5	33	0.16	47	0.37	1	2	4	3	2	4	4	4	5	3	5
28-Jul	35	33.5	33	0.16	45.5	0.37	1	2	3	4	3	4	4	4	5	4	6
28-Jul	34.5	33	32.4	0.16	54.4	0.36	1	1	3	3	3	4	4	4	5	3	5
28-Jul	34.7	33	32.8	0.16	46	0.36	2	1	2	3	1	4	4	4	5	3	5
4-Aug	34.5	34.5	34	0.2	55.4	0.4	2	1	2	3	1	4	4	4	5	3	6
4-Aug	35.2	34.5	34	0.2	45	0.38	2	2	2	3	1	4	4	4	5	3	6
4-Aug	31	34.5	34	0.2	45	0.37	3	2	3	4	2	4	4	4	5	4	6
4-Aug	34.5	34.5	34	0.2	45	0.38	1	1	2	3	3	4	4	4	5	3	6
4-Aug	34.5	34.5	34	0.2	45	0.38	3	2	2	4	3	4	4	4	5	3	6
4-Aug	34.5	28	27.5	0.2	51.3	0.39	3	2	3	3	2	4	4	4	5	4	4
4-Aug	34.5	35	34.6	0.2	51.6	0.39	1	1	4	3	2	4	4	4	5	3	5
4-Aug	34.5	34.5	34	0.2	51.1	0.4	1	1	2	5	4	1	2	3	6	6	5
4-Aug	34.5	34.7	34.3	0.2	51.3	0.39	1	2	2	5	5	1	1	4	4	7	5

4-Aug	33	34.5	34.2	0.2	51.1	0.38	2	2	2	4	3	2	2	4	4	7	5
4-Aug	34.5	35.2	35	0.2	46.8	0.4	3	2	3	7	5	2	1	4	4	5	6
4-Aug	34.4	31	30.8	0.2	45	0.5	1	1	2	4	4	1	1	4	5	5	4
4-Aug	34.5	34.5	34	0.2	46.1	0.4	2	1	3	4	2	2	4	4	5	5	7
5-Aug	34.4	34.5	34	0.2	46.1	0.4	1.6	1	2	5	4	2	2	6	3	4	6
5-Aug	34.4	34.5	34	0.16	46.1	0.4	1.6	2	2	6	5	2	2	6	3	4	5
5-Aug	34.8	34.5	34	0.16	46.1	0.4	1.6	1	3	5	4	3	2	6	5	5	5
5-Aug	36	34.5	34	0.16	46.1	0.4	1.6	2	3	6	3	1	3	2	3	5	6
5-Aug	34.5	34.5	34	0.16	46.1	0.4	1.6	2	2	7	5	1	3	7	5	4	4
5-Aug	34.5	33	32.5	0.16	40	0.5	1.6	2	2	7	5	1	1	7	5	4	4
5-Aug	34.5	34.5	34	0.16	46.1	0.4	1.6	1	2	5	4	3	3	6	5	4	6
5-Aug	34.4	34.4	34	0.16	46	0.38	1.6	2	2	5	3	3	3	5	4	4	4
5-Aug	34.4	34.5	34	0.16	46.1	0.38	1.6	1	2	6	5	2	1	4	5	4	5
6-Aug	34.4	34.4	34	0.2	46	0.32	1.6	1	2	5	3	4	3	5	1	5	5
6-Aug	34.4	34.4	34	0.2	46	0.38	1.6	2	3	7	5	1	3	4	5	4	5
6-Aug	34.4	34.8	34.4	0.2	46.4	0.39	1.6	2	2	6	3	1	2	4	5	5	5
6-Aug	34.4	36	35.6	0.2	47.6	0.50	1.6	2	2	6	4	2	3	5	1	5	7
6-Aug	34.4	34.5	34	0.2	46.1	0.38	1.6	1	3	6	3	1	3	4	3	4	5
6-Aug	34.4	34.5	34	0.2	46.1	0.30	1.6	2	3	4	2	2	3	4	5	4	5
6-Aug	34.4	34.5	34	0.2	46.1	0.38	1.6	2	2	4	3	3	2	4	5	4	5
6-Aug	34.4	34.4	34	0.2	46	0.38	1.6	1	4	7	3	1	3	6	5	4	4
13-Apr	27	25.7	25.9	0.03	48.8	0.6	1.2	2	2	4	3	2	3	5	4	5	4
13-Apr	27	25.7	25.9	0.03	48.8	0.7	0.8	2	3	4	3	2	3	4	3	5	4
13-Apr	27	25.7	25.9	0.03	48.8	0.65	1.2	2	2	3	3	4	3	4	1	4	4
13-Apr	27	25.7	25.9	0.03	48.8	0.6	1.6	2	2	7	3	4	3	4	5	5	4
13-Apr	27	25.7	25.9	0.03	48.8	0.65	2	2	1	5	3	3	3	4	3	5	4
12-Apr	24	25	25	0.02	47.2	0.7	1.6	1	1	5	1	2	3	3	1	5	4
12-Apr	24	25	25	0.02	47.2	0.75	1.2	2	3	5	4	2	2	5	4	5	4
12-Apr	24	25	25	0.02	47.2	0.8	1.2	2	4	4	3	3	2	4	3	5	4
12-Apr	24	25	25	0.02	47.2	1	1.2	2	3	6	5	1	1	6	5	5	4
12-Apr	24	25	25	0.02	47.2	0.8	1.2	1	3	6	4	2	2	6	4	5	5
11-Apr	26	25.2	25	0.02	50	0.8	1.2	1	2	5	3	3	2	4	4	4	4
11-Apr	26	25.2	25	0.02	50	0.7	1.2	1	2	5	3	3	2	4	4	4	2
11-Apr	26	25.2	25	0.02	50	0.75	1.6	2	2	5	3	2	2	6	4	5	4
11-Apr	26	25.2	25	0.02	50	0.8	2	2	3	5	4	2	2	6	4	5	4
11-Apr	26	25.2	25	0.02	50	0.65	2	1	2	5	4	2	2	6	5	5	4
11-Apr	26	25.2	25	0.02	50	0.8	0.8	2	2	6	4	3	2	6	4	4	3
11-Apr	26	25.2	25	0.02	50	0.85	0.8	2	3	4	2	2	3	4	5	4	4
11-Apr	26	25.2	25	0.02	50	0.8	1.2	1	3	6	4	2	2	6	4	5	4
10-Apr	25	23.9	24.2	0.01	46.3	0.7	1.2	1	2	5	3	3	2	4	4	5	4
10-Apr	25	23.9	24.2	0.01	46.3	0.8	1	1	2	5	3	3	2	4	4	6	4
10-Apr	25	23.9	24.2	0.01	46.3	0.6	1	2	2	5	3	2	2	6	4	5	4
10-Apr	25	23.9	24.2	0.01	46.3	0.65	1.6	2	3	4	2	2	3	4	5	5	4
11-Apr	24.4	25.5	25.6	0.03	47	0.75	2	2	2	3	4	4	3	4	4	6	4
11-Apr	24.4	25.5	25.6	0.03	47	0.6	1	2	2	3	3	3	3	3	3	6	7
11-Apr	22.9	23.8	23	0.01	59.2	1	1	2	3	5	4	2	2	5	4	6	4
11-Apr	22.9	23.8	23	0.01	59.2	0.8	2	2	4	4	3	3	2	4	3	6	2
11-Apr	22.9	23.8	23	0.01	59.2	0.8	1.2	2	3	6	5	1	1	6	5	6	4
11-Apr	22.9	23.8	23	0.01	59.2	0.7	1.6	1	3	6	4	2	2	6	4	4	4
11-Apr	22.9	23.8	23	0.01	59.2	0.8	1.2	1	2	5	3	3	2	4	4	5	4
5-Apr	25.3	24.3	24	0.02	48	0.7	2	1	2	5	3	3	2	4	4	5	4
5-Apr	25.3	24.3	24	0.02	48	0.8	2	2	2	5	3	2	2	6	4	5	4
5-Apr	26	24.5	24	0.02	57.3	0.6	2	2	3	5	4	2	2	6	4	5	4
5-Apr	26	24.5	24	0.02	57.3	0.7	1.6	1	2	5	4	2	2	6	5	6	4
5-Apr	26	23.5	25	0.01	53.6	0.7	1.6	2	2	6	4	3	2	6	4	4	4
5-Apr	28.7	26.5	26.5	0.02	34.4	0.7	3	2	3	4	2	2	3	4	5	7	5
5-Apr	28	22.4	24	0.02	63.2	0.8	3	1	3	6	4	2	2	6	4	6	4
5-Apr	28	22.4	24	0.02	63.2	0.8	1.6	2	2	5	3	2	2	6	4	5	5
5-Apr	28	22.4	24	0.02	63.2	0.8	1.6	2	3	5	4	2	2	6	4	5	4
5-Apr	25	22.6	23	0.02	54.1	0.7	1.2	1	2	5	4	2	2	6	5	6	4
9-Apr	25	22.6	23	0.02	54.1	0.7	1.2	2	2	6	4	3	2	6	4	4	5
9-Apr	25	22.6	23	0.02	54.1	0.7	1.2	2	3	4	2	2	3	4	5	4	3
9-Apr	25	22.6	23	0.02	54.1	0.8	1.6	1	3	6	4	2	2	6	4	6	3
9-Apr	25	22.6	23	0.01	54.1	0.7	0.8	2	4	4	3	3	2	4	3	4	4
9-Apr	24	22.6	23	0.02	67	0.85	1.2	2	3	6	5	1	1	6	5	5	4
7-Apr	26	23.7	24	0.02	52	0.7	1.6	1	3	6	4	2	2	6	4	5	4
7-Apr	26	23.7	24	0.02	52	0.8	1.6	1	2	5	3	3	2	4	4	5	4

7-Apr	24	23.7	24	0.02	52	0.8	1.6	1	2	5	3	3	2	4	4	5	4
9-Apr	24	22.4	24	0.02	55	0.7	1.6	2	2	5	3	2	2	6	4	7	4
9-Apr	24	22.4	24	0.02	55	0.7	1.2	2	3	5	4	2	2	6	4	5	4
9-Apr	24	22.4	24	0.02	55	0.7	2	1	2	5	4	2	2	6	5	5	4
9-Apr	24	22.4	24	0.02	55	0.7	1.6	2	2	6	4	3	2	6	4	5	4
9-Apr	26.7	23.8	26	0.02	51.2	0.85	2	2	3	4	2	2	3	4	5	4	4

Ghadames Thermal comfort Field Survey Data

date	To	Ti	Tg	Air V	RH%	CLO	MET	Gender:	Age:	1.	2.	3.	4.	5.	6.	7	AMV
27-Dec	22.7	24.7	24.4	0.19	40	1.2	3	1	4	5	4	3	4	5	5	5	4
27-Dec	22.7	24.7	24.3	0.19	40	1	1.6	1	4	5	5	4	3	6	6	5	4
27-Dec	22.7	24.7	24.3	0.2	42	1.2	3	1	3	4	4	4	3	5	6	5	4
27-Dec	22.7	24.7	24.3	0.2	45	1.2	3	1	3	4	5	4	3	4	5	4	4
27-Dec	22.7	24.7	24.3	0.1	44	1	1.6	1	4	5	4	3	4	4	5	4	4
27-Dec	21	23	22.7	0.2	45	1.96	3	1	3	5	5	4	3	4	3	4	4
27-Dec	21	23	22.7	0.5	44	1.96	1.6	1	4	5	4	5	3	5	5	4	4
27-Dec	21	23	22.7	0.5	40	1.2	3	1	4	5	4	3	5	5	4	4	3
27-Dec	21	23	22.6	0.2	30	1	2	1	3	5	5	6	5	5	4	4	4
27-Dec	22.7	24.7	24.3	0.19	44	1.96	1.6	1	3	4	5	4	4	6	6	5	4
27-Dec	22.7	24.7	24.3	0.2	44	1.96	1.6	1	4	5	6	5	5	4	5	6	4
27-Dec	22.7	24.7	24.3	0.2	44	1	1	1	4	5	4	4	5	5	5	6	4
27-Dec	22.7	24.7	24.4	0.2	44	1.62	1	2	2	4	3	6	3	4	1	5	4
27-Dec	20	17	16.7	0.1	40	1	1	2	4	2	3	6	2	6	1	4	3
27-Dec	20	17	16.7	0.15	40	1	2	1	3	3	3	5	3	5	2	4	3
28-Dec	20	19	18.6	0.22	40	1	3	1	3	4	3	4	3	4	4	4	3
28-Dec	20	18	17.6	0.12	40	1	3	1	2	4	4	4	3	3	1	4	3
28-Dec	20	17	16.6	0.1	40	1	3	1	2	3	3	5	3	4	2	4	3
28-Dec	20	19	18.6	0.1	40	1	1.6	1	3	2	3	5	3	5	2	4	3
28-Dec	20	19	18.7	0.2	40	1.2	3	1	1	4	3	5	3	4	2	4	3
28-Dec	20	17	16.7	0.12	40	1	1.6	1	2	4	4	4	3	4	2	4	2
28-Dec	20	17	16.7	0.2	45	1	1.6	1	1	4	3	5	3	4	2	4	3
28-Dec	20	17	16.7	0.2	40	1.2	3	1	2	5	3	5	3	3	2	4	2
28-Dec	17	19	18.6	0.2	40	1	1.6	1	2	4	4	4	3	5	3	4	3
28-Dec	17	19	18.6	0.1	44	1	1.6	1	2	4	3	5	3	6	4	4	4
28-Dec	17	19	18.6	0.2	40	1	1.6	1	2	4	4	4	3	4	2	6	3
29-Dec	17	19	18.6	0.2	40	1.96	3	1	3	4	4	4	3	5	4	5	3
29-Dec	13	15	14.7	0.1	38	1	3	1	4	4	3	4	3	4	3	5	2
29-Dec	17	19	18.7	0.12	40	1.2	3	1	2	4	3	5	3	4	2	4	3
29-Dec	17	20	18.7	0.13	40	1.2	3	2	3	4	4	5	3	5	4	4	3
29-Dec	17	20	18.6	0.1	39	1	1.6	1	3	4	4	6	2	5	4	4	3
29-Dec	17	20	18.6	0.2	40	0.5	3	2	2	6	4	3	3	4	4	4	3
29-Dec	17	19	18.6	0.2	45	0.6	3	1	2	4	3	6	3	4	1	4	3
29-Dec	17	19	18.6	0.1	40	1	2	1	2	4	3	6	3	4	1	4	2
29-Dec	17	19	18.6	0.2	40	1	2	1	2	4	3	6	3	4	1	4	3
29-Dec	17	19	18.7	2	40	1	2	1	1	4	3	5	3	4	2	5	3
22-Jul	39.7	37	36.5	0.2	23.9	0.4	3	1	4	3	2	4	4	4	4	4	5
22-Jul	39.7	37	36.5	0.2	23.9	0.4	1.6	1	3	3	2	4	4	4	4	4	5
22-Jul	39.7	35.7	35.2	0.2	23.9	0.4	3	1	3	4	3	4	4	4	4	4	5
22-Jul	39.7	35.7	35.2	0.2	23.9	0.4	3	1	4	4	3	4	4	4	4	4	5
22-Jul	39.7	35.7	35.2	0.2	23.9	0.5	1.6	1	3	5	3	4	4	4	4	4	5
22-Jul	38	34	33.6	0.1	22.2	0.35	3	1	4	5	3	4	4	4	4	4	7
22-Jul	38	34	33.5	0.1	22.2	0.4	1.6	1	4	5	3	4	4	4	4	4	6
22-Jul	38	34	33.5	0.5	22.2	0.45	3	1	3	5	2	4	4	4	4	4	4
22-Jul	38	34	33.5	0.5	22.2	0.38	2	1	3	5	3	4	4	4	4	4	4
23-Jul	41	36	35.6	0.2	23.9	0.4	1.6	1	4	5	3	4	4	4	4	4	5
23-Jul	41	38	37	0.2	23.9	0.5	1.6	1	4	5	3	4	4	4	4	4	7
23-Jul	39.7	38	37	0.2	23.9	0.5	1	2	2	5	3	4	4	4	4	4	6
23-Jul	41	37	36.3	0.2	23.9	0.4	1	2	4	4	2	4	4	4	4	4	5
23-Jul	41	34	33.3	0.22	16.2	0.98	1	1	3	3	2	4	3	3	3	3	4
24-Jul	36	34	33.8	0.1	16.2	0.4	2	1	3	3	2	4	4	4	4	3	4
24-Jul	37	30	29	0.1	18.2	0.4	1.6	1	2	3	2	4	4	4	4	3	4
24-Jul	37	33	32	0.2	17.2	0.4	1.6	1	2	3	2	4	4	4	4	3	4
24-Jul	37	31	30	0.1	16.2	0.5	1.6	1	3	3	2	4	3	3	3	3	4

