CLIMATIC DESIGN AS A TOOL TO CREATE COMFORTABLE, ENERGY- EFFICIENT AND ENVIRONMENTALLY WISE BUILT ENVIRONMENT - (TRIPOLI-LIBYA)

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To My Country

In memory of my father
To my kind mother

To my father in law

To my husband Adel, and my children
Rawad, Magdolin and Ammar

To my sisters and their families

To all of them I dedicate this thesis

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DECLARATION

I declare that this thesis is based on an original investigation and full acknowledgment is given of all sources used. This study has not previously been submitted for a degree or similar award at any institution. To the best of my knowledge and belief, no material in this thesis has been previously published or written by another person, except where due reference is made.

This thesis includes material that has been published in internationally refereed journals and conference proceedings.

ABBREVIATIONS

AGENDA 21	Conference of the United Nations on Environment and Development, of the Earth Summit held at Rio in 1992
AIA	The American Institute of Architects
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
Aw	Köppen climate classification (tropical wet and dry climate)
BBC	The British Broadcasting Company
BEQUEST	Building Environmental Quality for Sustainability through Time
BIPV	Building Integrated Photovoltaic
BRE	The Building Research Establishment
BWh	Köppen climate classification (desert climate)
CDAUP	The Centre for Desert Architecture and Urban Planning
CIBSE	The Chartered Institution of Building Services Engineers
CLEAR	Comfortable Low Energy ARchitecture
CRISP	Centre for Research and Industrial Staff Performance
DDT	Dichloro Diphenyl Trichloroethane (It is one of the most famous pesticides in the world).
DEFRA	Department for Environment, Food and Rural Affairs
DoE	Department of Energy
EBS	Enertia Building Systems
ED	Environmental Defense
EERE	Energy Efficiency and Renewable Energy
EIA	Energy Information Administration's
GDP	Gross Domestic Product
GECOL	The General Electric Company of Libya
HVAC	Heating, ventilating and air-conditioning
IPCC)	The U.N Intergovernmental Panel on Climate Change a group of scientists convened by the United Nations
ISO	International Organization for Standardization
IUCN	The International Union for Conservation of Nature
KBDA	Kensington Business District Association
MRTEE	Manitoba Round Table on Environment and Economy
NCSU	The North Carolina Solar Center
NREL	National Renewable Energy Laboratory
OECD	Design of sustainable building policies
ORTEE	Ontario Round Table on the Environment and the Economy ,
PED	Public Education Department
SD	Sustainable development
SP LAJ	Socialist People's Libyan Arab Jamahiriya(Official Name of Libya)
UIA	The International Union of Architects
UNCED	The World Commission of Environment and Development
UNEP	The UN environment programme
USAID	United States Agency for International Development
WCMC	World Conservation Monitoring Centre
WEC	The World Energy Council
WWF	the World Wildlife Fund

GLOSSARY

Courtyard houses	An area of ground, without roof, that has walls or building around it
Windcatcher	Catch wind to provide ventilation, it can be "Doors, Windows, *Mushrabiyeh*, *Malqaf* or Staircases.
Mushrabiyeh	A wooden lattice screen used on windows to provide privacy, reduce glare and allow cool breezes to enter homes in the heat of summer
Malqaf - Badgir	Wind tower: The function of this tower is to catch cooler breeze that located at a higher level above the ground and to direct it into the interior of the buildings.
Solarium- green house	Sunrooms: An isolated gain system has its integral parts separate from the main living area of a house
Solar panels	Describes two types of devices that collect energy from the sun: • Solar photovoltaic modules use solar cells to convert light from the sun into electricity. • Solar thermal collectors use the sun's energy to heat water or another fluid such as oil or antifreeze
Gasr	Kind of mountain building used as storehouse or a fortified granary
Iwan	Large place in the side of a courtyard
Sardab	Basement level in Iranian or Iraqi courtyard houses
Qa'as	The main room in the traditional Cairo house
Majlis	A place of sitting, used to describe various types of special gatherings.
Ghibli	Hot dry and dusty winds that blow from the Sahara Desert or belief
Jabel	A mountain
Aboskefa	Kind of houses, part of it dogged in the Mountain
Aldawames	Rooms in underground mountain houses
Bioclimatic chart	developed to incorporate the outdoor climate into building design. The chart indicates the zones of human comfort in relation to ambient temperature and humidity, mean radiant temperature (MRT), wind speed, solar radiation and evaporative cooling.
Psychrometric chart	The psychrometric chart graphically represents the interrelation of air temperature and moisture content and is a basic design tool for building engineers and designers.

ABSTRACT

Contemporary architecture reveals its similarity in almost every part of the world without any consideration of regional characteristics in contrast to vernacular architecture which is almost always climatically appropriate, where architects and builders traditionally had to design with respect to nature and the local climate. Contemporary Libyan architecture has rarely recognized the local climate or renewable energy issues, and these subjects are neglected or rarely studied. Whereas Libyan local vernacular architecture includes traditional solutions that have been tested over centuries, providing passive design for low energy consumption as well as creating architecture related to the local environment. This architecture provides a motivating and valid lesson and it also illustrates and presents a wealth of knowledge about how humans remain in touch with nature and how they adjust to the local natural environment and climate.

This research aims to provide guidelines for architects to consider how to incorporate climatic design in creating architecture related to the local environment that should provide more sustainable solutions in hot climate regions. The study uses the concept of sustainable development to offer a holistic perspective to establish a body of knowledge on passive climatic design that could benefit architects when designing future housing. According to this general understanding, this research project focuses on the interrelationship between passive climatic design and vernacular architecture in such situations. It aims to look at the theoretical and experimental studies that have demonstrated the usefulness of passive climatic design techniques in context with the cooling of buildings in hot regions in order to establish climatic design guidelines using Tripoli, Libya as the case example.

The guidelines are developed for housing design, and take on board the opinions of end users and professionals as well as understanding building performance from the climatic point of view. This research has, therefore, adopted a broad methodology to achieve the aim. Both deductive and inductive approaches have been selected where theoretical strategies are first confirmed from the existing literature which are then investigated using an array of appropriate methods (questionnaire, interviews and focus group as well as sampling the internal temperatures inside selected case study houses) to examine the thermal comfort in both vernacular and contemporary housing. This research is mainly qualitative with quantitative methods also used in the sampling. The results of the study are merged together to produce guidelines that can help architects in terms of using climatic design principles in future housing in hot climate regions.

The main conclusions of the study are:

- Respondents depend on air-conditioning to achieve internal comfort in all house types that increases concern about energy efficiency and increasing pollutions.
- Respondents prefer houses that combine traditional and modern features.
- Courtyard houses have many positive points, but there are some functional disadvantages and this house type has a negative image.
- Contemporary houses provide more comfort, flexibility, privacy, area and possibilities to use new technology.
- However measurements undertaken show better passive thermal performance in the courtyard house than in other contemporary examples.

CHAPTER ONE

CHAPTER ONE:	INTRODUCTION
CHAPTER TWO:	SUSTAINABLE DEVELOPMENT
CHAPTER THREE:	CLIMATIC DESIGN
CHAPTER FOUR:	LIBYA- GENERAL BACKGROUND
CHAPTER FIVE:	RESEARCH METHODOLOGY
CHAPTER SIX:	ANALYSIS OF THE FINDINGS OF THE QUESTIONNAIRE, INTERVIEWS AND TEMPERATURE MEASUREMENTS
CHAPTER SEVEN:	THE FINAL CLIMATIC DESIGN GUIDELINES FOR HOUSING
CHAPTER EIGHT:	CONCLUSION AND RECOMMENDATIONS

CHAPTER ONE: INTRODUCTION

1.1 INTRODUCTION

This chapter is an introduction to the thesis. It is divided into the following parts:

- General background to climatic design
- Some information about the Libyan climate and housing
- Statement of the problem
- Research aim and objectives
- Research questions
- Statement of methodology
- Limitation of the research
- Justification of the research
- Expected contribution to knowledge

1.2 GENERAL BACKGROUND

Sustainable development is not a new idea. The attention given towards the protection of farmland, forests, fisheries, cultural landscapes, historical areas and its aesthetics, etc., dates back at least to the eighteenth century (Gomes, 2003). Brundtland (1987: 8) defined sustainable development (SD) as "*...development that meets the needs of the present without compromising the ability of future generations to meet their own needs*". Emhemed (2005) used the same definition and Sherlock (1991: 293) echoed Brundtland's definition: "*Sustainability means living now in such a way that we do not threaten future life*".

Sustainability in general deals with the relationships between human and natural systems and considers the long term. The concept of sustainable architecture and construction appeared more or less at the same time as did the evolution of the concept of sustainable development. Sustainable design is the conception and understanding of environmentally sensitive and responsible expression issues as a part of the evolving matrix of nature (McDonough, 2000). Cofaigh et al. (1996) described sustainable buildings as those buildings that have minimal adverse effects on the natural environment, on its immediate surroundings and on the wider regional and global setting. Park (1998) summarised the four major principles of sustainable building design as follows:

1. Providing a healthy environment for the workplace by providing good ventilation;

2. Selecting building technologies and materials that are "green", such as using local materials;
3. Consuming less energy in the new systems in buildings than is the norm in current market standards;
4. Having a recycling plan for waste and water.

Accordingly, sustainable architecture can be defined as an architecture that meets human needs and has minimum impact on the natural environment. It is a planned effort at designing a built environment that is energy and ecologically considerate both internally and externally.

This research will touch on various aspects of the sustainability of buildings, but will concentrate mainly on those related to environmental performance especially climatic design considerations such as orientation, building envelope, building materials, energy efficiency, passive ventilation and functionality. These areas are seen as the main building blocks for delivering environmentally sustainable building designs. The next section explores the state of the environment as a main part of understanding the need for sustainable architecture and its relation to climatic design.

1.2.1 Environment

The environment is a complex system that makes up our surrounding circumstances, and enables us to live on the earth. It includes air and water systems, which cover most of the earth's surface, also the animals, plants and much more. This section will elaborate the importance of environmental awareness especially to climate change, and the relationship between the manmade environment and architecture. These are extremely important foundations that should be considered in climatic design.

Environmental Awareness and Climate Change

Climate change is one of the most difficult problems facing the world today. The burning of fossil fuels together with a range of man's other activities and the resultant increase in carbon dioxide emissions has become a main cause of climate change and global warming. A considerable amount of literature has been published on climate change, most of which shows that we are facing a really dangerous problem. It is generally recognized that the IPCC (Intergovernmental Panel on Climate Change) is the most reliable body in the world on this subject (e.g. Roaf 2007 and others) and will be a major source in the project.

The IPCC (2007) explains that warming of the climate system is evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global mean sea level. New data since the Third Assessment Report showed that losses from the ice sheets of Greenland and Antarctica have very likely contributed to the sea level rise recorded over 1993 to 2003 'by approximately 3.1 mm per year'.

The World Energy Council (2007) maintained in its report on Energy and Climate Change that over 80% of man-made emissions of CO_2 come from industry and agriculture. Roaf (2007) was sure that the rise in carbon dioxide in the atmosphere by over 30% (as reported above) is due to human activities. The IPCC (2007) adopted the Summary for Policymakers from the first volume of "Climate Change 2007". This report confirmed that it is more than 90 percent certain that human activities, led by burning fossil fuels, explain most of the warming in the past 50 years.

Environment and architecture

McMullan (2002:2) identified that '*the built environment is formed by buildings and structures that humans construct in the natural environment*'. The impact of contemporary buildings has been highlighted by Enertia Building Systems (2006) Building is the second largest industry in the world after agriculture, and the pollution from the heating and cooling of buildings causes the main damage to the environment and is growing to be greater than that of pollution from cars.

The role of the architectural designer in reducing the impact of buildings on the environment has been mentioned by Gann (Cole and Lorch, 2003) As a result of the increasing concerns about global climate change, there is increasing pressure on professionals to design buildings that are more environmentally friendly and can resist the future changing weather.

1.2.2 Climate

Hyde (2000) defined climate as the broad meteorological condition relating to a region; it is related to temperature, humidity, wind, vegetation and the light specific to geographical location.

Classification of climate for the purposes of building design by means of regions has been undertaken because the differences of climate from region to region are reflected in the building design. Based on this criteria Köppen (1918) established a classification system consisting of main climate groups which were subdivided into climate types and subtypes as follows: tropical climate, dry (arid and semi-arid) climate, temperate climate, continental climate and polar climate.

Understanding the local climate and its influences on life is essential for the design of a more sustainable future using less energy and, therefore, lower carbon. The current understanding of how to design with climate in mind is summarised in the next section.