24-Jul	37	35	34	0.11	18.2	0.4	1.6	1	1	3	2	4	3	3	3	3	4
24-Jul	36	34	33.5	0.11	18.2	0.4	1.6	1	2	4	3	4	3	3	3	3	4
24-Jul	36	31	30	0.12	16.2	0.36	1.6	1	1	4	3	4	3	3	3	2	4
24-Jul	36	32	31	0.12	16.2	0.36	1.6	1	2	3	3	4	3	3	3	3	4
24-Jul	36	32	31	0.12	16.2	0.4	1.6	1	2	2	1	4	3	3	3	2	4
24-Jul	36	31	30	0.2	18.2	0.36	1.6	1	2	3	2	4	4	4	4	3	4
24-Jul	34	32	31.5	0.2	18.2	0.36	1.6	1	2	4	2	4	4	4	4	4	4
25-Jul	37	38	37.2	0.1	18.2	0.4	1.6	1	3	3	2	4	4	4	4	3	7
25-Jul	37	38	37.2	0.2	18.2	0.4	3	1	4	4	3	4	4	4	4	3	5
25-Jul	37	38	37.2	0.2	25	0.5	1.6	1	2	4	3	4	4	4	4	2	5
25-Jul	37	33	32	0.12	19	0.4	3	2	3	4	3	4	4	4	4	4	4
25-Jul	37	33	32	0.12	19	0.4	3	1	3	4	2	4	4	4	4	4	4
25-Jul	37	32	31	0.13	19	0.4	1.6	2	2	4	2	4	4	4	4	4	4
25-Jul	37	33	32	0.1	19	0.4	3	1	2	4	2	4	4	4	4	4	4
25-Jul	37	33	32	0.2	19	0.4	1.6	1	2	4	2	4	4	4	4	4	4
25-Jul	37	32	31.2	0.1	19	0.4	3	1	2	4	3	4	4	4	4	4	4
25-Jul	37	30	29.4	0.12	19	0.4	2	1	1	4	3	4	4	4	4	4	4
25-Jul	37	30	29.4	0.2	19	0.4	3	1	3	4	3	4	4	4	4	4	5
5-Apr	30	24	24	0.1	27	0.7	1	1	4	4	3	4	3	3	3	3	5
5-Apr	30	24	24	0.1	27	0.7	0.8	1	3	4	3	4	3	3	3	2	6
5-Apr	30	24	24	0.1	27	0.7	0.8	1	3	3	3	4	3	3	3	3	5
5-Apr	30	23.7	23	0.1	27	0.7	3	1	4	2	1	4	3	3	3	2	4
5-Apr	30	23.7	23	0.1	27	0.7	3	1	3	3	2	4	4	4	4	3	4
5-Apr	30	23.7	23	0.1	27	0.7	2	1	4	4	2	4	4	4	4	4	4
5-Apr	30	26	23	0.1	17.5	0.7	1	1	4	3	2	4	4	4	4	3	4
5-Apr	30	22	23	0.1	24	0.65	1	1	3	4	3	4	4	4	4	3	4
5-Apr	30	22	23	0.1	24	0.6	1	1	3	4	3	4	4	4	4	2	3
5-Apr	30	22	23	0.1	24	0.65	1	1	4	4	3	4	4	4	4	4	4
5-Apr	30	22	23	0.1	24	0.6	1.2	1	4	4	2	4	4	4	4	4	4
6-Apr	27	23.7	23	0.1	27	0.65	1	2	2	4	2	4	4	4	4	4	4
6-Apr	23	22	23	0.1	27	0.65	0.8	2	4	4	2	4	4	4	4	4	5
6-Apr	27	23.7	23	0.1	27	0.7	1	1	3	4	2	4	4	4	4	4	3
6-Apr	27	23.7	23	0.1	27	0.65	3	1	3	4	3	4	4	4	4	4	3
6-Apr	27	23.7	23	0.1	27	0.7	0.8	1	2	4	3	4	4	4	4	4	6
6-Apr	27	23.7	23	0.1	27	0.65	2	1	2	4	3	4	4	4	4	4	3
6-Apr	27	23.7	23	0.1	27	0.7	2	1	3	4	3	4	3	3	3	3	3
6-Apr	26	24	23	0.1	24	0.65	1	1	1	4	3	4	3	3	3	2	3
6-Apr	26	24	23	0.1	24	0.65	1	1	2	3	3	4	3	3	3	3	4
6-Apr	26	24	23	0.1	24	0.65	0.8	1	1	2	1	4	3	3	3	2	3
6-Apr	26	24	23	0.1	24	0.65	1	1	2	3	2	4	4	4	4	3	4
7-Apr	27	26	26	0.1	42	0.7	1	1	2	4	2	4	4	4	4	4	4
7-Apr	27	26	26	0.1	42	0.65	0.8	1	2	3	2	4	4	4	4	3	4
7-Apr	27	26	26	0.1	42	0.8	3	1	2	4	3	4	4	4	4	3	4
7-Apr	26.5	25	25	0.1	19	0.65	1	1	3	4	3	4	4	4	4	2	4
7-Apr	26.5	25	25	0.1	19	0.65	1	1	4	4	3	4	4	4	4	4	3
7-Apr	26.6	24	24.5	0.1	20	0.7	2	1	2	4	2	4	4	4	4	4	3
7-Apr	26.6	24	24.5	0.1	20	0.65	0.8	2	3	4	2	4	4	4	4	4	4
7-Apr	26.6	24	24.5	0.1	20	0.65	0.8	1	3	4	2	4	4	4	4	4	4
10-May	33	27	27	0.1	40	0.7	2	2	2	4	2	4	4	4	4	4	4
10-May	33	27	27	0.1	40	0.7	2	1	2	4	3	4	4	4	4	4	4
10-May	33	27	27	0.1	40	0.7	2	1	2	4	3	4	4	4	4	4	7
10-May	30	25	25	0.1	35	1	1	1	2	4	3	4	4	4	4	4	4
10-May	30	25	25	0.1	35	1	2	2	3	4	2	4	4	4	4	4	5
10-May	30	25	25	0.1	35	1	2	1	3	4	2	4	4	4	4	4	4
10-May	28	22	25	0.1	40	0.8	1	2	2	4	2	4	4	4	4	4	3
10-May	28	24	25	0.1	40	0.7	1	1	2	4	3	4	4	4	4	4	4
10-May	28	26	25	0.1	40	0.8	1	1	2	4	3	4	4	4	4	4	4
10-May	28	26	25	0.1	40	0.8	2	1	2	4	3	4	4	4	4	4	4

Gheryan Thermal comfort Field Survey Data

date	To	Ti	Tg	Air V	R H %	CLO	ME T	Ge nd er:	Age :	1.	2.	3.	4.	5.	6.	7	AMV
31-Dec	12	14	13.7	0.15	66	1.2	1.6	1	2	2	2	4	4	4	4	4	4
31-Dec	12	14	13.7	0.15	65	1.2	2	1	3	3	2	4	4	4	4	4	4

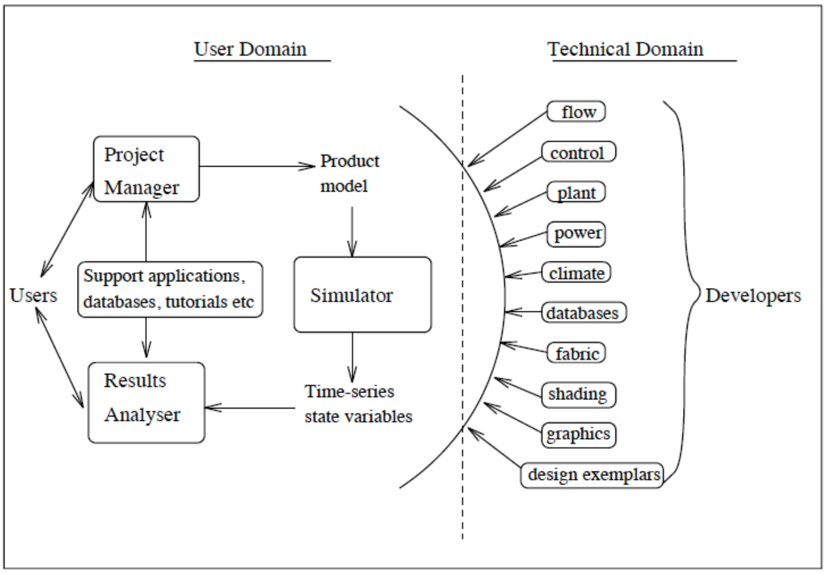
31-Dec	7.6	9.6	9.3	0.15	66	1.25	2	1	3	1	2	4	4	4	4	4	4
31-Dec	13.8	15.8	15.5	0.15	66	1.25	1.6	1	3	3	2	4	4	4	4	4	4
31-Dec	10	12	11.6	0.15	67	1.6	2	2	3	2	2	4	4	4	4	4	4
31-Dec	9.3	11.3	10.9	0.15	68	1.62	2	2	4	2	2	4	4	4	4	4	4
31-Dec	16	18	17.6	0.15	65	1.2	3	1	3	3	2	4	4	4	4	4	4
31-Dec	13	15	14.6	0.15	69	1.2	2	1	3	2	2	4	4	4	4	4	4
31-Dec	14	16	15.6	0.15	70	1.2	3	1	3	3	3	4	4	4	4	4	4
31-Dec	13.6	15.6	15.2	0.15	80	1.4	3	1	3	2	3	4	4	4	4	4	4
31-Dec	13.6	15.6	15.3	0.15	70	1.4	1	1	3	3	3	4	4	4	4	4	4
31-Dec	12	14	13.7	0.15	79	1	3	1	3	2	2	4	4	4	4	4	4
31-Dec	13.6	15.6	15.3	0.15	77	1	3	1	3	3	2	4	4	4	4	4	4
31-Dec	7.6	9.6	9.3	0.15	66	1.3	2	1	3	2	2	4	4	4	4	4	4
1-Jan	8	10	9.7	0.5	76	1.3	1.6	1	2	2	2	4	4	4	4	4	4
1-Jan	13.6	15.6	15.2	0.5	77	1.96	3	1	3	4	3	4	4	4	4	4	4
1-Jan	13.6	15.6	15.2	0.5	66	1.96	3	1	3	4	3	4	4	4	4	4	4
1-Jan	13.6	15.6	15.2	0.5	63	1.96	3	1	3	2	2	4	4	4	4	4	4
1-Jan	13.6	15.6	15.2	0.5	55	1.2	3	1	2	3	3	4	4	4	4	4	4
1-Jan	13.6	15.6	15.2	0.5	54	1.4	1.6	1	3	3	3	4	4	4	4	4	4
1-Jan	14	16	15.7	0.5	55	1.62	3	2	3	3	3	4	4	4	4	4	4
1-Jan	16.2	18.2	17.9	0.5	55	1.4	3	2	3	3	3	4	4	4	4	4	4
1-Jan	14	16	15.7	0.5	55	1.2	1.6	1	1	3	3	4	4	4	4	4	4
1-Jan	13.8	15.8	15.5	0.5	56	1.4	3	1	2	3	3	4	4	4	4	4	4
1-Jan	9.3	11.3	11	0.5	58	1.4	1.6	2	2	2	2	4	4	4	4	4	4
1-Jan	7.6	9.6	9.2	0.5	60	1.4	3	1	3	1	2	4	4	4	4	4	4
1-Jan	13.6	15.6	15.2	0.5	60	1.62	3	2	3	3	3	4	4	4	4	4	4
1-Jan	13.6	15.6	15.2	0.5	60	1.4	3	2	2	2	2	4	4	4	4	4	4
4-Jan	16.2	18.2	17.8	0.5	66	1.4	3	2	2	3	3	4	4	4	4	4	4
4-Jan	16.2	18.2	17.8	0.5	66	1.4	3	1	3	1	2	4	4	4	4	4	4
4-Jan	11.1	13.1	12.7	0.5	66	1.2	3	1	2	2	3	4	4	4	4	4	4
4-Jan	13.6	15.6	15.3	0.5	67	1.2	1	1	2	2	2	4	4	4	4	4	4
4-Jan	13.6	15.6	15.3	0.5	65	1.2	3	2	3	2	2	4	4	4	4	4	4
4-Jan	11.1	13.1	12.8	0.5	64	1.4	1.6	2	2	2	3	4	4	4	4	4	4
4-Jan	11.1	13.1	12.8	0.5	72	1.4	2	1	3	2	3	4	4	4	4	4	4
4-Jan	11.1	13.1	12.8	0.5	67	1.4	2	1	3	2	3	4	4	4	4	4	4
4-Jan	13.8	15.8	15.5	0.5	64	1.96	1	1	4	2	3	4	4	4	4	4	4
4-Jan	13.6	15.6	15.2	0.5	60	1.4	2	2	3	2	3	4	4	4	4	4	4
4-Jan	13.6	15.6	15.2	0.5	60	1.4	1.6	1	3	2	3	4	4	4	4	4	4
4-Jan	13.8	15.8	15.4	0.5	60	1.4	2	1	2	2	2	4	4	4	4	4	4
5-Jan	13.6	15.6	15.2	0.2	60	1.4	3	1	3	2	2	4	4	4	4	4	4
5-Jan	13.6	15.6	15.2	0.2	60	1.2	1.6	1	3	2	3	4	4	4	4	4	4
5-Jan	13.6	15.6	15.2	0.2	60	1.2	2	1	2	3	2	4	4	4	4	4	4
5-Jan	11	13	12.6	0.2	60	1.4	1.6	1	3	3	3	4	4	4	4	4	4
5-Jan	10	12	11.7	0.2	55	1.4	2	1	3	1	2	4	4	4	4	4	4
5-Jan	7.6	9.6	9.3	0.2	55	1.3	2	1	1	1	1	4	4	4	4	4	4
5-Jan	16.2	18.2	17.9	0.2	55	1.4	1.6	1	3	3	2	4	4	4	4	4	4
5-Jan	16.2	18.2	17.9	0.2	55	1.2	1.6	1	2	3	2	4	4	4	4	4	4
5-Jan	16.2	18.2	17.9	0.2	55	1.96	2	1	3	3	2	4	4	4	4	4	4
5-Jan	16.2	18.2	17.9	0.2	55	1.4	1	1	3	1	1	4	4	4	4	4	4
5-Jan	16.2	18.2	17.9	0.2	55	1.4	2	1	2	2	2	4	4	4	4	4	4
3-Aug	33	33.7	32.4	0.15	38	0.4	1.6	1	3	4	3	5	2	5	4	2	2
3-Aug	34	33	33.6	0.15	34	0.4	3	1	2	2	3	6	3	4	1	3	3
3-Aug	19	29	18	0.15	31	0.5	3	1	3	4	3	6	3	4	3	3	3
3-Aug	19	28.8	18	0.15	34	0.52	1.6	1	3	2	4	4	3	4	3	3	3
3-Aug	19	28.8	18	0.15	35	0.5	3	1	3	2	4	4	3	4	1	3	3
3-Aug	19	28.8	18	0.15	32	0.4	1.6	2	3	2	3	5	3	4	1	3	3
3-Aug	29.7	33.7	29	0.15	40	0.6	3	2	4	4	3	4	3	3	3	3	3
4-Aug	27.2	31.2	27	0.2	37	0.5	2	1	3	3	2	2	6	3	4	6	6
4-Aug	27.2	31.2	27	0.2	35	0.5	1.6	1	3	2	3	3	3	4	1	3	3
4-Aug	26	28.6	25.6	0.2	34	0.48	1.6	1	3	2	3	6	3	4	2	3	3
4-Aug	26	28.6	25.6	0.2	34	0.48	1	1	3	2	3	4	3	4	3	3	3
4-Aug	26	28.6	25.6	0.2	34	0.48	1	1	3	2	3	6	3	4	1	3	3
4-Aug	35	35	34	0.2	34	0.48	1	1	3	2	3	4	3	4	1	3	3
4-Aug	18.6	22.6	18	0.2	34	0.48	2	1	3	2	3	4	3	4	1	3	3
4-Aug	19.6	22.6	19	0.2	34	0.48	1.6	1	3	2	3	4	3	4	3	3	3
4-Aug	25.6	28.6	25	0.2	34	0.48	2	1	2	2	3	6	3	4	1	3	3
27-Aug	25.6	28.6	25	0.12	34	0.48	2	1	3	2	3	4	3	4	3	3	3
27-Aug	25.6	28.6	25	0.12	34	0.5	1	1	3	2	3	4	3	4	1	3	3

27-Aug	25.6	28.6	25	0.12	34	0.5	3	1	3	2	3	4	3	4	1	3	3
27-Aug	25.6	28.6	25	0.12	34	0.5	1.6	1	2	2	4	7	3	6	1	3	3
27-Aug	28.2	31.2	27	0.12	35	0.5	3	1	3	3	3	4	3	4	3	3	3
27-Aug	28.2	31.2	28	0.12	35	0.5	3	2	3	5	4	5	3	5	4	3	3
27-Aug	28.2	31.2	28	0.12	35	0.46	1.6	2	3	7	3	7	3	6	5	3	3
27-Aug	25.8	28.8	25	0.12	33	0.46	3	1	1	5	4	4	3	3	1	3	3
27-Aug	21.3	24.3	21	0.12	30	0.46	1.6	1	2	6	3	5	3	5	3	3	3
27-Aug	19.6	22.6	19	0.12	28	0.46	3	2	2	4	3	5	3	4	1	3	3
30-Aug	25.6	28.6	25	0.2	33	0.46	2	1	3	5	1	3	3	4	3	3	3
30-Aug	25.6	28.6	25.4	0.2	33	0.4	1.6	2	3	4	4	5	3	3	5	3	3
30-Aug	28.2	31.2	28	0.2	33	0.4	1.6	2	2	5	3	7	3	6	5	3	3
30-Aug	19.6	22.6	19.2	0.2	33	0.46	1	2	2	7	5	7	3	7	3	3	3
30-Aug	23.1	26.1	23	0.2	32	0.46	1	1	3	3	4	4	1	5	1	1	1
30-Aug	25.6	28.6	25	0.2	33	0.46	1	1	2	5	4	7	3	6	4	3	3
30-Aug	25.6	28.6	25	0.2	33	0.46	2	1	2	6	3	5	3	7	5	3	3
30-Aug	23.1	26.1	23	0.2	33	0.5	1.6	2	3	6	3	5	3	6	2	3	3
30-Aug	23.1	26.1	23	0.2	33	0.46	2	2	2	4	5	5	3	5	5	3	3
30-Aug	23.1	26.1	23	0.2	33	0.46	2	1	3	5	4	6	3	6	2	3	3
30-Aug	25.8	28.8	25.2	0.2	33	0.45	1	1	3	5	4	7	3	7	5	3	3
30-Aug	25.6	28.6	25.2	0.2	33	0.5	3	1	4	7	5	7	3	7	5	3	3
30-Aug	25.6	28.6	25.2	0.2	33	0.4	1.6	2	3	6	3	6	3	6	5	3	3
1-Sep	32	35	32	0.2	33	0.4	3	1	3	6	3	6	3	7	5	3	3
1-Sep	32	35	32	0.2	33	0.46	3	1	2	7	3	7	3	6	4	3	3
1-Sep	32	35	32	0.2	33	0.47	1.6	1	3	6	4	5	3	6	3	3	3
1-Sep	32	35	32	0.2	33	0.46	3	1	3	5	3	3	3	3	1	3	3
1-Sep	34	37	33.8	0.2	37	0.46	1.6	1	2	6	4	3	3	3	1	3	3
1-Sep	34	37	33.8	0.2	37	0.46	3	1	3	5	3	3	3	2	3	3	3
1-Sep	34	37	33.8	0.2	28	0.46	2	1	3	4	3	4	3	4	1	3	3
1-Sep	34	37	33.6	0.2	35	0.48	1.6	1	1	4	3	4	3	4	3	3	3
2-Sep	32	34	32.8	0.2	35	0.47	1.6	1	3	6	3	7	3	7	5	3	3
2-Sep	32	35	32.8	0.2	30	0.48	1	1	2	5	3	7	3	3	5	3	3
2-Sep	26	29	25.7	0.2	30	0.48	1	1	3	4	3	4	3	3	1	3	3
2-Sep	27	30	26.8	0.2	31	0.46	1	1	3	4	3	4	3	4	3	3	3
15.4.2012	26.4	24	25	0.1	50	0.65	2	2	2	4	2	4	3	3	1	3	3
15.4.2012	26.4	24	25	0.1	60	0.65	3	2	3	4	4	4	3	3	1	4	4
15.4.2012	28	25	25	0.1	44	0.65	2	1	3	3	4	4	3	4	3	4	4
15.4.2012	27	24	25	0.1	44	0.65	3	1	3	2	2	4	3	3	1	3	3
15.4.2012	26.4	24	25	0.1	44	1.2	1	1	3	1	1	4	3	1	1	5	5
16.4.2012	25.4	23	24	0.1	44	1.2	3	2	4	4	4	4	3	3	3	4	4
16.4.2012	25.4	23	24	0.1	44	0.65	1	1	3	3	3	4	3	3	1	4	4
16.4.2012	25.4	23	24	0.1	45	1.2	3	2	3	3	3	4	3	4	1	4	4
17.4.2012	23	20	23	0.1	45	1	1	2	3	2	2	4	3	1	1	1	1
17.4.2012	23	20	20	0.1	45	0.7	5	1	3	2	1	4	3	1	1	1	1
17.4.2012	22	21	21	0.1	45	1.2	3	1	3	2	2	4	3	2	1	2	2
17.4.2012	22	21	21	0.1	45	0.7	4	1	3	1	1	4	3	1	1	1	1
18.4.2012	22	21	21	0.1	50	0.7	4	2	3	1	1	4	3	2	2	2	2
18.4.2012	22	21	21	0.1	50	0.65	3	1	3	3	2	4	3	3	3	3	3
18.4.2012	22	21	21	0.1	50	0.65	4	2	2	2	1	4	3	1	1	1	1
18.4.2012	22	21	21	0.1	50	0.65	2	2	3	4	3	4	3	2	2	2	2
20.4.2012	24.6	23.1	23.1	0.1	50	0.65	6	1	3	4	3	4	3	4	3	4	4
20.4.2012	24.6	23.1	23.1	0.1	50	1.2	2	2	3	4	4	5	3	3	1	3	3
20.4.2012	26	25.3	25.3	0.1	50	0.6	2	2	2	4	4	4	3	5	5	5	5
20.4.2012	24	23	23	0.1	50	0.65	4	1	3	4	3	4	3	4	3	4	4
21.4.2012	20	23	20	0.1	60	0.7	6	1	3	4	4	4	3	4	3	4	4
21.4.2012	20	23	20	0.1	60	0.7	5	2	3	4	3	4	3	5	4	5	5
22.4.2012	24	23	23	0.1	45	1	4	1	1	4	3	4	3	2	5	2	2
22.4.2012	24	23.5	23.5	0.1	45	1.2	3	1	2	4	3	4	3	4	3	4	4
22.4.2012	24	23	23	0.1	45	1.2	5	2	2	4	2	4	3	3	2	3	3
22.4.2012	24	23	23	0.1	45	0.6	3	1	3	3	2	4	3	4	4	4	4
22.4.2012	24	23.5	23.5	0.1	45	0.65	4	2	3	5	4	5	3	4	5	4	4
22.4.2012	26	23	23	0.1	45	1.2	2	2	2	4	3	5	4	4	3	4	4
22.4.2012	22	20	20	0.1	45	0.6	2	2	2	4	3	4	3	4	3	4	4
22.4.2012	23.5	22.5	22.5	0.1	45	0.6	2	2	3	6	2	4	3	4	3	4	4
22.4.2012	22	21	21	0.1	45	1.2	5	2	2	4	2	4	2	4	2	4	4
22.4.2012	22	21	21	0.1	50	1.2	2	2	2	4	3	4	3	4	3	4	4
22.4.2012	23	22.2	22.2	0.1	50	0.6	2	2	3	4	3	4	4	4	3	4	4
20.4.2012	24.6	23.1	23.1	0.1	50	0.7	2	1	2	3	2	5	3	3	1	3	3

20.4.2012	26	25.3	25.3	0.1	50	0.7	2	2	3	4	4	4	4	6	1	6	6
21.4.2012	20	19	19	0.1	50	1.2	5	1	3	4	4	4	3	5	4	5	5
21.4.2012	20	19	19	0.1	50	0.7	1	2	4	5	4	4	3	6	5	6	6
21.4.2012	22	20	20	0.1	50	0.7	1	2	3	4	4	4	3	4	3	4	4
22.2.2012	23	22	22	0.1	50	0.7	2	2	3	4	2	4	3	4	4	4	4
22.4.2012	23	22	22	0.1	50	0.7	2	2	2	4	4	5	4	3	2	3	3
22.4.2012	24	23.4	23.4	0.1	50	0.7	2	2	3	4	4	5	3	4	4	4	4
22.4.2012	24	23	23	0.1	50	0.6	1	2	3	5	4	4	3	4	1	4	4
22.4.2012	24	23	23	0.1	50	0.6	1	2	2	7	4	5	4	5	4	5	5
22.4.2012	24	23	23	0.1	50	0.6	2	2	3	5	5	4	3	6	5	6	6
22.4.2012	24	23	23	0.1	50	0.6	1	2	3	4	4	6	3	6	2	6	6
22.4.2012	22	21	21	0.1	50	0.6	1	1	1	4	4	4	3	4	3	4	4
22.4.2012	23	21.6	21.6	0.1	50	0.6	2	2	3	5	2	4	2	4	1	4	4
22.4.2012	23	21.8	21.8	0.1	50	1.2	2	2	2	5	3	5	4	4	4	4	4
22.4.2012	23	22	22	0.1	50	0.7	6	2	3	4	1	5	4	4	2	4	4
22.4.2012	23	22	22	0.1	50	0.7	4	1	3	3	2	6	2	3	4	3	3

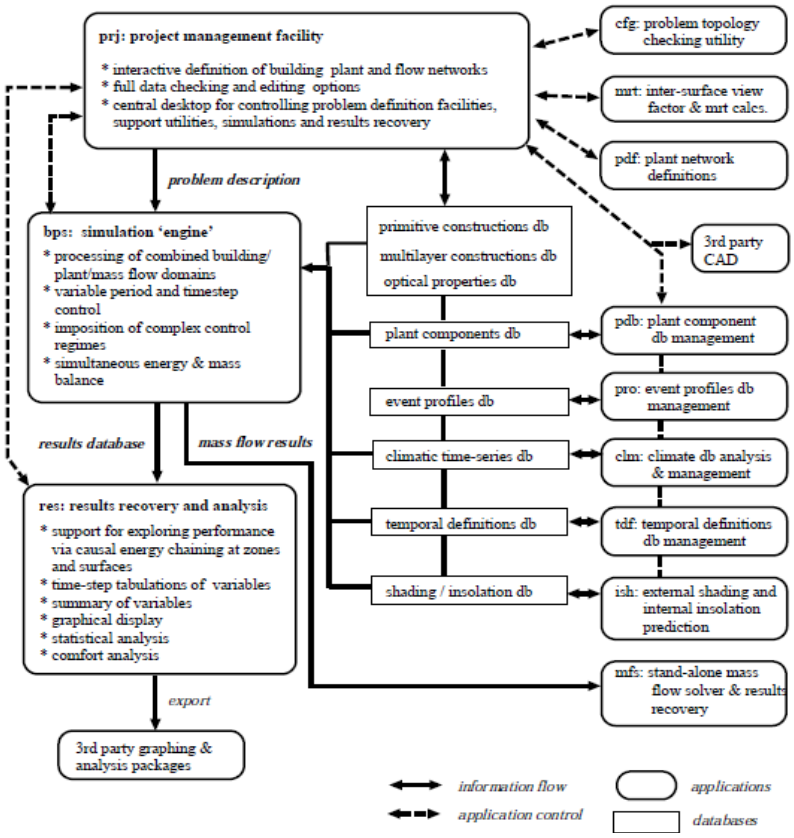
Appendix C: The Energy Simulation Data

The (ESP-r) is an integrated simulation system that has been the subject of sustained development since 1974 (Clarke 2011), it has been used for the analysis a range of building performance issues, and it can also be applied to the building at the early stages of the design, in addition, to the regular application in the analysis of an existing buildings. It is a powerful simulation tools, and a dynamic thermal simulation environment for the analysis of energy and mass flows and environmental control systems within the built environment. It follows the pattern of 'simulation follow description', shown in figure where additional technical domain solvers are evoked as the building and system description evolves (Clarke 2001).



Appendix B 1- ESP-r program structure

The (ESP-r) program contains database folder allows the user to add or modify an existing database for model requirements. The database is structured in figure (7-2), it can be accessed and modified and a simulation can be run for different database. For example for the same model a simulation can be run using deferent climatic database, this is useful in testing the same model under different climate.