Climatic design

Climatic design is, in essence, to take maximum advantage of nature and the climate in particular in order to design the built environment. It may seem to be a new trend in building design, but it is an idea that has been with us for a long time. Fathy (1973:3) believed that "*Over many centuries, the people in each part of the earth have learned, by trial and error, how to deal with their environment; their solutions to the problem of housing grew out of countless experiments and accidents, out of the experience of generations of builders who kept what worked and rejected what did not, and these solutions were passes on as tradition.*" Arslan and Kumkale (2005) confirmed Fathy's opinion that man, in order to survive, observes nature and by imitating, understanding the processes in nature that provides solutions for his existence.

Hyde (2000) mentioned that climate responsive design is an essential part of the environmental framework that is being developed in order to reduce environmental impacts and provide for human well-being. Cofaigh et al. (1996) explained that the simplest way of cooling a dwelling is by natural ventilation which can be achieved by using the benefits of night-time air and the evaporative effect of water such as fountains and pools.

Cofaigh et al. (1996) and Givoni (1998) summarised the main objectives of bioclimatic design in hot-humid regions as follows:

- Minimising the solar heating of the buildings;
- Maximizing the rate of cooling in the evenings;
- Providing effective natural ventilation, even during rain;
- Providing spaces for semi-outdoor activities as an integral part of the living space.
- Preventing entry of insects while the windows are open for ventilation; and
- Using vegetation and water for positive cooling.

Factors affecting climatic design

As stated above, architects can achieve the passive design of buildings by studying the macro- and micro-climate of the site, applying bioclimatic architectural principles to combat the adverse conditions, and taking advantage of the periods of more desirable conditions. Some common design elements that directly or indirectly affect thermal comfort conditions and the energy consumption in a building as collected from many sources such as The State of Queensland (2008); Muhasien (2006); Krawietz (2006); CLEAR (2004); Hui, (1997) and Givoni (1998) are as follows:

- Building layout and site landscaping;
- Landscaping of adjacent ground to provide shading;
- The plan and orientation of the dwelling;
- Orientation of the main rooms and the openings;
- Location and shape of the openings;
- Size and details of the windows and doors;
- Organization and subdivision of the indoor space;
- Shading of openings and walls;
- Protection of openings against excessive solar access and rain penetration.
- Provision of verandas and balconies;
- Location of internal walls with respect to cross-ventilation;
- Roof type and form;
- Ceiling heights;
- Thermal and structural properties of the walls and roof;
- Location of particular rooms; and
- Materials used for construction and insulation.

To achieve the aim of this research, an understanding of vernacular architecture and contemporary passive design strategies in hot regions can assists providing the climatic design guidelines. The next section will simplify some of the techniques that can be used to achieve climatic design starting by clarifying the relationship between climatic design and vernacular architecture.

Climatic design and vernacular architecture:

The phrase “vernacular" or "traditional" as used in architecture denotes buildings produced by a cultural group for itself and serving as a framework for its daily life. Hassan Fathy explains how "*the vernacular architecture of the Arab world and neighbouring regions not only solved the climatic problems but did so with a combination of beauty and physical and social functionality*" (Oliver, 2003: 11).

Park (1998) stated that vernacular architecture is by its very nature “green” because it is profoundly linked to the land. The use of locally available materials; good orientation of buildings taking advantage of natural prevailing winds and sun patterns; using natural systems of solar heating and ventilation; and the use of durable materials means that many historic buildings already meet many of the principles outlined for new structures intended to be of a sustainable design.

Gedik (2004) and Hyde (2000) believed that climatic design can be learned from, and inspired by, observation of old traditional buildings. Traditional models can be examined as examples which inform the architecture, rather than providing a set of readymade solutions. Roaf et al., (2003 and 2005) maintains that traditional buildings have much to teach architects about how to design regionally suitable structures.

The features of vernacular architecture are useful in order to understand the importance of this architecture and how to improve these features to meet today’s needs.

Passive climatic design

Passive design is becoming the main approach in achieving sustainable architecture. Several theoretical and experimental studies have demonstrated the usefulness of Passive Design techniques. In the context of cooling buildings in hot-dry and warm-humid climates, passive techniques mainly aim towards reducing heat infiltration through the building envelope and the provision of fenestration for inducing desired natural ventilation indoors (Mathur and Chand, 2002). Reardon (2005) explained that passive design is design that does not require mechanical heating or cooling; dwellings that are passively designed take advantage of natural energy flows to sustain thermal comfort.

According to the U.S. Department of Energy (2004) and Panchyk (1984) passive solar design or climatic design is designing the components of a building: windows, walls and floors to collect, store, and distribute solar energy in the form of heat in the winter and reject solar heat in the summer.

Passive solar design techniques have been clarified by many references; for instance, the U.S. Department of Energy (2004) and Christensen (1994) who stated that there are three basic types of passive solar design; direct heat gain, indirect heat gain (thermal storage wall systems and roof pond systems) and isolated gain (solar green house). Others such as Evans (2007) and Roaf et al. (2003) added two other types; combined (mixing more than one type) and composite (mixing passive and active systems).

To sum up, the concept of passive climate control is completely in line with the notion of sustainable building. It provides an alternative to a mechanical air-conditioning system and, as such, can be an essential part of low energy solutions.

1.3 LIBYA: GENERAL BACKGROUND

Libya is located in the middle of North Africa. It is the fourth largest country in Africa with total area of 1.760 million square kilometres and the coastline along the Mediterranean Sea is 1955 kilometres long. The population (in 2006) was estimated to be 5.75 million. Tripoli is the capital (gpco.gov, 2005).

Libya is situated between 25° 00' North latitude and 17° 00' East longitude and Tripoli, the capital, is located at 32° 54' North latitude and 20° 4' East longitude (mapsofworld.com, 2007). Libya's latitude and longitude have placed it in a unique climatic zone where as many as five different types of climate can be observed, but the main climatic influences in Libya are the Mediterranean Sea, the Sahara desert and the mountain region. Dioxides (1964) confirmed that Libya geographically and climatically is divided into the some three regions; the coastal plain region; the mountainous region and the desert and semi-desert region (90% of Libya is desert). The weather in the Mediterranean region and semi Mediterranean Sea (coastal region) is hot and dry in the summer, mild and wet in the winter (photius.com, 2005).

The research focusses on Tripoli which is located in the hot-dry maritime climatic region. The main problem with this region is excessive heat and it has unusually large day – night temperature variation. In this region there are also periods of high humidity, which also has to be addressed.

Libya has been selected as the region of investigation for the following reasons:

- The northern Libyan climate is very representative of the Mediterranean climate as a whole with a very wide temperature range.
- This region includes examples of traditional buildings which are still occupied.
- Little research has been undertaken on this area.
- Previous research studies have shown that people in Tripoli, Libya prefer a number of features found in traditional houses (Amer, 2007; Madi, 2005; Emhemed, 1997).
- The experience of the author and the funding from the Libyan government.

Location of the case studies

For the purposes of this research Tripoli has been chosen as the location of the case studies because of the following:

1. The old city of Tripoli is one of the cities in North Africa where the geographical and climatic characteristics are similar to those in the Mediterranean region and this will mean that the findings can be applied more widely.
2. The cultural conditions are typical of those in most Moslem and Arab countries.
3. It is the capital of Libya, where about 40% of the total Libyan population resides, and data is available on the housing situation in the city.
4. Its old city is still in a good condition and holds good examples of local architecture whereas many old cities in the Mediterranean region have been almost destroyed. In fact, there remain a substantial number of traditional houses in Tripoli, which are largely unaltered from their original built state, are well maintained and are still occupied.
5. There are a range of good examples of modern construction to use in comparison with the traditional dwelling forms.
6. The researcher's professional experience is in this area and she has contacts there with agencies and construction professionals.

1.4 STATEMENT OF THE PROBLEM

The research problem addresses the interrelation between climatic design, vernacular architecture and the dynamics of change, development, environmental protection and sustainability. Many modern buildings in hot climatic regions do not perform well and require extensive use of mechanical systems in order to create a habitable, comfortable condition, which consumes energy. Much contemporary housing design in Tripoli is in the so-called international style that reveals similar characteristics in almost every part of the world with scant consideration of the local or regional architecture (Amer, 2007). Amer also shared some dissatisfaction with some aspects of traditional houses.

This raises the question of what type of architecture is needed to take proper consideration of environmental principles and the nature of the place. This study will explore whether and how climatic design can be used to address this problem by strengthening the interrelation between architecture and the local climate.

1.5 RESEARCH AIM AND OBJECTIVES

This research aims to provide guidelines for architects when considering how to practice climatic design in creating architecture related to the local environment that can provide more sustainable solutions in hot climate regions with a particular focus on Tripoli.

In order to achieve the aim of this research the following objectives were set:

1. To investigate the role of climatic design in providing a proper stable comfortable internal microclimate in a natural way.
2. To identify the characteristics of passive systems and natural energy in designing buildings and analysing the solutions of vernacular architecture, housing and passive design systems in a hot climate region.
3. To investigate traditional and contemporary housing characteristics in Tripoli in order to understand how these houses perform in the context of current life style needs and requirements.
4. To examine the degree of householder satisfaction with both traditional and contemporary housing in terms of the internal microclimate.
5. To explore the opinions of design and construction professionals in terms of climatic design of modern housing for Tripoli society.
6. To sample the temperature inside selected local and contemporary houses to clarify actual internal and external conditions.
7. To compare the opinions of householder and experts on the comfort conditions with the sample measurements taken in the houses, in order to understand and challenge the perceptions and expectations of comfort.
8. To establish a set of guidelines for designing new urban housing projects which use a combination of climatic design principles and contemporary technology to provide more

environmentally friendly housing solutions that meet social needs and functional expectations.

1.6 RESEARCH QUESTIONS

The main research question is:

1. How to practice climatic design in future housing in hot climates in a way that reinterprets the best features of traditional and contemporary approaches and provides a housing architecture relevant to the functional and environmental problems that are anticipated in this century?

To answer the main question, two subsidiary questions should be answered:

1. Why do we need climatic design and what are the underlying principles?
2. What can we learn from traditional housing solutions and can they deliver good performance for modern society?

1.7 STATMENT OF METHODOLOGY

This research examines the influences of climate in designing buildings in Tripoli, Libya. Understanding the quality of the buildings and meeting the physical and environmental needs required the following methodology was used.

According to Baker (2001) there are basically two contrasting extremes in research philosophies known as positivism and phenomenological or interpretiveism. However Saunders et al., (2003) expanded the categorization of philosophies by identifying another dimension of philosophy, named realism which falls within the two extremes. They stated that combining the two approaches is possible as it will enable the researcher to collect benefits from both.

The nature of architectural work is mainly to provide comfortable buildings for people; therefore, understanding peoples' opinion is very important as well as the performance of the building itself. Accordingly, the main research philosophy is interpretiveism; therefore, this research is mainly inductive. However, a deductive approach has been used to help contribute additional knowledge to the research, and in that way the different methods complement each other to reduce the biases inherent in the case study strategy.

To achieve specific research objectives, triangulation methods were used for data collection and data analysis. Each of the different methods (questionnaire, semi-structured interviews and focus group as well as direct observation, sampling and the collection of supporting documentation) are used to capture a more complete, holistic and contextual portrayal of the case studies and reveal the varied dimensions of the best way to conduct passive design in future housing. Moreover, methodological triangulation can be employed in both quantitative validation and qualitative inquiry studies. The research design adopted is both qualitative and quantitative. The principal data collected for this study are qualitative in nature and analysed using a non-quantified method by Excel and Nvivo software; quantitative data was also gathered, namely the sampling of temperatures in selected case studies.

1.8 LIMITATION OF THE RESEARCH

The opportunity to study sustainable architecture in general terms and climatic design for hot-humid regions specifically opens a very wide canvas. Therefore, the research scope has to be limited as follows:

- For fully sustainable housing, it is important to study all the 'triple bottom-line': the social, economical and environmental factors. This study touches two main aspects of sustainable housing, concentrating on those related to environmental performance but considering also the socio-cultural diminutions of ease of use in the Libyan context.
- The main objectives of climatic design are to help in solving three main problems: to reduce pollution, to reduce energy consumption and to provide local or special identity. This thesis concentrates on climatic design but does not explore fully all the possible dimensions of cultural identity.
- One of the main factors of climatic design is choosing appropriate building materials. This study addresses material selection primarily from the point of view of its thermal performance.
- Earth-sheltered and underground housing are ideally suited to this climate. This study does not fully cover this area of research.
- The study's aim is to provide general guidelines. However, in order to be fully implemented in any building, each guideline needs more detailed analysis (i.e., the appropriate windows' dimensions, overhangs' sizes for shading, specific kind of vegetation, etc.) These detailed studies are not addressed in this thesis.