Appendix B 3- Relation between the ESP-r application modules and databases Clark 2010

From the ESP-r database folder three databases were modified, according to the environmental

File Type	Extension
Geometry	.geo
Construction	.con
Operations	.opr
Shading/Insolation	.shd
View Factors	.vwf
Air Flows	.air
Convection Coefficients	.hcf
Site Obstructions	.obs
System Configuration	.cfg
System Control	.ctl
Mass Flow Network	.mfn
Utilities	.utl
Transparent Constructions	.tmc
Casual Gains Control	.cgc

```
Database Maintenance
  model path: .\
  ________________________________
a annual climate        : C:/Esru/esp-r/climate/clm67
b multi-year climate    : None
c pressure distributions : C:/Esru/esp-r/databases/pressc.db1
d materials             : C:/Esru/esp-r/databases/material.db3.a
e constructions         : C:/Esru/esp-r/databases/multicon.db3
f plant components      : C:/Esru/esp-r/databases/plantc.db1
g event profiles        : C:/Esru/esp-r/databases/profiles.db2.a
h optical properties    : C:/Esru/esp-r/databases/optics.db2
i mould & mycotoxins    : None
j miscel components     : C:/Esru/esp-r/databases/mscomp.db1
```

Appendix B 2- ESP-r Files and Database

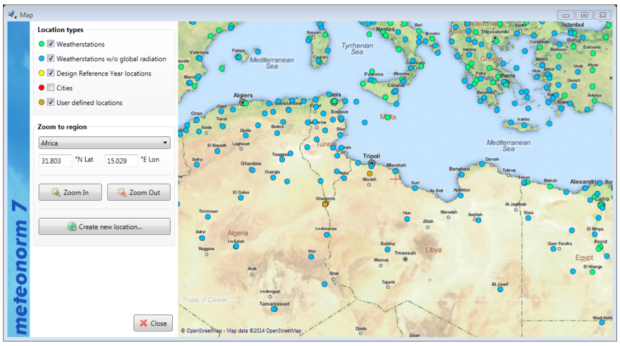
requirements for each city; the climatic database, the material database and the construction database were developed for each city illustrated in the following

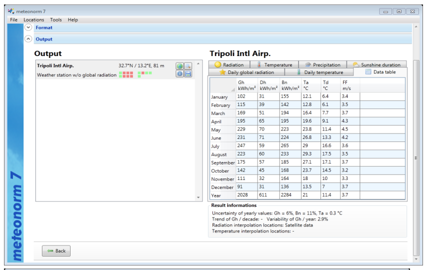
Climatic data Climate Database

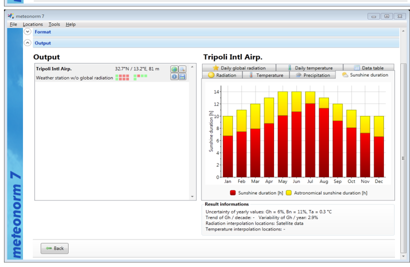
For the (ESP-r) simulation requirements, the thermo physical properties of the material are listed in Table. For the new material two types of materials were added to the database, the ‘sand dry block’ used as wall construction and the ‘Date palm wood’ used as insulation material. Moreover, the ‘Date palm wood’ is used for the roof construction in the old city in Tripoli and Ghadames, and the Sundry sand block used in the old city of Ghadames.

In multilayer construction database the definition of the composition of the construction in term of thickness and its thermo-physical properties. The order of the material wrote from outside to inside the model. Although the programme had many constructions in its database, new constructions have been added to include the vernacular construction material, the contemporary and the new proposed construction. The building construction was made from six basic components of the building envelope, the external wall, internal wall, roof, ceiling, ground floor, door and window.

Climate database for the three cities have been obtained form METEONORM Software as EPW files and converted to (ESP-r) binary climate file. Climate database .The METEONORM is comprehensive meteorological reference that provides meteorological data for solar applications and system design at any location. The software data is based on weather stations and geostationary satellites. The climatic data consist of eight parameters, global radiation, ambient air temperature humidity, precipitation, wind speed, wind direction and sunshine duration.

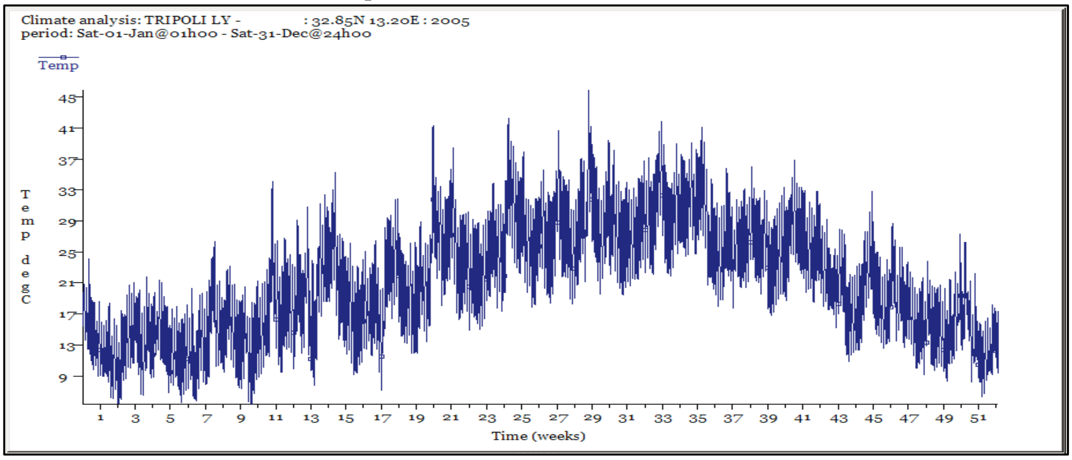




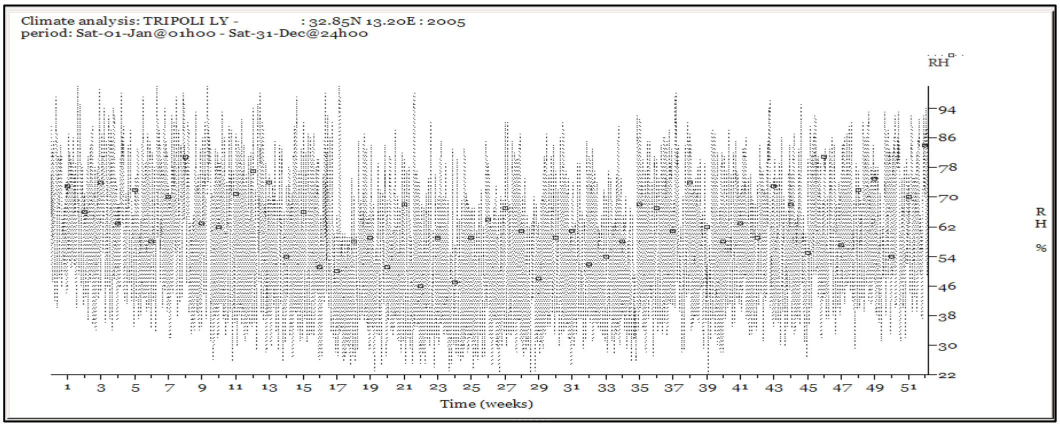


Appendix B 4- Meteonorm Global Meteorological database software

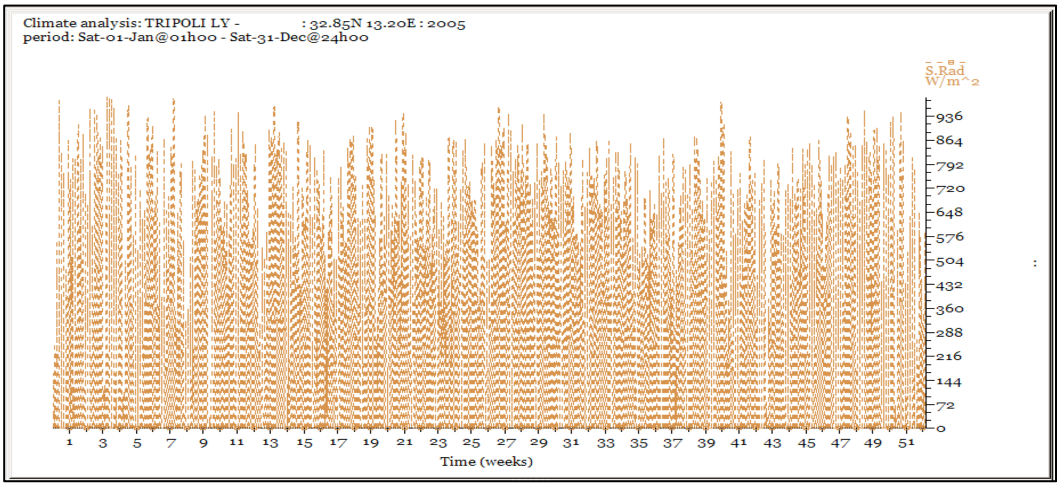
ESP-r, Climatic data for Tripoli



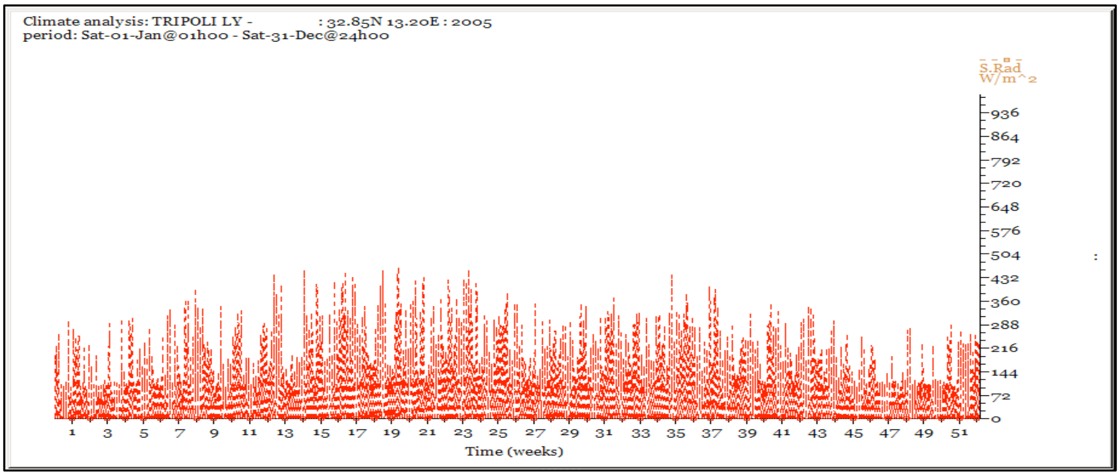
Appendix B. 5-Annual plot of ambient temperature (Dry bulb temperature)



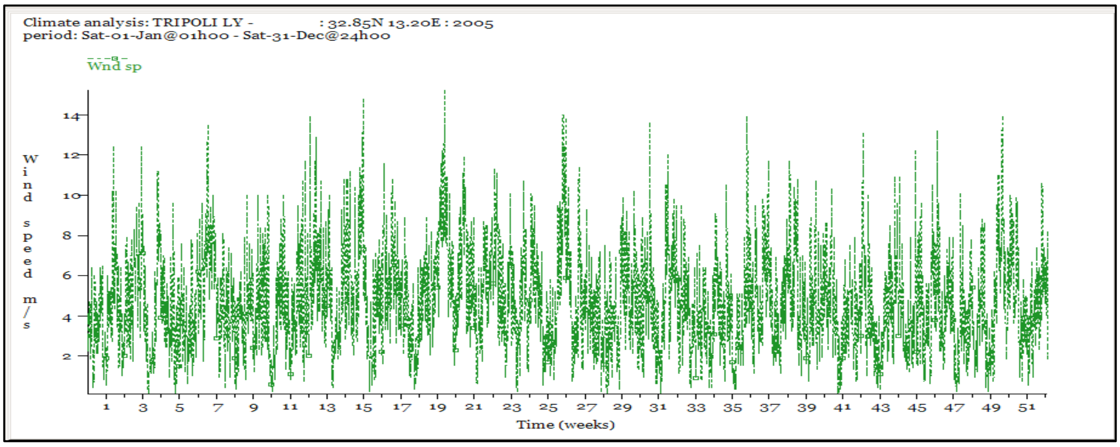
Appendix B. 6 -Relative humidity (%)



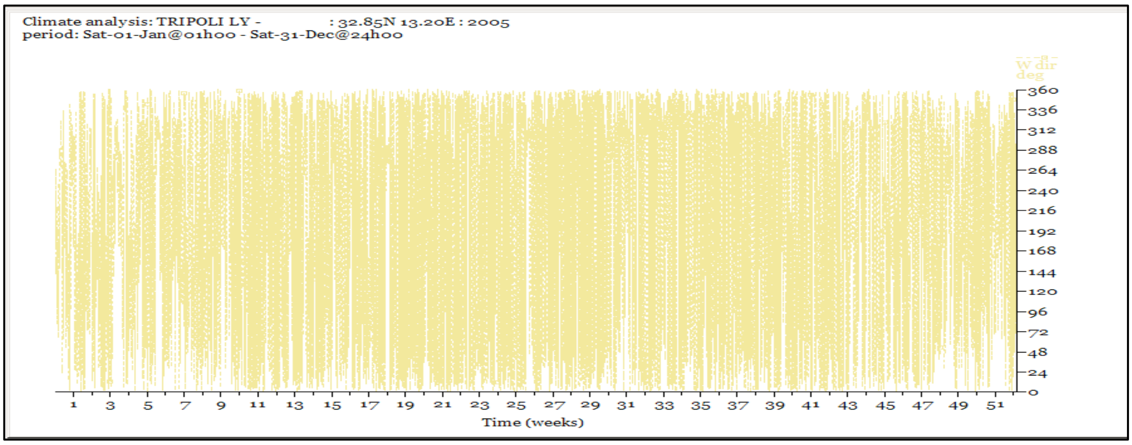
Appendix- B. 7. Direct normal solar



Appendix B. 8-Diffuse solar

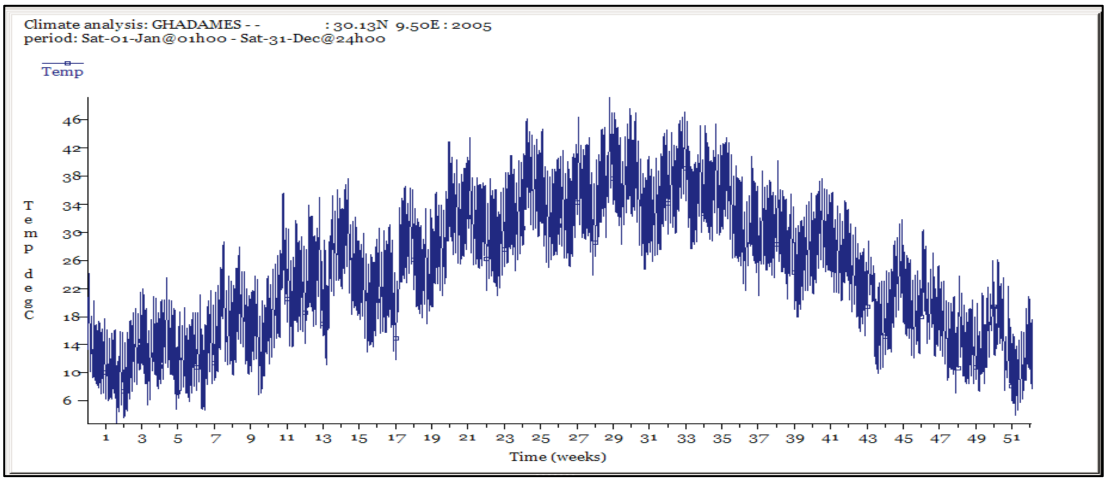


Appendix B. 9 wind direction (m/s)