- Various research methods and multiple data collection is used in this study; however, much more detailed measurements would be needed for a full scientific evaluation the thermal comfort and energy consumption.

1.9 JUSTIFICATION OF THE RESEARCH

This research examines the influences of climate in designing buildings in hot dry Mediterranean climate zones and in Libya in particular. This area of work has been selected for the following reasons:

1. In modern building greater reliance has been placed on mechanical cooling and ventilation equipment to provide comfortable conditions. In the U.S.A. energy consumption in the building sector accounts for 40% (EIA, 2006) and it accounts for 66% in Libya (GECOL, 2006);
2. In terms of the potential effect of dwellings on climate change, domestic heating and energy generation accounts for 81% of the total emissions of greenhouse gases with 78% being CO_2 (IPCC, 2001);
3. Contemporary Libyan architecture is typical of a number of Middle Eastern countries and now rarely recognises local climate, tradition, culture, or environment, and issues related to these subjects are usually neglected or rarely studied (Amer, 2007);
4. There is a strong risk that as the developing world industrialises it will follow the affluent countries and air-conditioning will become a user expectation and thus a standard feature in dwellings in hot climatic zones. If this trend remains unchecked this will raise energy consumption and CO_2 emissions;
5. Therefore there is a need to search for a modern architecture suitable for hot climatic zones that uses less energy intensive approaches and builds on natural or passive methods formulated through climatic and passive design principles;
6. Currently there is little research into the performance of, and user satisfaction with, buildings constructed using traditional climatic design principles in the Arab world;
7. As there are a number of traditional dwellings (which have intrinsically applied these principles) still occupied in Libya, then the study of these buildings can help to identify whether these principles can deliver modern buildings that can meet current user expectations and requirements.
8. The Libyan government has adopted new strategies towards sustainable urban development. Libya plans to develop the world's first eco-region, a 550,000-hectare site

of desert and forest that extends inland from the Mediterranean coast of Libya and is to be developed into the world's largest sustainable area by Sir Norman Foster (Brahic, 2007). Jackson (2007) and Rose (2007) have stated that Saif Al Islam Al Gaddafi has spearheaded the biggest sustainable tourism project in the world, in the Green Mountain area along the Mediterranean Coast about 1,200 km from Tripoli. These developments need to be informed by climatic design.

1.10 EXPECTED CONTRIBUTION TO KNOWLEDGE

This research is intended to make both academic and practical contributions as follows:

1. As mentioned in point 6 in the above section there is a shortage of empirical studies regarding the effective use of climatic design principles in Arabic countries and particularly in Libya. The contribution of this research will begin to fill the gap in the literature on Arabic countries;
2. Climatic design has been applied in a number of western countries. This study will explore how these principles need to be developed and adapted for the Arab world beyond the work already undertaken by Hassan Fathy and his disciples;
3. This study will provide a set of guidelines based on climatic design principles for use in designing new urban housing projects which may help the designer to find better solutions to the new buildings in the Mediterranean climatic regions;
4. The guidelines will provide useful support to the eco-region vision.

1.11 THESIS STRUCTURE

The thesis includes an introduction and seven chapters. This structure presents the different phases of the work chronologically.

Chapter one: An introductory chapter that provides the background study. It gives a general overview of the thesis, details the aspects that are investigated in this study and outlines the methodology and methods. It also provides the thesis structure.

Chapter two: looks at the main literature relevant to the research problem of this study. The chapter discusses and provides an overview of sustainable development as an important approach which deals with the natural environment generally, and the built environment in particular. It spans many disciplines; sustainable development, sustainable architecture and climate considerations.

Chapter three: reviews and assesses climatic design and its effects on architecture and urban morphology of the traditional built environment in different places in the world. It consists of two sections; it begins with traditional solutions and finishes with contemporary solutions.

Chapter four: deals with an overview of the Libyan profile and reviews the vernacular architecture from the climatic point of view. It provides detailed information about Tripoli as a case study.

Chapter five: presents the research methodology used in this study in detail and the organization of the case studies.

Chapter six: presents the empirical study. It aims to analyse the findings of the empirical investigations of the case studies.

Chapter seven: provides a discussion and comparison of the findings. It provides the final guidelines

Chapter eight: deals with the conclusion of the thesis discussing its achievements and contribution to knowledge. It concludes the work of the thesis, provides the final version of the guidelines and gives directions for future research.

CHAPTER TWO

CHAPTER ONE:	INTRODUCTION
CHAPTER TWO:	SUSTAINABLE DEVELOPMENT
CHAPTER THREE:	CLIMATIC DESIGN
CHAPTER FOUR:	LIBYA- GENERAL BACKGROUND
CHAPTER FIVE:	RESEARCH METHODOLOGY
CHAPTER SIX:	ANALYSIS OF THE FINDINGS OF THE QUESTIONNAIRE, INTERVIEWS AND TEMPERATURE MEASUREMENTS
CHAPTER SEVEN:	THE FINAL CLIMATIC DESIGN GUIDELINES FOR HOUSING
CHAPTER EIGHT:	CONCLUSION AND RECOMMENDATIONS

CHAPTER TWO: SUSTAINABLE DEVELOPMENT

2.1 INTRODUCTION

This chapter reviews and synthesises the relevant literature to further the discussion on climatic design in the built environment as shown in (Figure 2.1). In addition to exploring the literature it has three aims: (a) to establish the need for this research, (b) to establish simple alternatives for concepts of climatic design, and (c) to identify the aim and objectives of the research, and raise the research questions for the empirical studies.

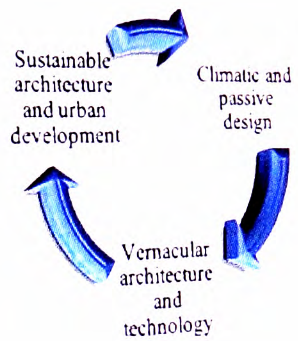


Figure 2.1: The main literature

This chapter uses the concept of sustainable development to offer a holistic perspective to the study of establishing a body of knowledge of passive climatic design that could be of benefit when designing future housing. (Figure 2.2) explains the relevant literature that needed to be explored in order to achieve the research aim. The review started with the big picture of sustainable urban development and its relation to sustainable architecture and building construction. There are 3 main factors to sustainable development: social, economical and environmental factors, the environmental factor is considered as the factor most related to climatic design and therefore, the emphasis in this thesis is on this factor. Accordingly, clarifying the impact of man and building on the environment will help to understand the research problem and answer the question why we need climatic design? After this clarification of the whole picture of the research, chapter three will go deeply into defining climate in general and its relation to internal thermal comfort in buildings. This will lead to an in-depth understanding of passive climatic design by addressing new techniques as well as old techniques from vernacular architecture supported by some examples. This part of study will help answer the last research question: what lessons can be learned from vernacular architecture? Also it will address the design strategies in warm-humid climates which could help in achieving the aim of providing guidelines to architects who are designing for hot regions generally and Tripoli, Libya specifically.

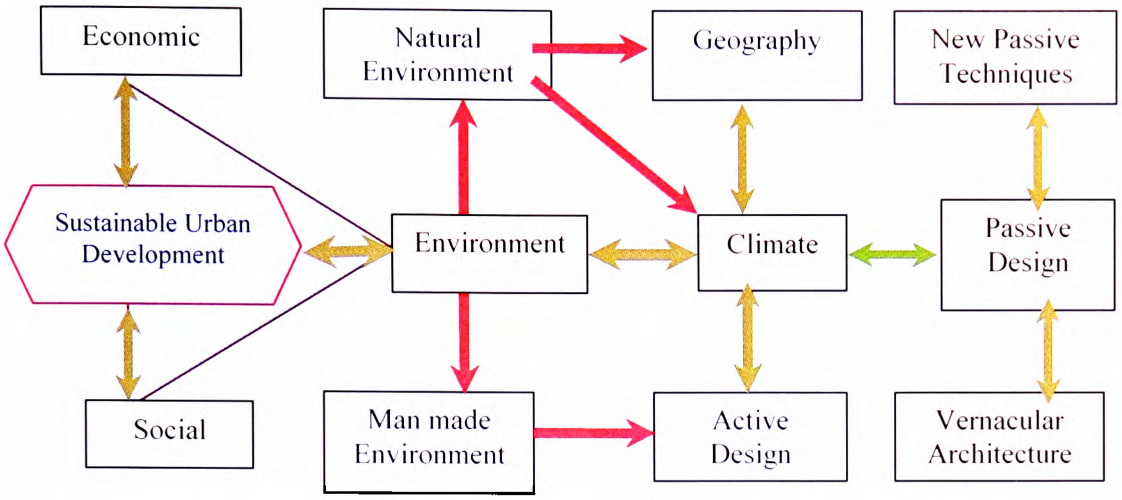


Figure 2.2: The relevant literature

2.2 SUSTAINABLE URBAN DEVELOPMENT AND SUSTAINABLE ARCHITECTURE

This part of the study discusses and provides an overview of sustainable development as an important approach for architects who deal with the natural environment generally, and the built environment in particular, to improve people's quality of life.

At the beginning of the environmental revolution between the 1960s and the 1970s damage to the natural system became a main concern. However, terms such as sustainability or sustainable development became mentioned more often during the last decade due to scientific evidence that excessive exploitation of natural resources in parallel with the ever-growing polluting agents would lead to irreversible environmental destruction (Gomes, 2003). Gomes explained that sustainable development is not a new idea; attention given towards the protection of farmland, forests, fisheries, cultural landscapes, historical areas and their aesthetics, etc., dates back at least to the eighteenth century. One of the early publications that increased public awareness about the environment was Rachel Carson's 'Silent Spring' published in 1962. This foreshadowed much of the understanding about people and environmental issues that face us today. She provided evidence on the impact of insecticides on ecology and proved the long-term existence of toxic chemicals in the land and in water and the presence of DDT even in mother's milk, as well as showing their danger to other living things, especially songbirds.

Brundtland (1987: 8) defined sustainable development (SD) as "...*development that meets the needs of the present without compromising the ability of future generations to meet their own* *needs*". This definition has since been accepted worldwide, despite some criticism for it being vague and subject to several different interpretations (Gomes, 2003).

For instance, at the Rio Earth Summit the 183 attending governments adopted the definition of sustainable development as given by the Brundtland Report (1987): "*Humanity has the ability to make development sustainable to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs*" (Brundtland Report, 1987:43). Emhemed (2005) also used the same definition and Sherlock (1991: 293) echoed Brundtland's definition: "*Sustainability means living now in such a way that we do not threaten future life*".

In addition, The Chartered Institution of Building Services Engineers 'CIBSE' (2007:5) has defined sustainability as "providing for the needs of the present without detracting from the ability to fulfil the needs of the future", and Canada's Commission on Conservation defined the need to live within the world's resources as: "Each generation is entitled to the interest on the natural capital, but the principal should be handed down unimpaired' (ORTEE, 1994).

On the other hand, McDonough (2000:17) thought that "*Sustainable development is a tentative concept that has not been defined very well*". He argued that there is still much debate as to what the word sustainability actually means and suggested that in its original context, the Brundtland definition was only the human point of view.

In order to embrace the idea of a global ecology with common values, the meaning must be expanded to allow all parts of nature to meet their own needs now and in the future. In more detail Robinson (2001) explained that sustainable development has many definitions but we can usefully think of SD in terms of 10 challenges: Clean Air; Transportation; Clean Water; Housing; Food; Jobs; Energy; Waste Disposal; Land Use, and Health Care.

According to the previous definitions, many references state that the key element of sustainable development (Figure 2.3) is integration across all three domains of SD: social, economic and environmental (Robinson, 2001).