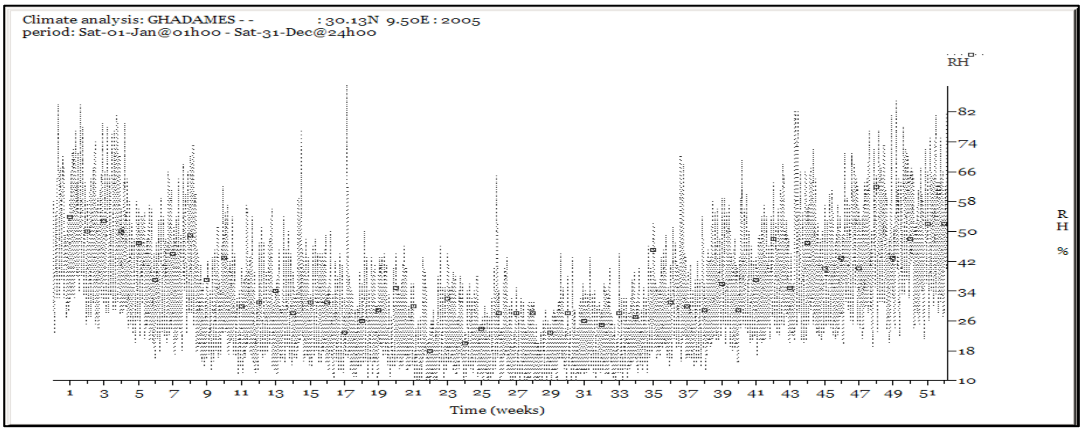


Appendix B. 6 wind direction (deg)

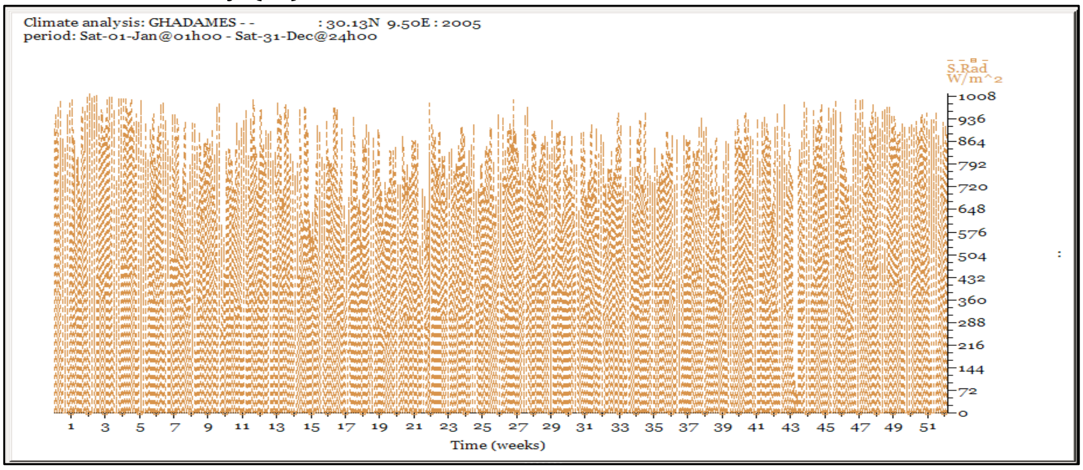
Climatic data for Ghadames



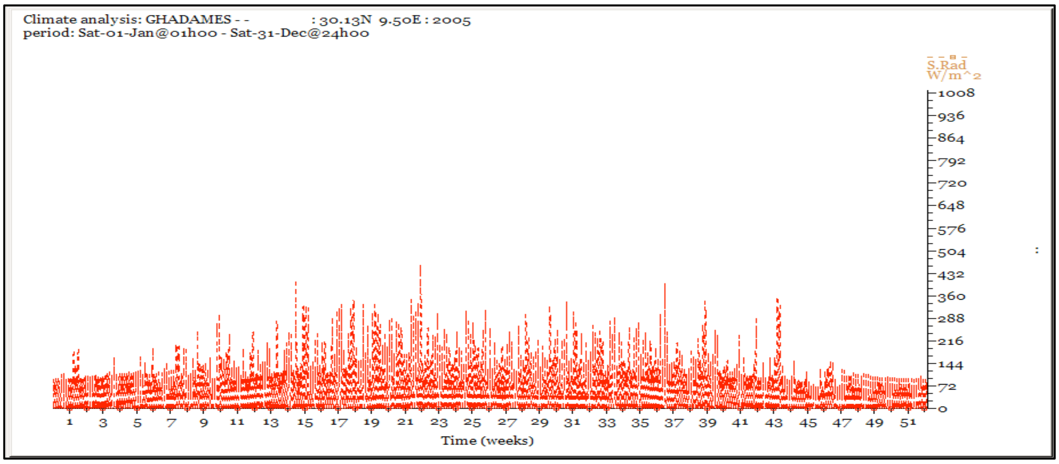
Appendix B 6-Annual plot of ambient temperature (Dry bulb temperature)



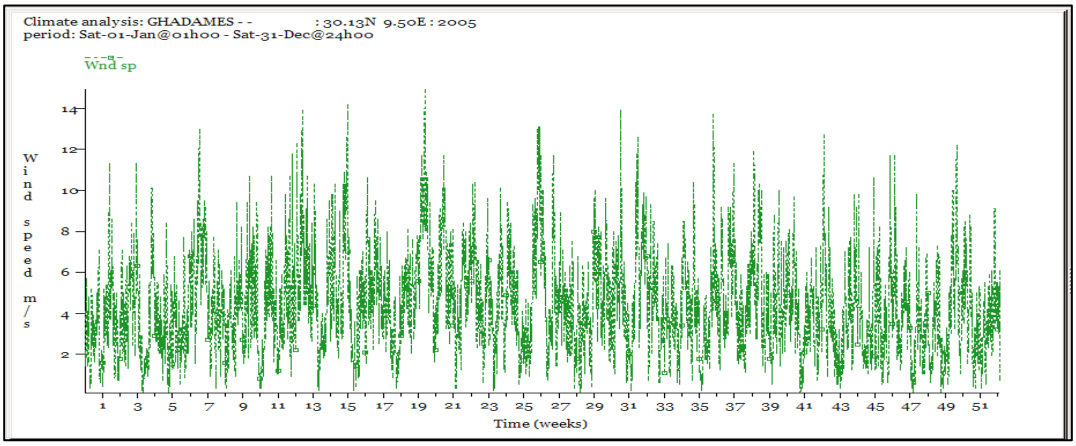
Relative humidity (%)



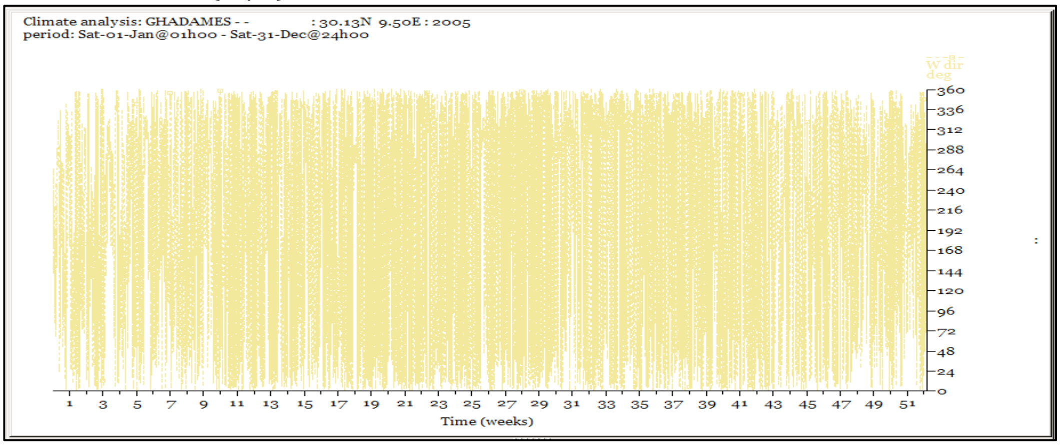
Direct normal solar



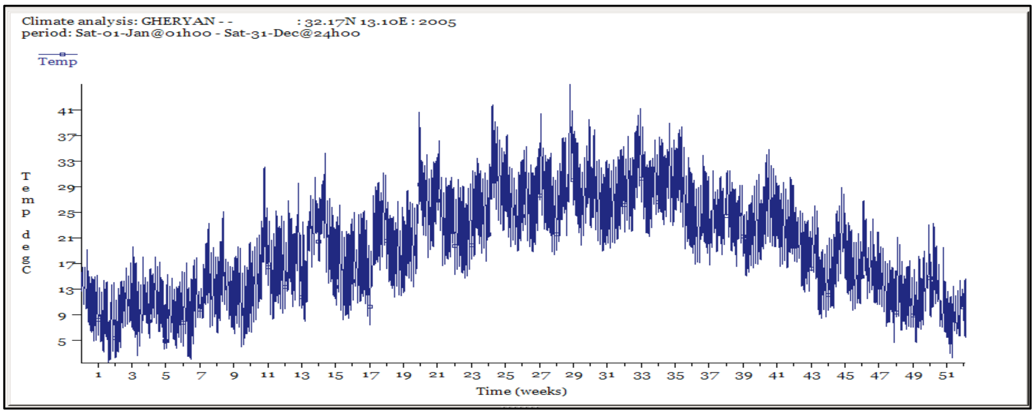
Diffuse solar



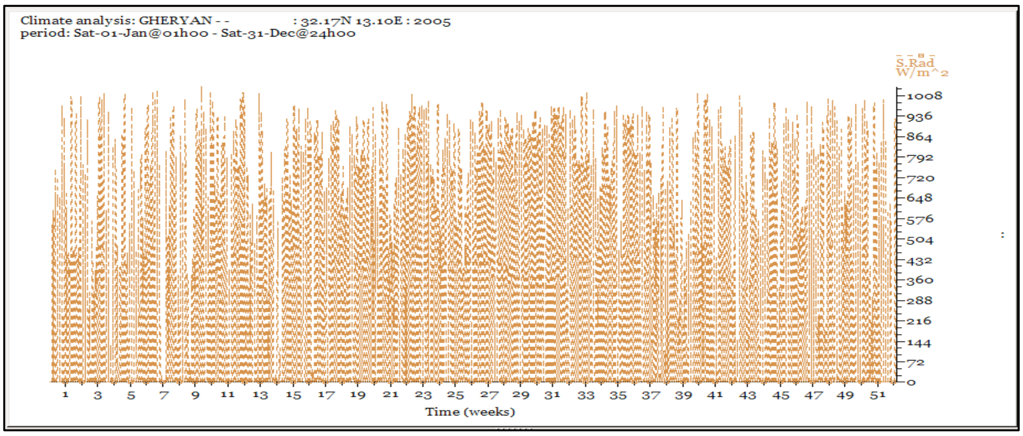
wind direction (m/s)



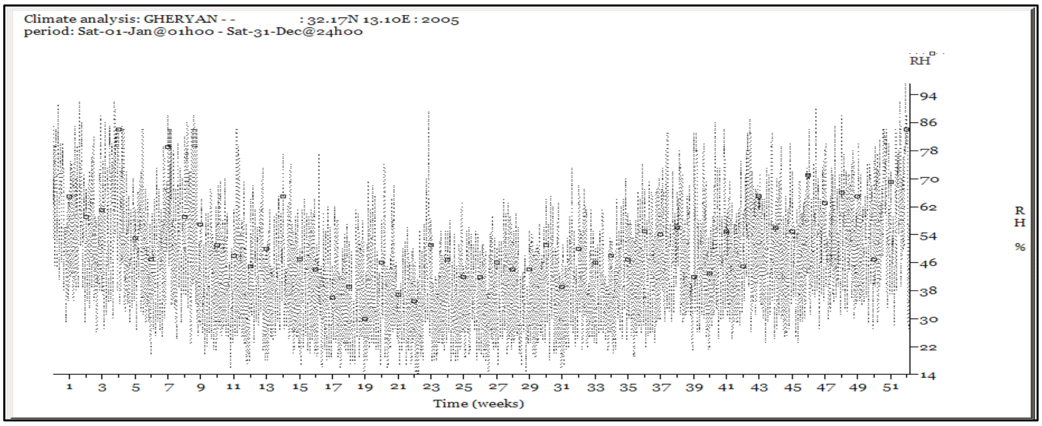
Climatic data for Gheryan



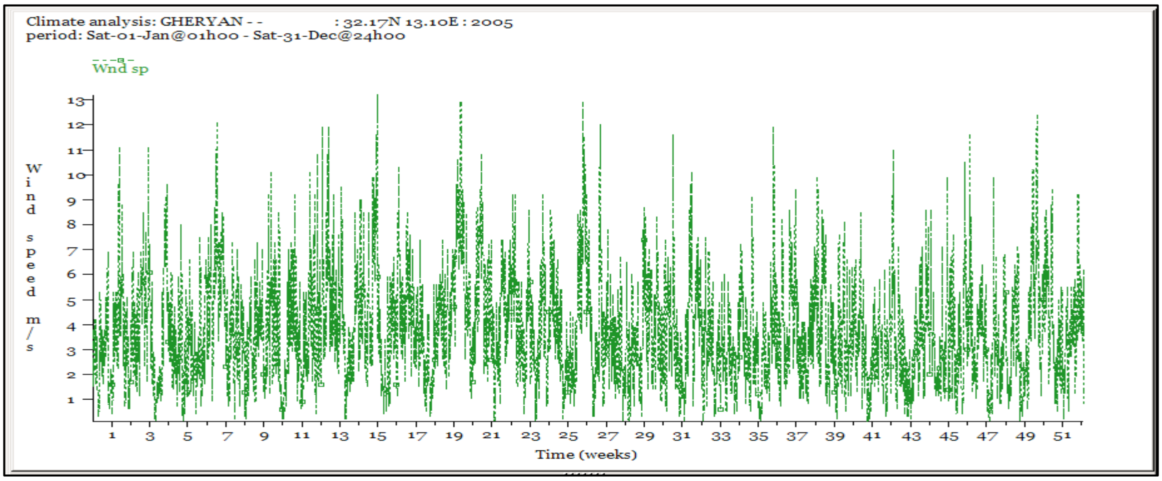
Appendix B 7-Annual plot of ambient temperature (Dry bulb temperature)