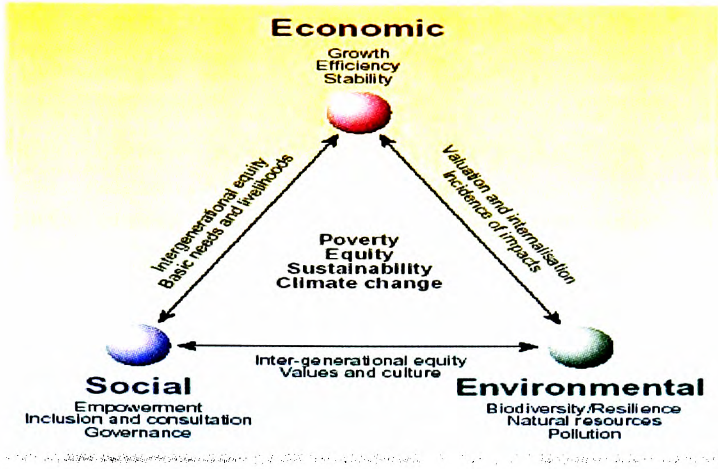


Figure 2.3: Elements of sustainable development. Source:Robinson (2001)

Evans (2007) clarified that the three domains of SD cited by Robinson are one of the three basic aspects of sustainable development (Figure 2.4), which are:

- Energy in the built environment, at national and international scale;
- Environmental impact of the built environment, caused by energy use at local, regional and world scale;
- Sustainability of the built environment, including the economic, social and environmental dimensions.

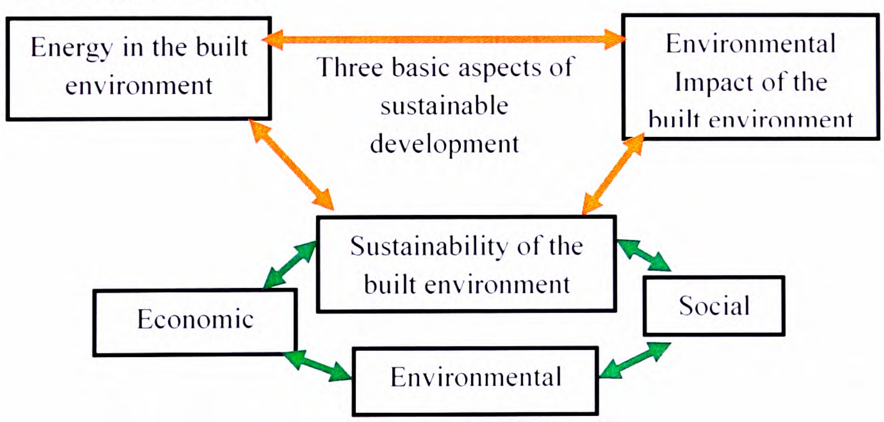


Figure 2. 4: Basic aspects of sustainable development
Source: Author based on Evans (2007)

Although Gomes (2003) stated that the term sustainable development is frequently considered vague and its many different interpretations have been criticised, sometimes as being conflicting, in practical terms the concept and the way it is understood by different institutions, organisations and other groups of people, may differ only slightly in some aspects. However, in the last four decades many actions occurred and events in the move towards sustainable development have been performed. Tzoulas (2006) stated that the idea of sustainable development can be traced back to the United Nations Conference on the Human Environment in Stockholm in 1972, followed by the Brundtland Commission report (1987).

A chronological summary of such dates as illustrated by CRISP (2001) is given in Table 2.1.

Table 2.1: Summary of the most important international steps towards sustainable development. Source: CRISP (2001)

1968	Paris Biosphere	Conference held in Paris that sounded the alarm of environmental degradation and the need for action.
1972	Limits to Growth	The so-called "Club of Rome" report, making the world aware that resources were not unlimited. "Limits" was published just prior to the Stockholm conference.
1972	Stockholm	First Conference of the United Nations on Environment. Call of the scientists for nature conservation
1980	World Conservation Strategy	Document prepared by the International Union for Conservation of Nature (IUCN), the UN environment programme (UNEP) and the World Wildlife Fund (WWF) on an integrated approach to global problems.
1986		Catastrophe of Chernobyl in Ukraine
1987	Brundtland Report for the United Nations	For a development which does not penalise the future generations. Identification of two risks: the greenhouse effect and the ozone layer destruction.
1987 /1993	Protocol of Montreal, London and Copenhagen Amendments	Commitment of the states to stop CFC consumption and production by 1/1/1995 and the HCFC consumption by 2015.
1992	Rio de Janeiro	Conference of the United Nations on Environment and Development: AGENDA 21, conventions on biodiversity and climate, statements on the forests. First perspective setting of the Northern and Southern approaches.
1994	Berlin	First Parts Conference: consensus to decrease back by 2000 the $C0^2$ emissions to their 1990 level.
1996	Geneva	Second Parts Conference on climatic changes: approval without reserve by the states of the IPCC (International Panel on Climate Changes).
1996	Istanbul	Habitat II Summit of the United Nations which recognised cities as partners of the United Nations and confirmed the Rio commitments.
1997	Kyoto	Third Parts Conference for the problem of global warming. By 2012 emissions of six major greenhouse gases must be reduced.
2001	New York	Habitat 2+5 implementation of the outcome from Habitat II
2002	Johannesburg	RIO+10 Conference on poverty, access to safe drinking water and sanitation, increasing the use of renewable energies and restoring depleted fish stocks.

The Rio agreements in 1992 formed a three points' framework of global concerns: energy (global warming and future supplies), ecology (biodiversity and rainforest protection) and environment (water resources and land). The agenda provided an inspiring fresh basis for architectural design such as attention to human activity being required, and building design informed by new concerns. Architects have to consider energy and other environmental resources and the building impact upon the ecology (Edwards and Hyett, 2001).

Curwell, in his chapter in Cole and Lorch (2003), cited ERC's (1996) four sided model of sustainable development (SD), known as PICABUE which includes; environment, equity, public participation and futurity. The different scales of response to SD in the urban environment, as approached in BEQUEST, are: a sustainable construction industry, a sustainable built environment, sustainable communities and global sustainability. Curwell also mentioned that there is a wide range of SD conceptual models, none of which provides an adequate representation of sustainable urban development. He identified a process model of SD (from the work of BEQUEST) as having five aspects:

- SD is a relative rather than an absolute concept;
- SD is a process, not a product or fixed destination;
- SD is concerned with a very long timeframe;
- SD is an ethical construct;
- SD must be culturally grounded (Curwell, 2003).

However, Jacobs (1999), who is quoted by Gann (2003: 41) in his chapter in Cole and Lorch, found that there are six core topics that emerge from the literature: environment-economic integration; futurity; environmental protection; equity; quality of life and participation.

The overall picture emerging from all these sources has been summarised by Cooper & Curwell (1996), (cited in Gomes 2003) into four principles given below:

- Environment: concern to protect the integrity of ecosystems.
- Futurity: concern for future generations.
- Public participation: concern that an individual can participate in the decisions affecting them.
- Equity: concern for today's poor and disadvantaged.

Sir Richard Rogers (2005), one of the most prominent members of the architectural profession, is a pioneer of the environmental cause believing that sustainability is not only about saving energy or money; it is about saving the planet.

In the speech by Saif Al-Islam Gaddafy, to a crowd of VIPs, local dignitaries and journalists, in the ruins of the Green Mountain's ancient city of Cyrene on the occasion of the announcement of the world's largest and most complete sustainable regional development project in Libya by Foster & Partners, he said "We must build our own societies in a way that minimises the release of greenhouse gases, while allowing every citizen to share in the social and economic benefits of a well-planned development". This statement has been quoted by many authors such as Rose (2007) and on many websites such as http://video.yahoo.com/watch/1145293/4131562

2.2.1 Guidelines for sustainable development

To meet the challenges of SD the process of defining actions/strategies to practise sustainability at local, national and international level is the main concern. Many organizations have defined sets of guidelines which usually include the main issues of SD, e.g. Gomes (2003) cited that BEQUEST (2000) had identified the policy issues considered to be the key critical success factors for effective change, such as:

"• *Whether sustainability assessment is mandatory or is just voluntary or market based,*

•*The need for integration of SUD issues and not just on economic regeneration but across spatial and temporal boundaries and across the various development and planning disciplines,*

•*Removal of technological and economic barriers to implementation through more effective replication of mainstream commercial constraints in demonstration and prototype schemes,*

•*Recognising the constraints of existing buildings and infrastructure and the need for an overall policy for managing the building stock as a whole,*

•*Decisions taken at the strategic level can be very constraining at lower levels"*

Gomes (2003) adapted guidelines for sustainable development from MRTEE (Manitoba Round Table on Environment and Economy, 1994) as follows:

1. ***Efficient use of resources:*** *encourage efficient use of resources and full environmental costing of decisions and developments.*
2. ***Public participation:*** *establish appropriate forums which encourage and provide opportunity for consultation and meaningful participation in the decision making processes by all citizens.*
3. ***Understanding and respect:*** *Understanding and respect for differing social and economic views, values and traditions and aspirations is necessary for equitable management of the common resources.*
4. ***Access to adequate information:*** *encourage and support the improvement and refinement of our environmental and economic information base and promotion of the opportunity for equal and timely access to information by all citizens.*
5. ***Integrated decision-making and planning:*** *encourage and support decision making and planning processes that are open, cross-sectoral, incorporate time horizons relevant to long-term implications and are efficient and timely.*

6. ***Substitution:*** *encourage and promote the development and use of substitutes for scarce resources where they are both environmentally sound and economically viable.*

Also, at the international level, Agenda 21 came out of the Earth Summit held at Rio in 1992 with its 27 principles all relevant for urban development. However, eleven of them are of particular relevance to urban re/development:

Principle 1*: Human beings are the centre of concerns for sustainable development.*

Principle 2*: They are entitled to a healthy and productive life in harmony with nature.*

Principle 3*: The right to development must be fulfilled so as to equitably meet developmental and environmental needs of present and future generations.*

Principle 4*: In order to achieve sustainable development, environmental protection shall constitute an integral part of the development process and cannot be considered in isolation from it.*

Principle 5*: All states and all people shall cooperate in the essential task of eradicating poverty as an indispensable requirement for sustainable development, in order to decrease the disparities in standards of living and better meet the needs of the majority of the people of the world.*

Principle 7*: States shall cooperate in a spirit of global partnership to conserve, protect and restore the health and integrity of the Earth's ecosystem. The developed countries acknowledge the responsibilities that they bear in the international pursuit of sustainable development in view of the pressures their societies place on the global environment and the technologies and financial resources they command.*

Principle 8*: To achieve sustainable development and a higher quality of life for all people, states should reduce and eliminate unsustainable patterns of production and consumption and promote appropriate demographic policies.*

Principle 10*: Environmental issues are best handled with the participation of all concerned citizens, at the relevant level.*

Principle 15*: In order to protect the environment, the precautionary approach shall be widely applied by states according to their capabilities. Where there are threats of serious irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation.*

Principle16*: National authorities should endeavour to promote the internalisation of environmental costs and the use of economic instruments, taking into account the* *approach that the polluter should, in principle, bear the cost of pollution, with due regard to the public interest and without distorting international trade and investment.*

Principle 17: *Environmental impact assessment, as a national instrument, shall be undertaken for proposed activities that are likely to have significant adverse impact on the environment and are subject to a decision of a competent national authority (BEQUEST 2001).*

The Sustainable Housing Forum (2003: 4) defined sustainable development as that which is designed and built to:

- Protect the environment, globally and locally and consequently, the critical life-support systems are maintained for present and future generations;
- Enable all people, now and in the future, to improve their quality of life through the pursuit of economic and social objectives, including social equity and environmental justice, in ways that simultaneously protect and enhance biodiversity, eco-systems and the earth's life-support systems, in particular:
  - By reducing global warming emissions;
  - By improving energy efficiency;
  - By reducing the consumption of natural resources, utilising renewable alternatives and minimising waste.

The CIBSE (2007:6) green guide defined sustainability as:

- Minimising natural resource consumption;
- Using renewable energy resources to achieve net zero energy consumption;
- Minimising emissions and greenhouse gases;
- Minimising discharge of solid waste and liquid effluents;
- Having minimal negative impacts on site ecosystems;
- Maximising the quality of the indoor environment.

Thus, Sustainable development is development that takes the impact on the environment into account and tries to minimise environmental damage. Sustainable architecture can be defined as a planned effort at designing a built environment that is energy and ecologically considerate both internally and externally. Accordingly the main goal of SD in the built environment is to protect and improve the quality of life as well as looking to the needs of future generations; consequently, sustainable architecture and building play an important role in the future development of the built environment. The principles of, and the importance of, sustainable architecture will be explained in the next section.

2.3 SUSTAINABLE ARCHITECTURE AND BUILDING CONSTRUCTION

Sustainability in general deals with the relationships between human and natural systems and considers the long term. Sustainable architecture can be defined as architecture that meets human needs and has a minimum impact on the natural environment.