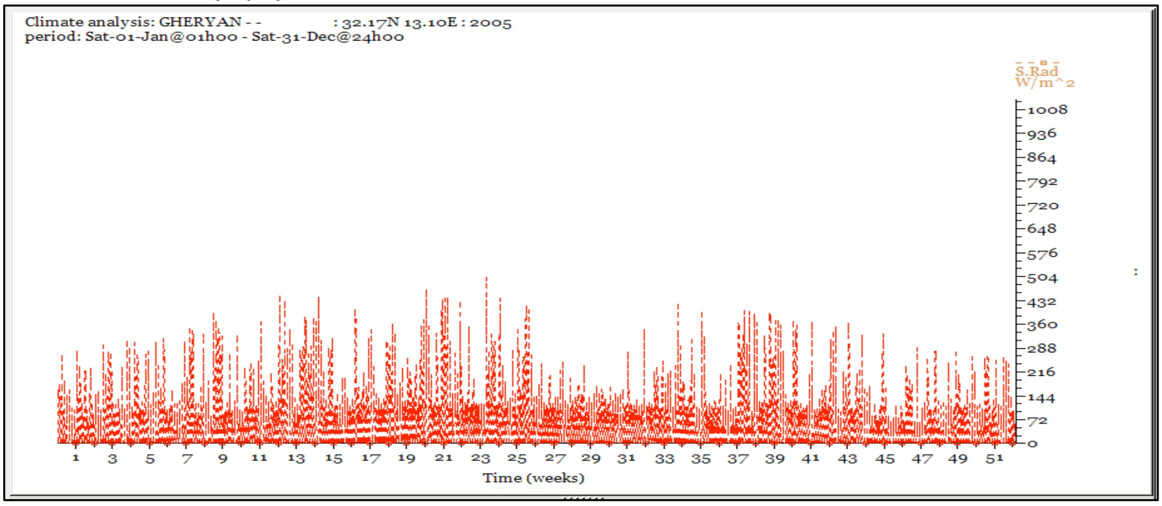
Direct normal solar



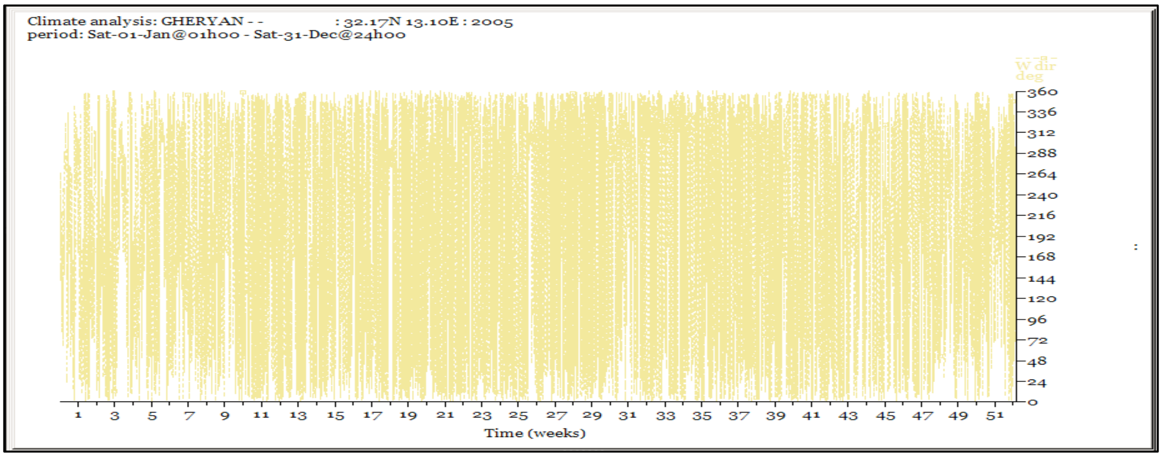
Relative humidity (%)



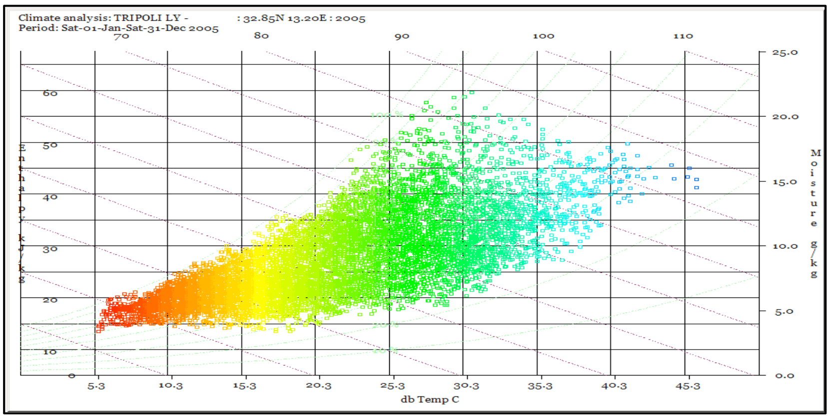
wind direction (m/s)



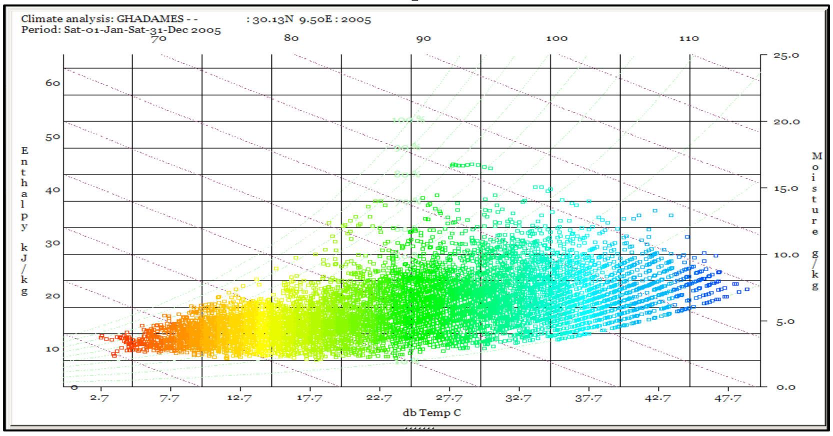
Diffuse solar



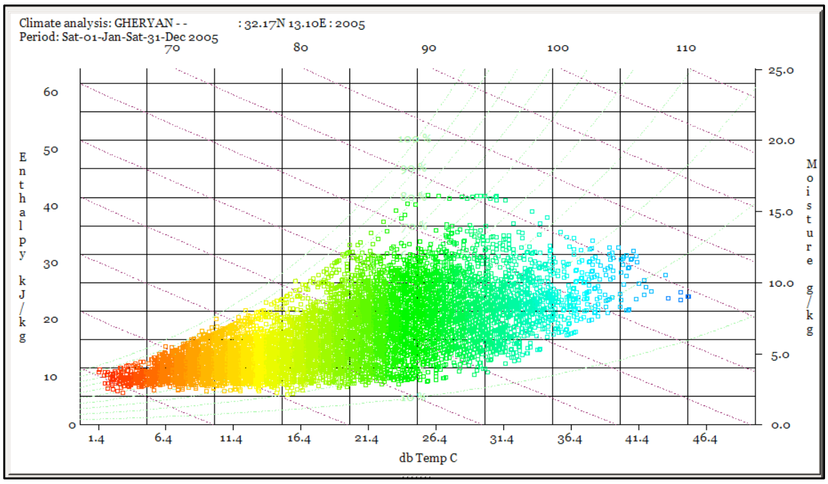
Annual Psychometrics charts



Tripoli



Ghadames



Gheryan

Climatic Data
Maximum and minimum temperature recorded in the three cities.

Month	Minimum Time	Maximum Time	Mean
Jan	5.3 @ 8h00 Sat-15	24.1 @16h00 Mon-03	13.4
Feb	5.5 @ 8h00 Wed-09	26.3 @16h00 Tue-22	13.6
Mar	5.3 @ 7h00 Wed-09	34.1 @16h00 Thu-17	16.5
Apr	7.1 @ 6h00 Sat-30	35.3 @16h00 Mon-11	19.1
May	11.8 @ 6h00 Thu-12	41.3 @16h00 Fri-20	23.4
Jun	14.8 @ 6h00 Sat-04	42.2 @16h00 Sun-19	25.9
Jul	18.2 @ 6h00 Fri-15	45.8 @16h00 Thu-21	28.7
Aug	19.4 @ 6h00 Thu-04	41.8 @16h00 Fri-19	29.4
Sep	17.7 @ 7h00 Sat-17	41.1 @16h00 Sun-04	27.3
Oct	15.1 @ 7h00 Fri-28	36.8 @16h00 Tue-11	24.4
Nov	9.9 @ 8h00 Tue-29	32.8 @15h00 Fri-11	18.5
Dec	6.2 @ 8h00 Sun-25	27.3 @15h00 Fri-16	14.6
All period	5.3 @ 8h00 Sat-15-Jan	45.8 @16h00 Thu-21-Jul	21.3

Relative humidity (%)

Month	Minimum Time	Maximum Time	Mean
Jan	34.0 @16h00 Wed-19	100.0 @ 8h00 Wed-12	65.5
Feb	32.0 @15h00 Sat-19	100.0 @ 5h00 Mon-14	63.4
Mar	26.0 @17h00 Wed-09	100.0 @ 7h00 Mon-07	59.7
Apr	26.0 @16h00 Thu-07	98.0 @ 7h00 Mon-25	55.6
May	23.0 @16h00 Sun-15	100.0 @ 6h00 Sun-01	50.1
Jun	23.0 @18h00 Wed-15	98.0 @ 7h00 Wed-01	48.4
Jul	23.0 @15h00 Wed-06	90.0 @ 6h00 Sat-09	51.0
Aug	25.0 @15h00 Fri-05	90.0 @ 7h00 Tue-02	51.6
Sep	26.0 @11h00 Thu-01	98.0 @ 7h00 Sun-18	57.4
Oct	22.0 @15h00 Sat-01	96.0 @ 7h00 Thu-27	56.9
Nov	27.0 @14h00 Fri-11	95.0 @ 6h00 Wed-09	60.0
Dec	29.0 @14h00 Thu-01	94.0 @ 9h00 Sat-31	63.3
All period	22.0 @15h00 Sat-01-Oct	100.0 @ 8h00 Wed-12-Jan	56.9

Climate data: GHADAMES - -
30.1N 9.5E: 2005 DN
Dry bulb temperature (C)

Month	Minimum Time	Maximum Time	Mean
Jan	2.7 @ 7h00 Wed-12	24.1 @15h00 Sat-01	12.4
Feb	4.6 @ 7h00 Tue-15	28.6 @14h00 Tue-22	14.4
Mar	6.8 @ 6h00 Tue-08	35.6 @17h00 Thu-17	20.2
Apr	11.0 @ 6h00 Sun-03	37.6 @15h00 Mon-11	23.5
May	16.8 @ 6h00 Thu-12	43.4 @16h00 Sat-28	29.5
Jun	20.8 @ 5h00 Wed-08	46.1 @15h00 Sun-19	32.9
Jul	23.8 @ 5h00 Fri-15	49.1 @15h00 Thu-21	36.3
Aug	24.6 @ 6h00 Thu-04	47.1 @16h00 Fri-19	35.8
Sep	20.4 @ 6h00 Wed-28	43.5 @15h00 Sun-04	31.4
Oct	15.2 @ 6h00 Fri-28	37.6 @15h00 Tue-11	26.2
Nov	8.8 @ 7h00 Tue-29	31.8 @15h00 Fri-11	19.0
Dec	3.9 @ 7h00 Sun-25	26.1 @15h00 Sun-18	13.9
All period	2.7 @ 7h00 Wed-12-Jan	49.1 @15h00 Thu-21-Jul	24.7

Relative humidity (%)

Month	Minimum Time	Maximum Time	Mean
Jan	23.0 @14h00 Sat-01	84.0 @ 7h00 Mon-03	49.0
Feb	16.0 @14h00 Fri-11	73.0 @ 6h00 Sun-27	39.3
Mar	12.0 @14h00 Thu-17	62.0 @ 7h00 Fri-11	29.6
Apr	11.0 @15h00 Mon-25	77.0 @ 6h00 Tue-12	27.8
May	10.0 @14h00 Sun-29	89.0 @ 2h00 Sun-01	24.3
Jun	10.0 @16h00 Thu-02	46.0 @ 5h00 Wed-08	21.5
Jul	10.0 @13h00 Sat-02	65.0 @ 6h00 Fri-01	20.1
Aug	10.0 @14h00 Tue-02	44.0 @ 6h00 Sat-20	21.7
Sep	13.0 @15h00 Sat-24	70.0 @ 5h00 Wed-14	30.3
Oct	15.0 @14h00 Fri-07	82.0 @23h00 Sun-30	37.4
Nov	20.0 @15h00 Thu-03	82.0 @ 1h00 Tue-01	42.4
Dec	19.0 @15h00 Thu-01	85.0 @ 7h00 Sun-11	47.9
All period	10.0 @14h00 Sun-29-May	89.0 @ 2h00 Sun-01-May	32.6

Climate data: GHERYAN - -
32.2N 13.1E: 2005 DN
Dry bulb temperature (C)

Month	Minimum Time	Maximum Time	Mean
Jan	1.4 @ 7h00 Wed-12	19.7 @15h00 Sat-22	10.0
Feb	1.9 @ 6h00 Tue-15	25.1 @15h00 Mon-28	11.1
Mar	3.9 @ 6h00 Tue-08	32.1 @15h00 Thu-17	15.3
Apr	7.3 @ 5h00 Sat-30	34.3 @15h00 Mon-11	18.5
May	11.6 @ 5h00 Tue-10	40.7 @13h00 Fri-20	23.1
Jun	14.6 @ 5h00 Wed-08	41.8 @15h00 Sun-19	25.9
Jul	18.3 @ 5h00 Fri-15	45.1 @16h00 Thu-21	28.7
Aug	19.0 @ 5h00 Thu-04	41.3 @15h00 Fri-19	28.8
Sep	16.4 @ 6h00 Wed-28	38.4 @15h00 Mon-05	25.6
Oct	12.4 @ 6h00 Wed-26	34.9 @15h00 Tue-11	22.1
Nov	7.1 @ 6h00 Tue-29	28.9 @14h00 Thu-10	16.0
Dec	2.1 @ 7h00 Mon-26	23.3 @15h00 Sun-18	11.3
All period	1.4 @ 7h00 Wed-12-Jan	45.1 @16h00 Thu-21-Jul	19.8

Relative humidity (%)

Month	Minimum Time	Maximum Time	Mean
Jan	26.0 @14h00 Wed-19	92.0 @ 8h00 Wed-12	58.7
Feb	20.0 @14h00 Fri-11	88.0 @ 2h00 Sat-19	51.6
Mar	16.0 @15h00 Thu-17	88.0 @ 3h00 Wed-02	44.3
Apr	16.0 @13h00 Mon-25	77.0 @ 4h00 Sat-09	39.4
May	15.0 @15h00 Fri-13	74.0 @ 5h00 Sun-22	35.5
Jun	14.0 @13h00 Sun-05	89.0 @ 5h00 Fri-10	35.3
Jul	15.0 @13h00 Tue-05	64.0 @ 5h00 Tue-12	35.9
Aug	16.0 @14h00 Fri-05	73.0 @ 6h00 Wed-10	38.2
Sep	19.0 @14h00 Mon-05	83.0 @22h00 Mon-19	46.4
Oct	21.0 @13h00 Fri-07	87.0 @ 5h00 Tue-25	49.2
Nov	23.0 @14h00 Mon-14	90.0 @ 6h00 Tue-22	50.7
Dec	27.0 @14h00 Fri-16	97.0 @ 6h00 Fri-30	57.3
All period	14.0 @13h00 Sun-05-Jun	97.0 @ 6h00 Fri-30-Dec	45.2

Cooling and Heating Degree day
Tripoli Degree Days

Climate data: TRIPOLI LY -
32.8N 13.2E: 2005 DN

Degree day analysis: heating base at 15.0 & cooling 24.0 Deg C

Month	Heat dd	Cool dd
Month: 1 avg/day	2.48	0.00
Month: 1 total	76.85	0.00
Month: 2 avg/day	2.60	0.01
Month: 2 total	72.70	0.41
Month: 3 avg/day	1.47	0.26
Month: 3 total	45.43	8.13
Month: 4 avg/day	0.75	0.67
Month: 4 total	22.43	20.13
Month: 5 avg/day	0.11	2.06
Month: 5 total	3.27	63.92
Month: 6 avg/day	0.00	3.35
Month: 6 total	0.01	100.51
Month: 7 avg/day	0.00	5.23
Month: 7 total	0.00	162.05
Month: 8 avg/day	0.00	5.65
Month: 8 total	0.00	175.13
Month: 9 avg/day	0.00	3.90
Month: 9 total	0.00	117.14
Month:10 avg/day	0.00	2.11
Month:10 total	0.00	65.33
Month:11 avg/day	0.45	0.28
Month:11 total	13.54	8.48
Month:12 avg/day	1.82	0.03
Month:12 total	56.29	0.91
Total:av/day	0.80	1.98
Period total	290.5	722.2