Hassan Fathy stated that a building is affected by its environment, by the climate of the locality and the buildings around it in addition to the other aspects such as the social, cultural, and economic situation that help to form its existence. Fathy explained that modern architects create new and different architecture because they are attracted by new modern innovation, and they forget the environment into which they implant their buildings and by so doing fail to achieve a key aim of architecture 'to be functional'. Also they fail to realize that the form has meaning only within the context of its environment (Fathy, 1986).

Hillman referred to making future cities more sustainable from a broader perspective as "*...reducing demand for space and water, heating, power, lighting, use of motorized transport and increasing self-sufficiency in lifestyle practices, improved access to facilities used in daily life, more flexible use of buildings, more recycling, and more use of land for growing food*" (Hillman, 1996: 42).

The concept of sustainable architecture and construction appeared more or less at the same time as the evolution of the concept of sustainable development. Sustainable design is the conception and understanding of environmentally sensitive issues and a responsible expression as a part of the evolving matrix of nature (McDonough, 2000). The Centre for Construction Ecology as quoted by Edwards and Turrent (2000: 125) defined sustainable construction as the "*making and organization of healthy buildings based upon resource efficient and ecological principles*". It is dependent upon three key issues: (a) minimum disruption to the local environment (b) the construction system, and (c) construction waste management. Brown (1991) stated that sustainable design concepts that includes the primarily function of future technologies must maintain biological diversity and environmental integrity, contribute to the health of air, water and soils, and incorporate design and construction that reflect bioregional conditions and reduce the impacts of human use.

Cofaigh et al. (1996) described sustainable buildings as those that have minimal adverse effects on the natural environment, on their immediate surroundings and on the wider regional and global setting. On the other hand, Sherlock (1991: 293) emphasised reduction in the consumption of energy as a step towards sustainability and argued that the best way for this is "*...to reduce our need to travel ... to live in compact cities where everything is close at hand*". Therefore sustainable buildings means consideration of the buildings and their interrelationship.

A green building is a high performance property that considers and reduces its impact on the environment and human health. It is designed to use less energy and water and to reduce the impacts of the materials used. This can be achieved through better sitting, design, material selection, construction, operation, maintenance, removal and possible reuse (Yudelson, 2008).

Roaf et al. (2005) defined a sustainable house ('eco-house') as a house that is closely connected to the site, society, climate, region and planet. She and her co-authors asked the question why do we not make all buildings more ecologically connected in this way, and they recognised that more appropriate sustainable alternatives are still not acceptable to society as a whole, even when modern buildings are contributing to the trends which undermine the planetary systems.

Housing has a greater influence upon global and social harmony than any other building type. Family life, community cohesion and ecological well-being need to be supported by housing (Emhemed, 2005). To achieve sustainable housing in any society, a central role should be given to both architecture and urban design. Many authors who spotted the importance of sustainable housing such as Edwards and Turrent (2000: 7) stated that "*...living in harmony with the environment has become an essential component of the design of homes and neighbourhoods in the third millennium*". Furthermore, in Hilary Armstrong's interpretation of sustainable housing, "*...housing is sustainable if everyone has the opportunity of access to a home that is decent; if it promotes social cohesion, well-being and self-dependence*" (Edwards and Turrent, 2000: 2).

Edwards and Hyett (2001) defined sustainable housing as that which creates sustainable communities in a resource-efficient manner. The resources are energy, water, land, materials and labour. Sustainable housing brings together physical, social and cultural factors into a single agenda. They explained that sustainable housing projects need to be:

- Energy-efficient;
- Efficient in the use of other resources, especially water;
- Designed to create robust, self-sustaining communities;
- Designed for long life;
- Designed for flexibility in lifestyle and tenure;
- Designed to maximize recycling;
- Healthy; and
- Designed to embrace ecological principles.

Gilkinson and Sexton (2007:2) cited the definition of the sustainable housing project by the British Broadcasting Company (BBC): "Sustainable housing is a form of affordable housing that also incorporates environmentally friendly and community based practices. It attempts to reduce the negative impact that homes can have on the environment through choosing better building materials and environmental designs." The importance of the home as a starting point for successful communities has been emphasised by Edwards and Turrent (2000) as the main building block of successful communities. The home as a family unit addresses three different strategies, economic development, social welfare and environmental welfare (Figure 2.5).

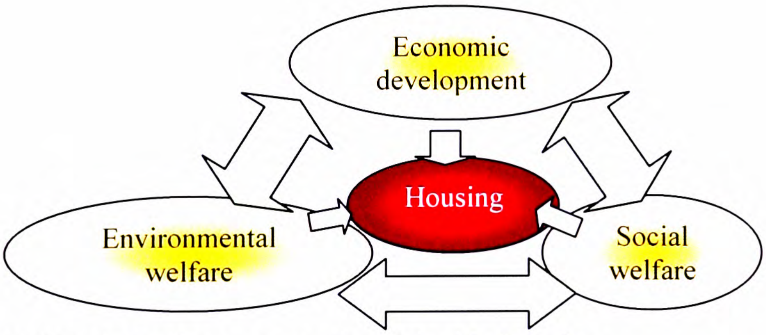


Figure 2. 5: The three dimensions of sustainable housing
Source: After Almansuri et al., (2009 D)

The impact of the built environment has been described by a number of authors (cited in Wetherill et al., 2007) as responsible for some of the most serious global and local environmental changes and has become a massive consumer of resources. Consequently, the construction industry is facing growing pressure to improve sustainability. To reach sustainability aims, it is accepted that the industry must change its approach to understanding the demands of society.

2.3.1 Principles of sustainable architecture

Sustainable design techniques are becoming increasingly important in building design. They should include all kinds of activities and processes that increase the capacity of people or the environment to meet human needs and improve the quality of human life. Many studies have been conducted on the principles of sustainable architecture. On this subject, studies by Park (1998), Edwards and Hyett, (2001), Reynolds (2000), John et al. (2005) and Wetherill et al. (2007) can be summarised as follows below.

Park (1998) believed that sustainable design encourages the use of natural and renewable materials, new technologies for the control of energy use, materials and products that have a long life and can themselves be recycled, and materials that can be efficiently maintained and renewed. Park summarised four major principles of sustainable building design as follows:

- Provide a healthy environment for the workplace by providing good ventilation;
- Select building technologies and materials that are "green", for example using local materials;
- Consume less energy in the new systems in the building than that consumed by market standards;
- Have a recycling plan for waste and water.

Edwards and Hyett (2001) confirmed that there are three key forces in the beneficial new world for design and construction;

- The use of ecology as a system;
- The broadening of sustainability agendas beyond merely energy conservation;
- The interaction between people, space and technology within a sustainability paradigm.

The same authors listed general rules in constructing more adaptable buildings as follows:

- The right of humanity and nature to exist in a healthy/sustainable condition;
- Recognize interdependence between human beings and the natural world;
- There are evolving connections between spiritual and material consciousness;
- Rely on natural energy flows;
- Understand the responsibility of design decisions upon human and natural systems' well-being;
- Create safe objects for long-term value; eliminate the concept of waste;
- Understand the limitations of design;

- Avoid functional specificity. Function is relatively short-lived compared to the structural life of buildings;
- Maximise access to daylight and natural ventilation;
- Maximise access to renewable energy;
- Designing for simplicity of operation, simplicity of service and construction allows for periodic upgrading and permits building users to understand the building;
- Design for long life. Long-lived buildings save on energy and waste. Low maintenance buildings may entail higher cost at their commencement but over their life time they are a wiser investment;
- Replaceability: It must be possible to upgrade a component or system within a building.

Reynolds (2000) set out the new design principles necessary for sustainability which are demonstrated by the "Hannover Principles", developed for EXPO 2000 held in Hannover, Germany. It includes:

- The right of humanity and nature to exist in a healthy/sustainable condition;
- Recognize interdependence between human beings and the natural world;
- Evolving connections between spiritual and material consciousness;
- Responsibility of design decisions upon human and natural systems well-being;
- Create safe objects to long-term value; eliminate the concept of waste;
- Rely on natural energy flows;
- Understand the limitations of design;
- Encourage direct communication between architects and local users.

To help the construction industry in its attempts to improve sustainability, Wetherill et al. (2007) proposed guidance which the industry should adopt:

- Minimisation of resource consumption;
- Maximisation of resource reuse;
- Use of renewable and recyclable resources;
- Protection of the natural environment;
- Creation of a healthy and non-toxic environment;
- Pursuit of quality in creating the built environment.

John et al., (2005) in their paper on sustainable building solutions, added some points which are quoted from the OECD and reported on them in their paper. They listed the five objectives for sustainable buildings as:

1. Resource efficiency;
2. Energy efficiency (including greenhouse gas emissions' reduction);
3. Pollution prevention (including indoor air quality and noise abatement);
4. Harmonisation with environment;
5. Integrated and systemic approaches.

In addition to the previous authors already mentioned, there are many other studies conducted on sustainable architecture such as those of Sherlock (1991), McDonough (2000), Cofaigh et al. (1996), John et al. (2005) and Roaf et al. (2005). According to all of these authors, the main principles of sustainable architecture are as follows:

- **Respect of the user's socio-cultural values**. Rapaport (1969) clarified that the variety in architectural form can be seen as a result of a host of social, cultural, economic, physical, and technological variables.
- **Adapting the climatic conditions.** Sustainable buildings should have the ability to benefit from local climatic conditions and adapt to the daily and seasonal climatic changes.
- **Energy conservation**. Buildings consume energy not only in their operation (for heating, lighting and cooling) but also in their construction. Construction often requires large amounts of energy for processes ranging from moving earth to welding. Also, the materials used in architecture must be produced, processed, and transported to the building site.
- **The use of local materials**. Using the provided local materials will significantly contribute in respecting and enhancing environmental issues.
- **Respect the location (site conditions).** It is essential to ensure that the building design and construction will not have a major effect on the site topography and the surrounding architectural style.
- **Water efficiency**. As water consumption is a serious ecological concern nowadays, it is imperative to consider regulating its use and reuse inside and outside buildings.
- **The use of natural light and ventilation**. Building and window design that utilizes natural light and ventilation will lead to conserving electrical lighting energy, shaving peak electric loads, and reducing cooling and heating energy consumption.

- **The studied use of colours**. Colours have physiological and psychological impacts on the human body and mind and in addition to their aesthetic values, they play a significant role in reducing and reflecting the solar radiation on external walls.
- **Treatments for ecological problems such as noise pollution**. Noise is like light in its effect on psychological human health; accordingly buildings should be protected from noise sources.

Based on these classifications, sustainable architecture and building design involves considering the whole life of buildings, taking environmental quality, functional quality and future values into account. It may be defined as design practices which struggle for integral quality, including economic, social and environmental performance in a broad way. This research will touch on various aspects of sustainability of buildings, but will concentrate mainly on those related to environmental performance especially climatic design considerations such as orientation, the building envelope, building materials, energy efficiency, passive ventilation and functionality. These areas are seen as the main building blocks for delivering environmentally sustainable building designs. The next section explores the environment as a major part of sustainable architecture and its relation to climatic design.

2.4 ENVIRONMENT

The environment is a complex system that makes up our surrounding circumstances, and enables us to live on the earth. It includes the air and water systems which cover most of the earth's surface, also the animals, plants and much more. The aim of this part of the study is to clarify two main points: (a) to verify the need for this kind of research, and (b) to answer the second research question which is why do we need climatic design? This section will elaborate the importance of environmental awareness especially to climate change, and the relationship between the manmade, environment and architecture. These are extremely important foundations that should be considered in climatic design (Figure 2.6).

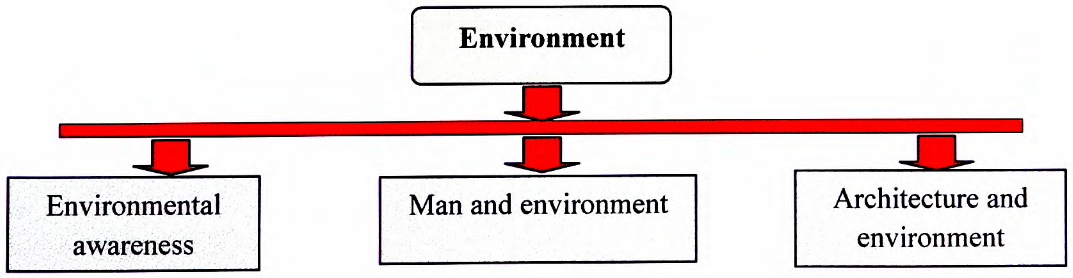


Figure 2. 6: The main parts of the environment

2.4.1 Environmental awareness and sustainable development

Rapoport (1977) defined the environment as series of relationships between elements and people, each relationship having a pattern. The environment reflects and helps relations and transactions between people and physical elements of the world. Whereas, Lawton described the environment as an ecological system having five components: the individual, the physical environment which includes all natural features and man-made features, the personal environment which is an important source of behaviour control, the super personal environment that results from the inhabitants, model personal characteristic and the social environment consisting of social norms and institutions (Lawton, 1970). Blowers (1993) clarified that there is no doubt that environmental concerns have become increasingly important and environmental awareness is now a serious part of future prospective. The environment seems to have become a main political concern at national and international levels since the end of 1980s.

Edwards (2003) suggested that climate change could be the greatest destabilising force politically and socially over the next century. A number of global environmental agreements have attempted to rectify the situation (see Table 2.2).

Table 2. 2: Global environmental agreements Source: Edwards (1999)

1972	Stockholm Conference on the Human Environment (UK)
1979	Geneva Convention on Air Pollution (UN)
1980	World Conservation Strategy (IL'CN)
1983	Helsinki Protocol on Air Quality (UN)
1983	World Commission on Environment and Development (UN)
1987	Montreal Protocol on Ozone Layer (UN)
1987	Our Common Future (Brundtland Commission) (UN)
1990	(Green Paper on the Urban Environment (EU)
1992	Earth Summit (Rio de Janeiro) (UN)
1996	Habitat Conference (UN)
1996	Kyoto Conference on Global Warming (UN)
2000	The Hague Conference on Climate Change

In support of this broader approach, Agenda 21, the report of the Rio Earth Summit (1992) promoted the reduction of CO_2 emissions as an important global issue and identified many problem areas that can engage designers, although some of these fall outside the traditional sphere of design activity. The report is extremely direct in its presentation of the challenge facing humankind.

The last 100 years has seen a further 25% increase in carbon dioxide and another doubling in the concentration of methane. The records show rapid warming until the end of World War 2, a slight cooling through the mid 1970s, and a second period of rapid warming since then, with the 1980s appearing to be the warmest decade (David et al. 1990). Similarly, Pitts (2004) maintained that the concentration of carbon dioxide in the atmosphere since 1750 has risen by more than 30%. Also Metz (2007) wrote of the increase in the atmospheric concentration of carbon dioxide and the greenhouse effect which contributes to global warming. Between 1970 and 2004 global greenhouse gas emissions had increased by 70%.

The UN Intergovernmental Panel on Climate Change (IPCC) has supported a report presented in 2001 on global temperatures which clarified that the increase in temperature was more than one degree Fahrenheit over the past century, and the hottest decade on record was the 1990s. The report states that the average temperature by 2100 will increase another 2.5 to 10.4°F which is more than 50% higher than the predictions of just five years ago (Environmental Defense, 2004).

Based on the frightening facts that are emerging about global warming and the effects of fossil fuel burning, buildings of the future should be in better harmony with their environment and should integrate the local influences of the specific climatic regions they are built in. Roaf, who is one of the main authors in the area of climatic design, claimed in a presentation in Tripoli (2007) that levels of atmospheric CO_2 now and projected for the next 100 years are higher than at any time in the last 440,000 years. The next section will explore this most difficult of environmental problems facing the world.

2.4.1.1 Global warming and climate change

Climate change is one of the most difficult problems facing the world today. The burning of fossil fuels together with a range of man's activities and the resultant increase in carbon dioxide emissions has become a main cause of global warming and climate change.

A considerable amount of literature has been published on climate change, most of which shows that we are facing a really dangerous problem. Most of the scientists believe that CO_2 emissions cause global warming and climate change through the greenhouse effect. Currently 40% of all CO_2 released within the built and human environment is from domestic housing (Gilkinson and Sexton 2007).

Edwards and Hyett (2001) identified four key interactions in global warming: transport, buildings, waste and consumption and population growth (Figure 2.7).

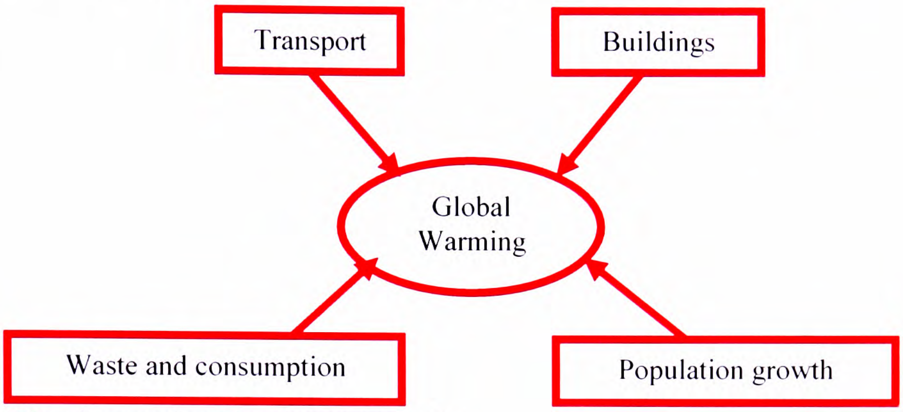


Figure 2. 7: Key interactions in global warming
Source: After Edwards and Hyett (2001:23)

El-Tantawi (2005) stated that the number of scientific publications on various aspects of climate change reached 7,000 abstracts during the period 1951-1997 covering 95% of the literature , with a steep exponential growth rate, doubling every 11 years.

The Energy White Paper (2003:6) stated that "*Climate change is real. Levels of CO_2 in the atmosphere, one of the main causes of climate change, has risen by more than a third since the industrial revolution and is now rising faster than ever before. This has led to rising temperatures: over the 20th century, the earth warmed up by about 0.6°C largely due to increased greenhouse gas emissions from human activities. The 1990s were the warmest decade since records began*".

In Mediterranean countries, where the climate is mild and hot, the increased use of air conditioning is a real problem for global warming because of the extensive use of fossil energies that are used for electricity generation (Bouguerra et al., 2010).

Davidson (2007) summarised the outcome of climate change as follows:

- It is very likely (over 90%) that human activities are causing global warming;
- Probable temperature rise by the end of the century ranges between 1.1 and 4.5°C;
- Sea levels are likely to rise by 28-43cm;
- Arctic summer sea ice is likely to disappear in the second half of century;
- It is very likely that parts of the world will see an increase in the number of heat waves;
- Climate change is likely to lead to increased intensity of tropical storms.

DEFRA (2004) confirmed that global warming will not only be felt many decades from now but that it is already happening and its impacts are obviously visible, and it has become the deepest environmental challenge of our time. Scientists have shown that the earth's average temperature has risen slightly in the last few decades, and the average temperature at the surface of the earth has increased over the past century by about 0.6°C (Figure 2.8).

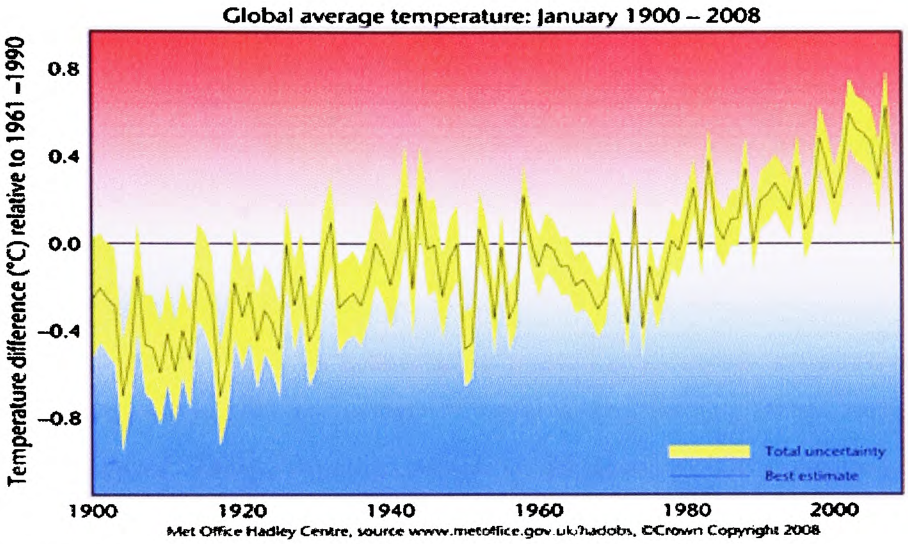


Figure 2. 8: Global average temperature - January 1900-2008
www.metoffice.gov.uk/corporate/pressoffice/2008/pr20080305b.html#g_a_r_temp

It is generally recognized that the IPCC is the most reliable body in the world on this subject (e.g. Roaf (2007) and others) and it will be a major source in this project.

The IPCC (2007) explained that warming of the climate system is evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global mean sea level. These direct observations are as follows:

1. Since 1850, in the instrumental record of global surface temperature, eleven of the last twelve years (1995-2006) were among the twelve warmest years;
2. Since at least the 1980s, the average atmospheric water vapour content has increased over land, ocean and in the upper troposphere;
3. The average temperature of the global ocean has increased since 1961 to a depth of at least 3000 m and the ocean has been absorbing more than 80% of the heat added to the climate system;
4. Mountain glaciers and snow cover have declined on average in both hemispheres;
5. New data since the Third Assessment Report shows that losses from the ice sheets of Greenland and Antarctica have very likely contributed to the sea level rise between 1993 to 2003 'by approximately 3.1 mm per year'.

Evans (2007:10) related the impact of climate change in the building sector to two complementary aspects, mitigation and prevention, with the following considerations:

- Mitigation: To reduce energy demand and the resulting emissions through improvements in building design as well as the introduction of building plant with improved efficiency.
- Prevention: Incorporate measures in building design to respond to the predicted future changes and reduce the unfavourable consequences.

El-Tantawi (2005) stated that warming over Libya was similar in magnitude to the global increase. Globally, the 1990s was the warmest decade since records began and 1998 was the warmest year in the last century. In Libya, it has also been observed that the 1990s was the warmest decade, while 1999 was the warmest year. The same source stated that the expected impacts of climate change will be acute in different aspects, such as bio-diversity, food security, water resources and human health. Libya is potentially one of the countries most at risk from the effects of climate change because it has limited natural resources (water and soil); it is located in an arid and semi-arid zone and more than 95% of its people live in its coastal zone which is threatened by sea level rise. Accordingly, Libya is vulnerable to climate change.

The need to become more environmentally aware is widely accepted. Thompson and Sorvig (2000; ix) supported this and stated "*mankind aided by technology, is well on the way to reversing, within the course of a few centuries, a process of 50 million years. We are consuming oil and coal reserves at a rate two million times faster than these reserves took to grow, and we are living well beyond our means at the expense of nature*". The World Energy Council (2007) maintained in its report on Energy and Climate Change that over 80% of man-made emissions of CO_2 come from industry and agriculture.

Roaf (2007) was sure that the rise in carbon dioxide in the atmosphere by over 30% (as reported above) was due to human activities. The IPCC (2007) adopted the Summary for Policymakers from the first volume of "Climate Change 2007". This report confirmed that it is more than 90 percent certain that human activities, led by burning fossil fuels, explains most of the warming in the past 50 years. The impact of man and architecture on the environment will be clarified in the next section.

2.4.2 Relationship between man and the environment

We are living during a unique time in human history, when mankind has largely achieved the ability to control aspects of his/her local environment. However the means by which this control is achieved is largely through energy intensive technologies contributing to the increase in CO_2 and to climate change problems as well as other issues such as local atmospheric pollution. Therefore, the relationship between man and the environment has become difficult and contentious.

Donnellan (2001) clarified that human activities have increased the amount of carbon dioxide in the atmosphere over the past 200 years by over 30%. In the same book, UNEP and WCMC gave other information about the impacts of human activities summarized as: from 80 to 85% of the carbon dioxides being added to the atmosphere as a result of the use of fossil fuel, burning coal, oil, and natural gas, concentration has increased 25% over the last 200 years.

In 1970 at the University of Essex, Hassan Fathy said that every advance in technology has been directed toward man's mastery of his environment. Until very recently, however, man always maintained a certain balance between his bodily and spiritual being and the external world. Disturbance of this balance may have a harmful effect on man, genetically, physiologically, or psychologically and however fast technology advances, all change must be related to the rate of change of man himself (Steele, 1989). Our early associates lived in sympathy with nature and lived in the moment. Fathy (1986) confirmed that man has for a long time reacted to his environment, using his materials to develop techniques and technologies, in the past he lived attuned to the environment. Edwards and Hyett (2001: 2) stated "*CO_2 production is essentially an urban consequence but the levels of emissions depend upon many factors: climate, land use patterns, density and lifestyle*".