Degree day analysis: heating base at 17.0 & cooling 26.0 Deg C

Month	Heat dd	Cool dd
Month: 1 avg/day	3.94	0.00
Month: 1 total	122.19	0.00
Month: 2 avg/day	3.99	0.00
Month: 2 total	111.81	0.02
Month: 3 avg/day	2.44	0.14
Month: 3 total	75.67	4.23
Month: 4 avg/day	1.38	0.36
Month: 4 total	41.52	10.94
Month: 5 avg/day	0.34	1.31
Month: 5 total	10.50	40.63
Month: 6 avg/day	0.04	2.24
Month: 6 total	1.09	67.13
Month: 7 avg/day	0.00	3.79
Month: 7 total	0.00	117.44
Month: 8 avg/day	0.00	4.10
Month: 8 total	0.00	126.95
Month: 9 avg/day	0.00	2.62
Month: 9 total	0.00	78.47
Month:10 avg/day	0.01	1.23
Month:10 total	0.36	38.28
Month:11 avg/day	1.10	0.12
Month:11 total	33.06	3.63
Month:12 avg/day	3.12	0.01
Month:12 total	96.74	0.18
Total:av/day	1.35	1.34
Period total	492.9	487.9

Ghadames Degree Days

Climate data: GHADAMES - -
30.1N 9.5E: 2005 DN
Degree day analysis: heating base at 19.0 & cooling 28.0 Deg C

Month	Heat dd	Cool dd
Month: 1 avg/day	6.73	0.00
Month: 1 total	208.50	0.00
Month: 2 avg/day	5.15	0.00
Month: 2 total	144.13	0.04
Month: 3 avg/day	1.82	0.31
Month: 3 total	56.42	9.75
Month: 4 avg/day	0.67	0.74
Month: 4 total	20.06	22.11
Month: 5 avg/day	0.02	3.15
Month: 5 total	0.57	97.63
Month: 6 avg/day	0.00	5.42
Month: 6 total	0.00	162.47
Month: 7 avg/day	0.00	8.39
Month: 7 total	0.00	260.16
Month: 8 avg/day	0.00	7.84
Month: 8 total	0.00	243.15
Month: 9 avg/day	0.00	4.16
Month: 9 total	0.00	124.85
Month:10 avg/day	0.08	1.27
Month:10 total	2.60	39.43
Month:11 avg/day	1.98	0.06
Month:11 total	59.27	1.86
Month:12 avg/day	5.43	0.00
Month:12 total	168.42	0.00
Total:av/day	1.81	2.63
Period total	660.0	961.5

Degree day analysis: heating base at 17.0 & cooling 30.0 Deg C

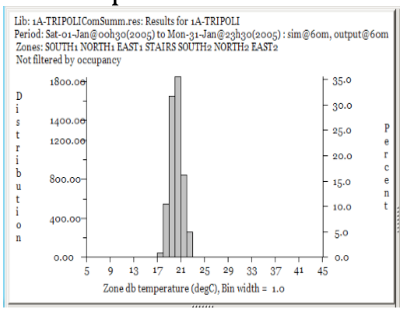
Month	Heat dd	Cool dd
Month: 1 avg/day	4.95	0.00
Month: 1 total	153.46	0.00
Month: 2 avg/day	3.65	0.00
Month: 2 total	102.19	0.00
Month: 3 avg/day	1.06	0.14
Month: 3 total	32.87	4.39
Month: 4 avg/day	0.28	0.38
Month: 4 total	8.43	11.31
Month: 5 avg/day	0.00	2.09
Month: 5 total	0.01	64.77
Month: 6 avg/day	0.00	3.97
Month: 6 total	0.00	119.12
Month: 7 avg/day	0.00	6.60
Month: 7 total	0.00	204.64
Month: 8 avg/day	0.00	6.05
Month: 8 total	0.00	187.50
Month: 9 avg/day	0.00	2.87
Month: 9 total	0.00	86.00
Month:10 avg/day	0.01	0.67
Month:10 total	0.45	20.85
Month:11 avg/day	1.10	0.01
Month:11 total	32.86	0.38
Month:12 avg/day	3.83	0.00
Month:12 total	118.65	0.00
Total:av/day	1.23	1.91
Period total	448.9	699.0

Gheryan Degree Days

```
Climate data: GHERYAN - -
 32.2N  13.1E: 2005  DN
Degree day analysis: heating base at  14.0 & cooling  23.0 Deg C
Month          Heat dd   Cool dd
Month: 1 avg/day   4.24   0.00
Month: 1 total   131.58   0.00
Month: 2 avg/day   3.64   0.01
Month: 2 total   101.87   0.33
Month: 3 avg/day   1.55   0.23
Month: 3 total   48.06   7.10
Month: 4 avg/day   0.66   0.65
Month: 4 total   19.76  19.65
Month: 5 avg/day   0.05   2.42
Month: 5 total    1.68  74.88
Month: 6 avg/day   0.00   3.97
Month: 6 total    0.00 118.98
Month: 7 avg/day   0.00   5.95
Month: 7 total    0.00 184.48
Month: 8 avg/day   0.00   5.99
Month: 8 total    0.00 185.84
Month: 9 avg/day   0.00   3.41
Month: 9 total    0.00 102.26
Month:10 avg/day   0.02   1.47
Month:10 total    0.53  45.66
Month:11 avg/day   0.91   0.15
Month:11 total   27.22   4.56
Month:12 avg/day   3.33   0.00
Month:12 total   103.29   0.03
Total:av/day      1.19   2.04
Period total     434.0  743.8
```

```
Degree day analysis: heating base at  16.0 & cooling  25.0 Deg C
Month          Heat dd   Cool dd
Month: 1 avg/day   6.04   0.00
Month: 1 total   187.22   0.00
Month: 2 avg/day   5.26   0.00
Month: 2 total   147.20   0.00
Month: 3 avg/day   2.54   0.11
Month: 3 total   78.61   3.46
Month: 4 avg/day   1.26   0.30
Month: 4 total   37.87   9.01
Month: 5 avg/day   0.23   1.52
Month: 5 total    7.22  47.08
Month: 6 avg/day   0.01   2.73
Month: 6 total    0.39  81.81
Month: 7 avg/day   0.00   4.39
Month: 7 total    0.00 136.05
Month: 8 avg/day   0.00   4.37
Month: 8 total    0.00 135.49
Month: 9 avg/day   0.00   2.21
Month: 9 total    0.00  66.22
Month:10 avg/day   0.10   0.81
Month:10 total    3.08  24.98
Month:11 avg/day   1.79   0.06
Month:11 total   53.61   1.66
Month:12 avg/day   4.97   0.00
Month:12 total   154.05   0.00
Total:av/day      1.83   1.39
Period total     669.3  505.8
```

Thermal Performance of the Model,
The charts illustrated the monthly distribution of air temperature in model in the three cities;
1. Tripoli house



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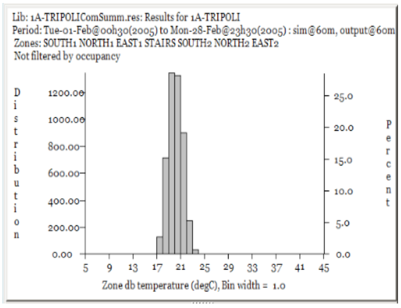

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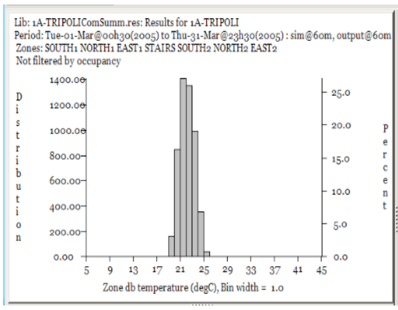

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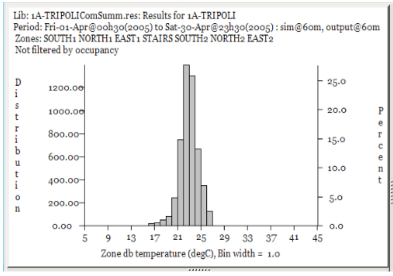

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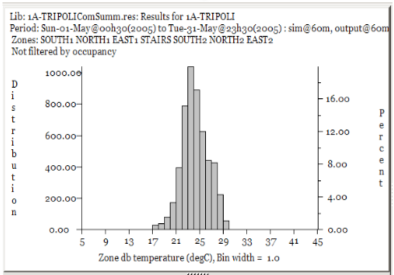

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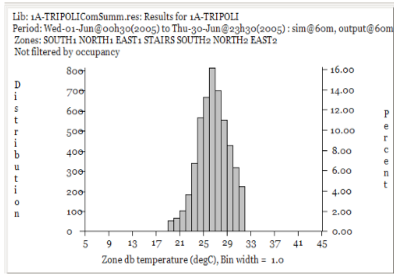

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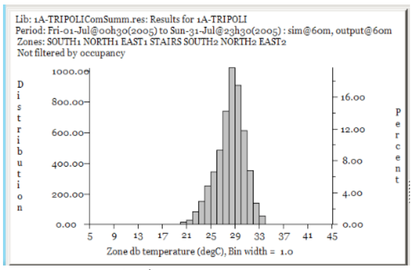
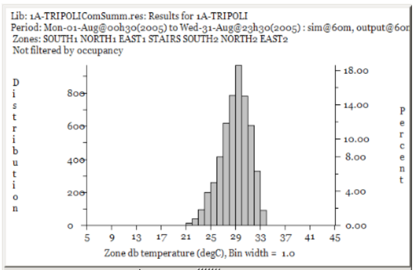


July



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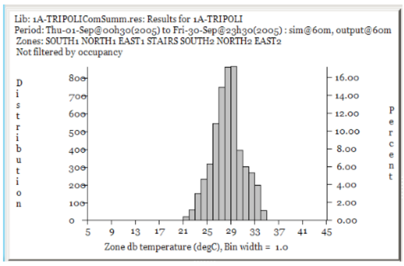

Septembe

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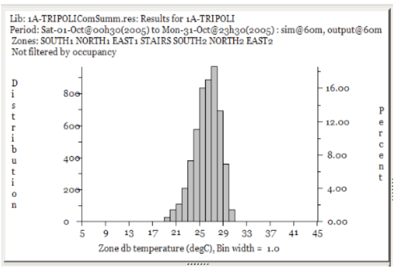

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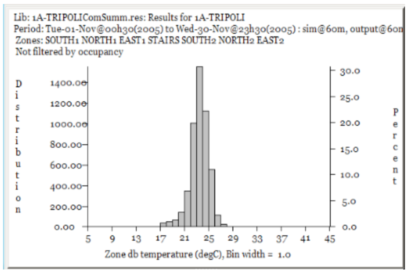
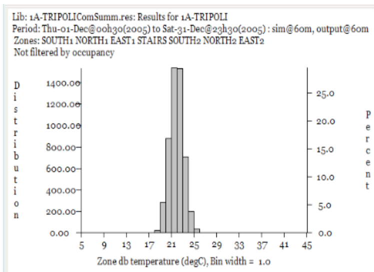
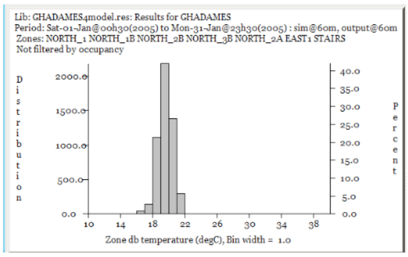


Novemb

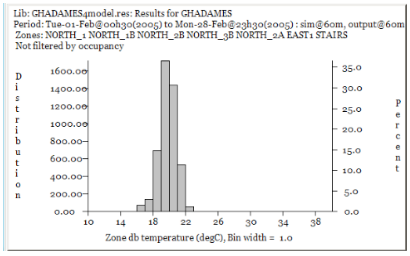


Decembe

2. Ghadames



January



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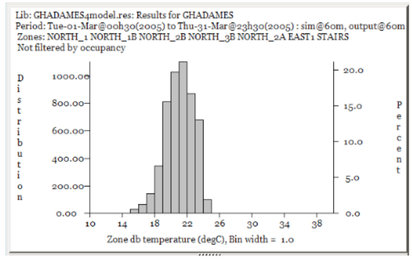

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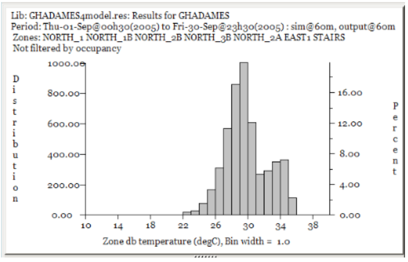
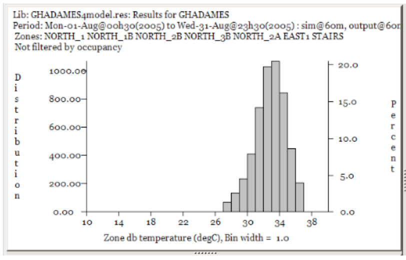
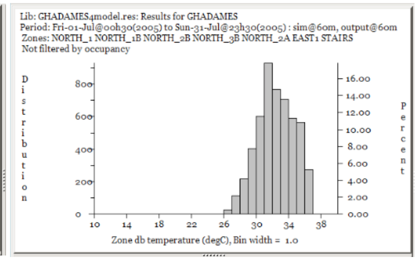


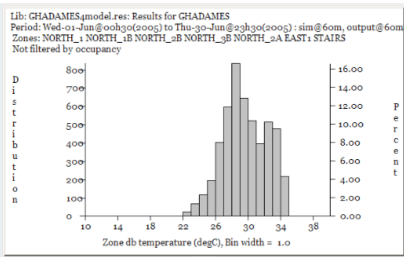
April



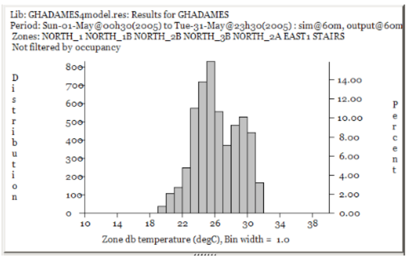
May



June



July



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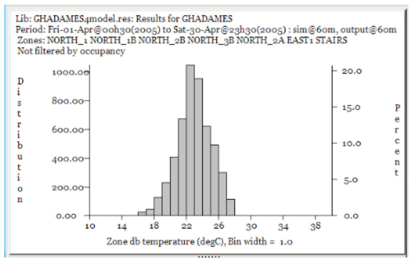
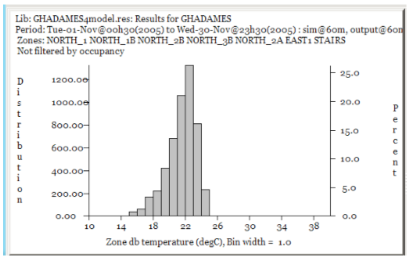
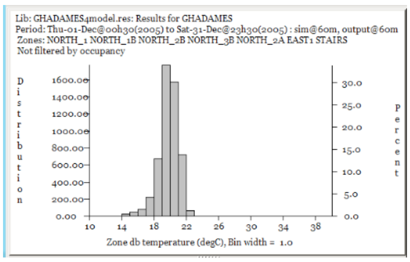
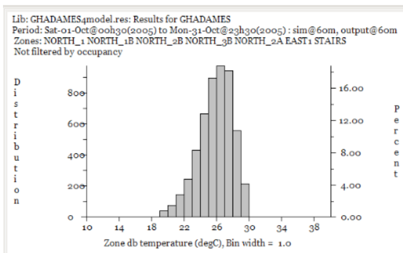