The severity and potential impact of the predicted climate changes, is largely produced as a result of man's activities. IPCC (2000:4) states "*there is new and stronger evidence that most of the global warming observed over the last 50 years is attributable to human activities*". Also the IPCC (2007) mentioned in the Fourth Assessment Report (which describes progress in understanding the human and natural drivers of climate change) that global atmospheric concentrations of carbon dioxide, methane and nitrous oxide have increased markedly as a result of human activities.

Environmental Defence (2004) confirmed that scientists have reached a general consensus that human activity is causing the planet to warm up and human-induced increases in atmospheric carbon dioxide and other greenhouse gases covering the earth in a thermal layer are pushing temperatures to extremes. Mungall and Mclaren (1990) described mankind as an animal that has moved out of ecological balance with its environment. They added that humankind has become the dominant force in changing the surface of the earth and an extravagant destroyer and a despoiler of other life on the planet and that mankind is also dominant in effecting and changing the earth's surface. In more detail, they explained that human activities in combination with new technologies are producing a large number of new and highly specialized chemicals that change our environment.

Similarly, Angell (1990) stated that, as a consequence of our greediness and ignorance, the world is becoming a place which brings restlessness and fear to many living beings. In addition, Fathy (1986) confirmed that all environmental changes must be related to the rate of change of man himself and the abstractions of the technologist and the economist must be continually pulled down to earth by the gravitational force of human nature.

Gore (1992) wrote in his book that the new relationship between human civilization and the earth's natural balance have usually had a huge impact on the environment and have become the dominant cause of change in the global environment. He added that this century has viewed remarkable changes in two factors that classify the physical reality of our relationship to the earth; a sudden surge of human population and the sudden acceleration of scientific and technological revaluation.

Similarly, Mclaren (1990) thought that there are two major forces preventing us from reaching true global sustainability: the growth in population and the continuous growth in using fossil fuels. Moreover, Kassuba (1980) clarified the situation concerning the growth of population over a period of time: by 1850 the number of humans on the earth reached the first billion which took millions of years, and 80 years further on (1930) another billion was added, by 1961 the third billion was added, and after only 16 years fourth billion was added; which means a lot of people appearing on earth in such a short amount of time.

The different effects of human activities, as provided by Wang and Chameides (2005) include the increase of buildings and infrastructure into inappropriate locations, the inappropriate use of coastal land, and the degradation of wildlife habitats; all these can compound the damage caused by global warming. McDonough (1993; 8) clarified his view on human needs as "*We need to listen to biologist John Todd's idea that we need to work with living machines, not machines for living in. The focus should be on people's needs, and we need clean water, safe* *materials, and durability. And we need to work from current solar income*". In support of these visions, Wetherill et al. (2007) explained that sustainable design is being supported on a global and inter-professional scale and that the world needs facilities that are more energy efficient that encourage preservation and recycling of natural resources.

A diagnosis of the global problem of climate change and its effects on life and the planet indicates that if we wish to maintain a worthwhile living environment for our children and future generations, a change towards a lower energy and/or a lower carbon society is a key part of more sustainable development. As more industrial and technical devices have been used without realising their side effects, the urban built environment has become the most energy consuming sector of society, contributing between 50 - 70% of CO_2 emissions directly through the heating and cooling of buildings and through the mobility requirements of urban populations. "*It is the responsibility of our generation to begin to adapt our buildings to ensure that we can stabilise climate change*" (Roaf et al., 2005:13).

According to the facts human activity is mainly responsible for climate change and urgent actions are needed to reduce environmental problems. It is essential that communities develop the ability to make informed decisions about their development strategies. Therefore major challenges that face the design profession exist in promoting implementation of climatic design and engaging the wider construction industry and the general public in the task of improving the environment performance of our buildings, neighbourhoods and cities. The next part of this study will discuss the importance and the impact of architecture on the environment.

2.4.3 Environment and architecture

A building is affected by its environment, the climate of the locality and the buildings around it in addition to the other aspects such as social, cultural, and economic aspects (Fathy, 1986). McMullan (2002:2) identified that '*the built environment is formed by buildings and structures that humans construct in the natural environment*'.

Although buildings and development provide numerous benefits to society, they also have significant environmental impacts. The impact of contemporary buildings has been highlighted by Enertia Building Systems (EBS) (2006). Building is the second largest industry in the world after agriculture, and the pollution from heating and cooling of buildings causes the main damage to the environment and is growing to be greater than that from cars. In this context, Krawietz (2006) identified that more than 50% of the energy produced is used in buildings and thinks that architects have, and will continue to have, an even more important role for the future of the planet. Furthermore, Lupton and Stellakis (2003: 1) clarified that "*buildings in total account for 46% of the UK's CO_2 emissions or approximately 63.5 million tonnes of carbon per year*". This includes construction, use, demolition and disposal. Evans (2007) also explained that while attention is placed on the impact of climate change and global warming in the occurrence of extreme events, small increases in the mean temperature will have a significant effect on the energy demand for the air conditioning of buildings.

Energy has become the most important resource for the development of any country and consumption of energy and energy demand worldwide has increased year on year over the last twenty years. Bouguerra et al. (2010) expected that world electricity consumption will be doubled by 2025 and that there will be a projected growth average of 3.5% yearly. Using air conditioning especially in mild and hot climates contributes to increasing electricity consumption. Elkhalifa and Balila (2010) believed that heating and cooling buildings contributes to more energy usage than any other aspect of a building's use. Consequently, the option of increasing dependence on natural lighting and passive heating and cooling is one of the most important choices.

Wafa (2006) explained that the concern about the consequences of standard building construction have prompted countless experiments and design improvements to make the built environment more energy efficient, less reliant on potentially limited CO_2 emitting fossil fuels and more reliant on renewable energy resources. Roaf et al. (2005) clarified that the diagnosis of the global problem of climate change and its effects on life and the planet indicates that in order to maintain a worthwhile living environment for our children and future generations, a change towards lower energy and a lower carbon society is an essential part of more sustainable development.

Ahsan and Svane (2010) stated that one of the major factors in the increased use of electricity by higher income groups is the use of air conditioning units. They concluded that the process of designing energy efficient residential buildings is through the acceptance of shared responsibility by architects, developers, interior designers and clients, who are the actors who can bring about a change in design practice.

In terms of the Libyan situation, the annual statistics from 2005 of the General Electric Company of Libya (GECOL) (2006) state that the amount of energy consumption during the five years (2001-2005) increased sharply from 12.921 GW/h in 2001 to 18.893 GW/h in 2005 (Table 2.3). Also GECOL (2009), in their annual report in 2008, stated that the amount of energy production had increased by 13% since 2007 (Figure 2.9).

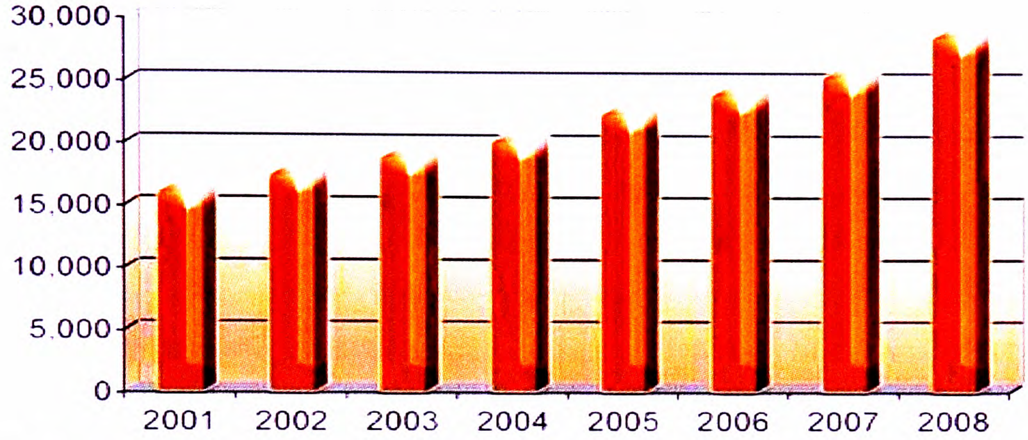


Figure 2.9: Development of energy production in Libya. Source: GECOL (2009)

In addition, according to 2002 estimations, energy consumption in Libya was 69.2 % from oil and 30.8 % from natural gas. The emissions of CO2 were attributed mainly to oil (71.7 %) and 28.3 % to natural gas (EIA, 2006), which means that the energy sector, which is the main source of greenhouse emissions in Libya, depends mainly on fossil fuels (oil and natural gas). Furthermore, El-kadi (2010) confirmed that the built environment produces 40 to 50% of greenhouse gasses production and 40% of the total energy consumed in Europe is related to buildings. Wafa (2010) stated that building accounts for 45% of worldwide energy use; specifically, it accounts 60% of Libya's, 45% of the EU's and 36% of USA's primary energy consumption.

Table 2. 3: Libyan energy consumption (GWh) Source (GECOL) 2006

Years	2001	2002	2003	2004	2005
Energy Consumption	12,921	14,208	15,527	16,548	18.893

2.4.4 The role of architects in protecting the environment

The important role of architects in protecting the environment has been mentioned by many authors. Gann (2003) stated that, as a result of the increasing concerns about global climate change, there are increasing forces on professionals to design buildings that are more environmentally friendly and can resist future changing weather. Fathy (1986) criticised modern architects because they are attracted by modern innovation, by creating new buildings of a different architecture and forget the environment into which they implant their buildings and fails to recognise the aim of architecture 'to be functional'. They also fail to realise that the form has meaning only within the context of its environment.

Fordham (2000) suggests that architects and engineers can help change the amount of energy consumption and CO_2 produced from buildings by analysing the energy use and flows. Roaf et. al., (2005) requested that users and owners of buildings wake up and take on a responsibility to future-proof their own interests against the demands of climate change. El-kadi (2010:85) stated that architects and architectural technologists have moral and ethical responsibilities towards the environment and that there is a need for cultural and professional step change. *It is not enough to pay lip service to the sustainability challenges*'. Edwards (1996, xiv) stated: "*Architects have a larger share of responsibility for the world's consumption of fossil fuel and global warming gas CO_2 than any other group. The structures that architects and engineers design, the way buildings are sourced and how they adapt over time influence the use of fossil fuel and production of UK*".

Similarly, many institutes and architects have responded to earlier discussions on the role of architects in the creation of a sustainable society. For instance, the World Congress of Architects (1993A) clarified that to minimise future poverty and to restore already degraded environments, architects are challenged to lead the way into the new field of environmentally conscious architecture and sustainable development that translates the requirements of a practical global ecosystem into the built environment. At the World Congress Expo 93 held in Chicago in June 1993, the International Union of Architects (UIA) and the American Institute of Architects (AIA) signed a Declaration of Interdependence for a Sustainable Future. The declaration states that today's society is degrading its environment and that the architects are committed to:

- Placing environmental and social sustainability at the core of practices and professional responsibilities;
- Developing and continually improving practices, procedures, products, and standards for sustainable design;
- Educating the building industry, clients and the public about the importance of sustainable design;

- Working to change policies in governments so that sustainable design becomes fully supported;
- Bringing the existing built environment up to sustainable design standards.

Constructing Excellence in the Built Environment (2008) set a checklist for designing for environmental sustainability as follows:

- Design for minimum waste of materials.
- Protect and enhance biodiversity using the biodiversity EPI (European Pollinator Initiative).
- Specify local and low environmental impact materials.
- Minimise energy use (eg lighting, heating/cooling, ventilation, insulation).
- Specify flexible information and communication services.
- Ensure high indoor air quality through effective ventilation, and specifying materials, finishes and cleaning products with minimal harmful effects.
- Specify zero ozone depletion and low NOx systems and materials.
- Ensure fittings use low volumes of water. Consider rainwater and grey water recycling.
- Discourage single-occupant car use through public transport and cycling provision, making the development safe and secure, providing showers and changing rooms.
- Consider ease of operation and maintenance through the commissioning time.
- Consider day lighting, ventilation, humidification, personal control, and space for well-being and comfort.
- Design for flexibility or deconstruction with minimum waste.

Translating theses general principles for housing Enertia Building Systems (EBS, 2006) explain that the aim of environmental architecture is be attractive, comfortable and reasonable and that it does not damage the earth in its construct, or its use. This can be achieved by the following:

- The house must be more comfortable and cost less;
- There should be a maximum use of renewable building materials and a minimum use of non-renewable, energy-intensive building materials like steel, brick, vinyl, aluminium and insulation materials;
- Designing with nature by capturing the energy falling on the house; and
- Design and build for a long useful service life and ensure that the house is strong and disaster resistant.