September

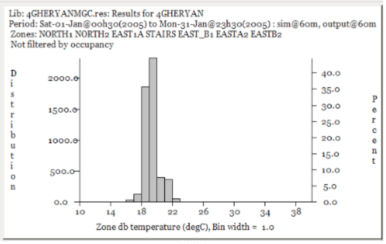






October November December

3. Gheryan



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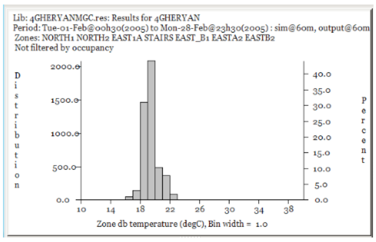

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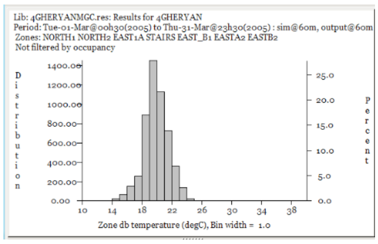

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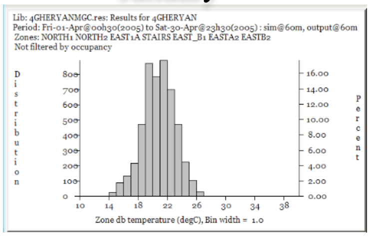

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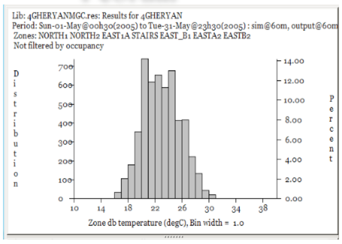

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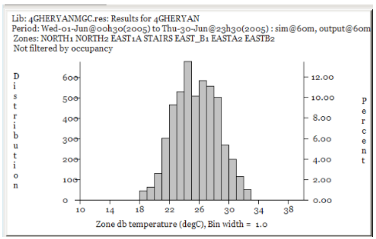

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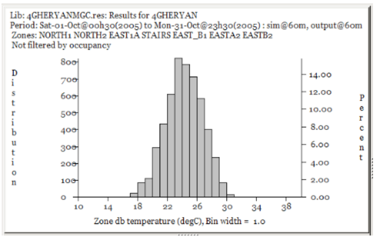

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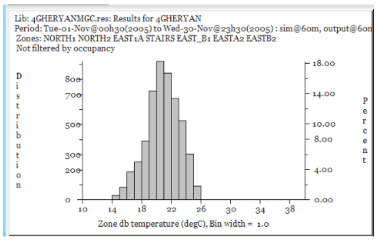

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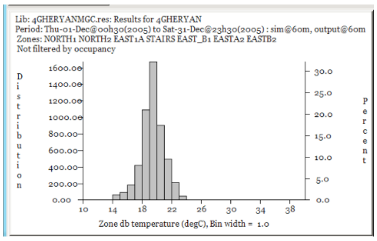

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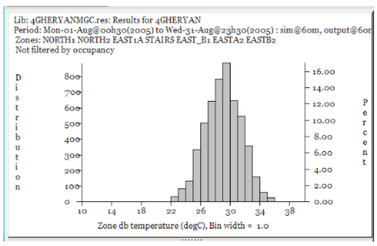

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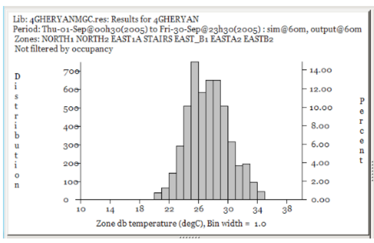

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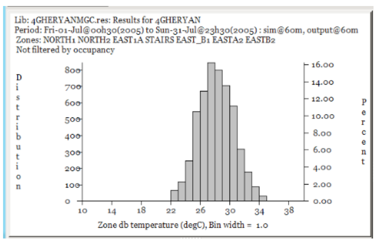
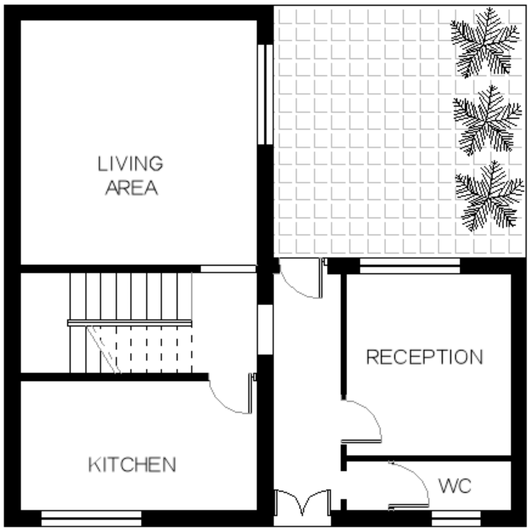
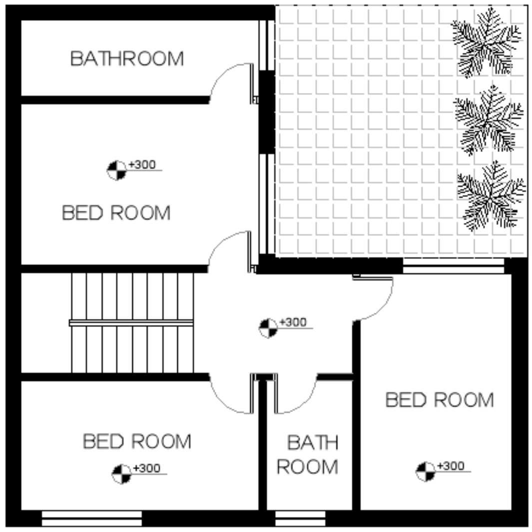


December

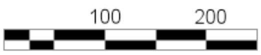
Tripoli's Model

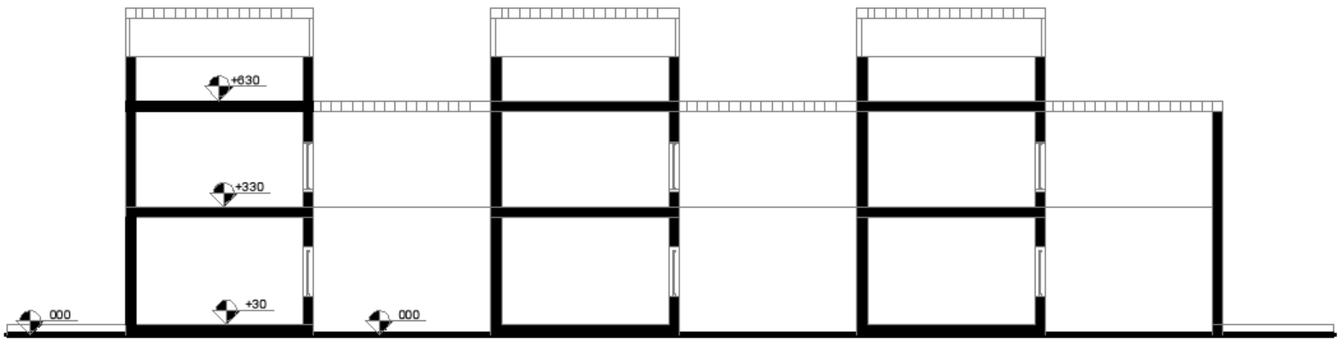


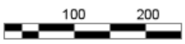
GROUND FLOOR



FIRST FLOOR

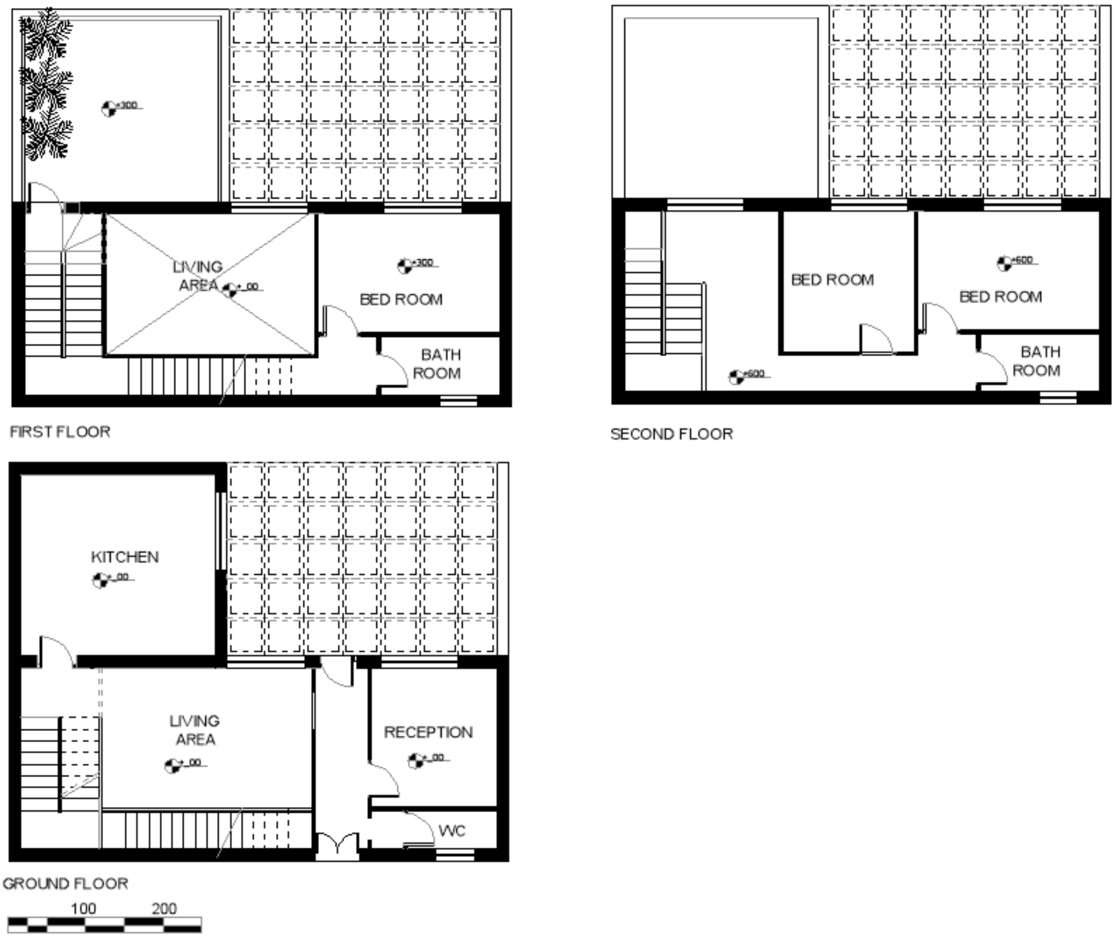


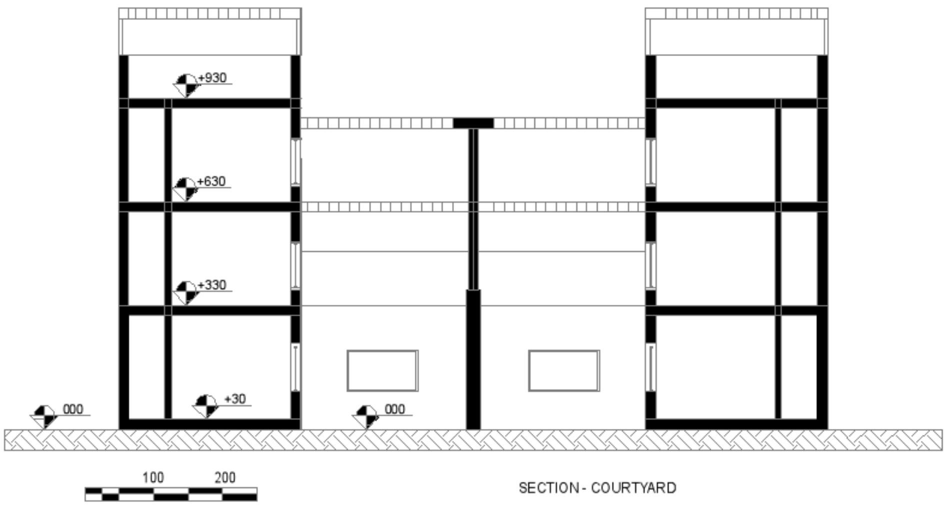




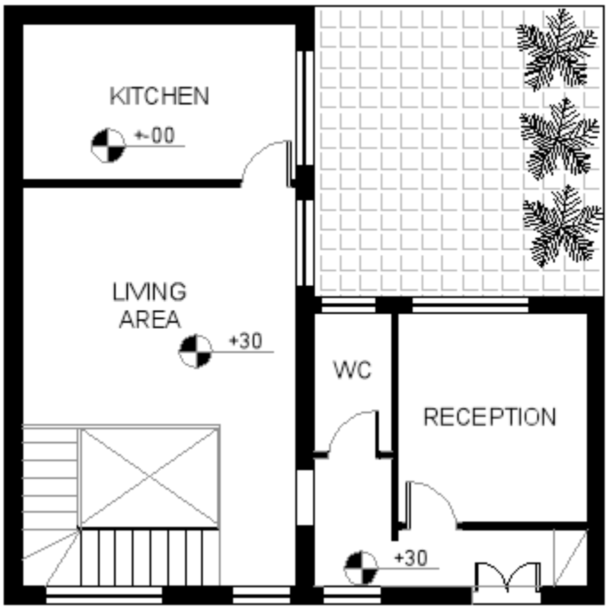
SECTION - COURTYARD

Ghadames's Model



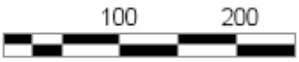


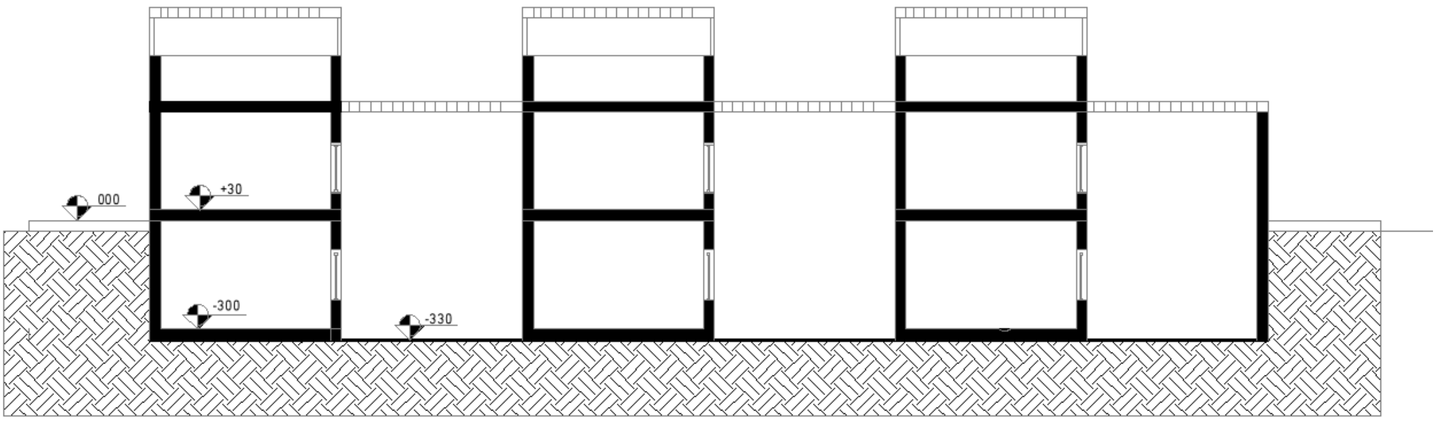
Gheryan's Model



GROUND FLOOR

UNDER GROUND FLOOR





SECTION - COURTYARD