Thus review of the literature leads to the inevitable inference that, although contemporary architecture may be succeeding in providing a comfortable interior environment, the use of energy to supply this level of comfort and convenience contributes damage to the environment and is unsustainable. Therefore, to continue to deliver high levels of functionality, environmental comfort and beautiful surroundings, raises the question that if architects work within the local climate context and respect the environment would this be effective in reducing the environmental impacts and provide a comfortable interior environment in a natural way that works with and harnesses the climate. The next section will give a general idea about climate and its importance in the built environment.

2.5 CLIMATE

'*The revolution of the globe gives the heartbeat of day and night which regulates the activities and responses of natural life*' (Olgyay, 1969:1). Many references define climate as the integration in time of the average weather conditions characteristic of a geographical location during a period of time, usually about 30 years (Koenigsberger et al.,1974). Climate is the general weather conditions over a long period of time; it is the sum of all the statistical weather information that helps describe a place or region (CLEAR, 2004). Climate is described through variables such as temperature, humidity, light, rainfall and wind.

When the short term variations of weather (sun, atmospheric pressure, wind, temperature) are observed at one place and are considered over a period of time they form a climate (McMullan, 2002). Hyde (2000) and Sartogo (2008) defined climate as the broad meterological condition relating to a region; it is related to the temperature, humidity, wind, vegetation and light specific to a geographical location. They also classified three levels of climate conditions: firstly, global conditions which dominate the geographical features of land, sea, sun and air of the region; next, local conditions which depend on water, topography, vegetation and the built envionment. Finally, there is the site conditions and building context.

2.5.1 Weather

Weather is the condition of the atmosphere at a particular place and time measured in terms of such things as wind, temperature, humidity, atmospheric pressure, cloudiness and precipitation (Hui, 1997). In most places, the weather can change from hour-to-hour, day-today and season-to-season. It is a composition of all meteorological variables (Olgyay, 1969). CLEAR (2004) add to above definition and state that weather is the current atmospheric conditions which are happening right now or is likely to happen tomorrow or in the very near future. The difference between climate and weather is that climate is the average pattern of weather in a place. While weather may change substantially from day-to-day, when changes in climate occur, they usually happen gradually over many years. For the purpose of building design, three components of weather that are most important are described in the next section.

2.5.1.1 Air temperature

CIBSE (2006:8) defined air temperature as "*the dry bulb temperature of the air in the space and is measured by a thermometer that is protected from any radiant heat exchanges, or is not affected by them*". Heat capacity is the amount of heat required to raise the temperature of a unit volume of material or a unit area of surface by one degree (Givoni, 1976). For architectural design purposes, the available local meteorological data on air temperatures can be used.

Baccoush (2006) clarified the heat transfer from one space to another happens through three methods; radiation, conduction and convection (Figure 2.10). He classified the heat gain to internal spaces into three types; direct heat gain, heat gain through roofs and walls and ventilation heat gain. The total amount of heat gain through openings (doors and windows) can be calculated by using this equation: (Q=A(I) 0) where A= area of window, I= radiation heat flow density and 0= solar gain factor of window glass.

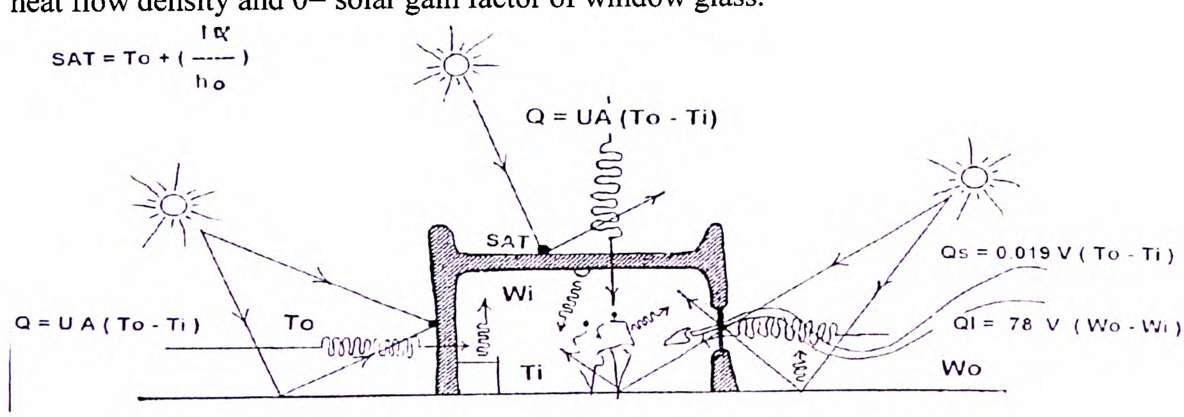


Figure 2. 10: Methods of heat transfer to interior spaces. Source: Baccoush (2006)

2.5.1.2 Air movement

In zones where humans live air movement and its speed and direction are important in achieving comfort because moving air will cause a cooling effect as heat is removed from the body by convection and evaporation. Ventilation is required to provide air for respiration and to achieve acceptable air quality (CIBSE, 2006).

Hui (1997) confirmed and specified that air quality is dependent upon the provision of ventilation, and cross ventilation is far more important in the tropics than in temperate zones. Greeno (1997:75) defined ventilation as "*the process of changing air in an enclosed space*". Accordingly, ventilation is needed to replace polluted air with clean air. Evans (2007) clarified that the use of cross ventilation or sensible air movement is one of the main strategies to reduce indoor temperature and that a variation of ventilation rates at different times of the day can help to achieve a significant reduction in internal temperature by increasing cooling when external air temperatures are lower at night.

McMullan (2002: 94) listed the following factors as the objectives of ventilation:

- Supply of oxygen;
- Removal of CO_2;
- Control of humidity for human comfort;
- Control of air velocity for human comfort;
- Removal of odours;
- Removal of micro-organisms, mites, moulds and fungi;
- Removal of heat;
- Removal of water vapour to help prevent condensation;
- Removal of particles such as smoke and dust;
- Removal of organic vapours from sources such as cleaning solvents, furniture and building products;
- Removal of combustion products from heating and cooking;
- Removal of ozone gas from photocopiers and laser printers; and
- Removal of methane gas and decayed products from ground conditions.

2.5.1.3 Relative humidity:

Relative humidity is the amount of moisture in the air. It is defined as the ratio of the absolute humidity to the maximum water vapour capacity of the air at a given temperature and CIBSE Guide A recommends that relative humidities in the range 40-70% RH are generally acceptable (CIBSE, 2006).

2.5.2 Classification of climates

Classification of climate for the purposes of building design by means of regions is undertaken because the differences of climate from region to region is reflected in the building design. Different regions of the world have different climate characteristics (CLEAR, 2004). Based on this criteria, Köppen (1918) established a classification system consisting of main climate groups, which were subdivided into climate types and subtypes. Köppen's classification includes quantitative definitions for these climate categories based on temperature and precipitation indices and uses two- and three-letter codes to designate climate types (Briggs et al., 2002). Köppen divides climate into five main groups and several types and subtypes:

Tropical climates: These climates are characterized by a constant high temperature. All twelve months of the year have average temperatures higher than 18°C. They are subdivided into 3 groups: tropical rain forest climate, tropical monsoon climate, tropical wet and dry or savanna climate.

Dry (arid and semi-arid) climates: These climates are characterized by the fact that precipitation is less than potential evapotranspiration.

Temperate climates: These climates have an average temperature above 10°C in their warmest months, and a coldest month average of between −3°C and 18°C. They are subdivided into: Mediterranean climate, humid subtropical climate, maritime temperate climate, the temperate climate with dry winters and maritime sub-arctic climate or subpolar oceanic climate.

Continental climates: These climates have an average temperature above 10°C in their warmest months, and a coldest months' average below −3°C. They are subdivided into: hot summer continental climate, warm summer continental or hemiboreal climate, continental sub-arctic or boreal (taiga) climate and continental subarctic climate with extremely severe winters.

Polar climates: These climates are characterized by average temperatures below 10°C in all twelve months of the year.

Rudolf Geiger presented the latest version of the Köppenin map in 1961; they presented a new digital Köppen-Geiger world map on climate classification for the second half of the 20th century (Figure 2.10) Kottek et al. (2006). Peel et al. (2007) produced a new global map of climate using the Köppen-Geiger system. They stated that globally the most common climate type by land area is BWh (14.2%, hot desert) followed by Aw (11.5%, tropical savannah).

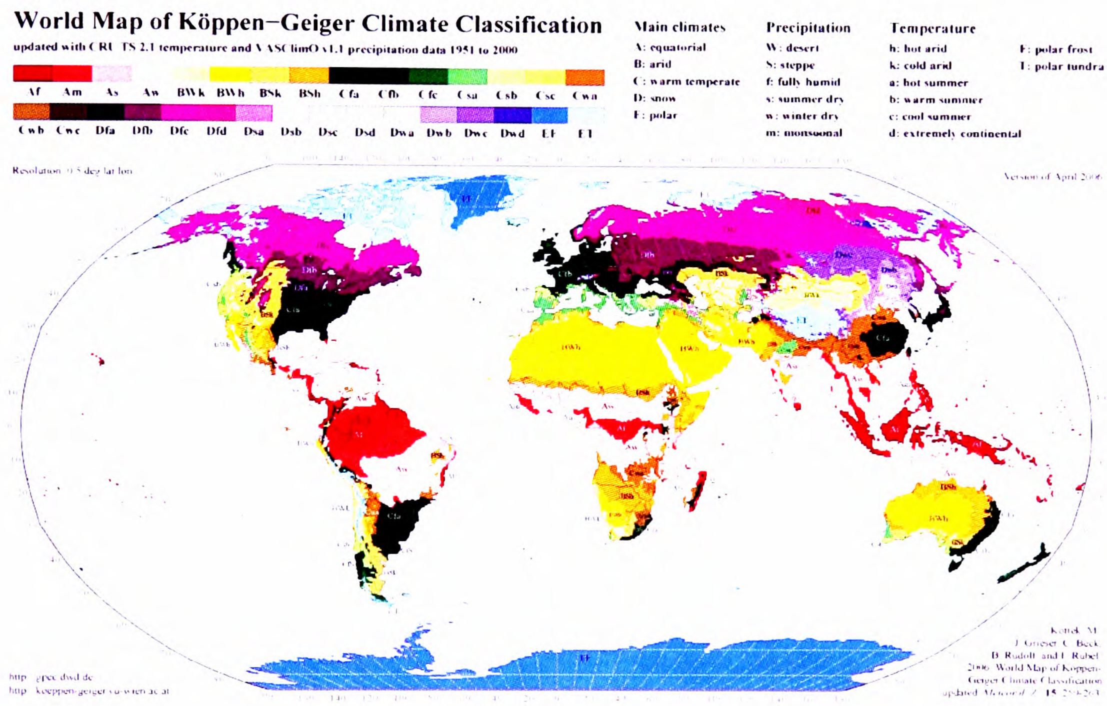


Figure 2.11: Köppen-Geiger world map. Source: Kottek et al., (2006)

Mathur and Chand (2002) indicated that there are five major climatic zones (hot-dry; warm-humid; cold; temperate and composite) and gave more specific maximum monthly temperatures which are different from those of Köppen as shown in (Table 2.4).

Table 2. 4: Five climatic zones. Source: After Mathur and Chand, (2002)

Climatic Zone	Mean Monthly Maximum Temperature °C	Mean Monthly Relative Humidity %
Hot-Dry	Above 30	Below 55
Warm-Humid	Above 25	Above 75
Temperate	Between 25-30	Below 75
Cold	Below 25	All vales
Composite	-	-

For the purposes of building design a simple system based on the nature of the thermal problem in the particular location is often used, for example, Hui (1997), as follows:

- **Cold climates**: where the main problem is the lack of heat (under heating), or an excessive heat dissipation for all or most parts of the year.
- **Temperate climates:** where there is a seasonal variation between under heating and overheating, but neither is very severe.
- **Hot-dry (arid) climates**: where the main problem is overheating, but the air is dry, so the evaporative cooling mechanism of the body is not restricted. There is usually a large diurnal (day - night) temperature variation.
- **Warm-humid climates**: where overheating is not as great as in the hot-dry areas, but it is aggravated by very high humidity, restricting the evaporation potential. The diurnal temperature variation is small.

alternativly, Coch (1998) classified the climate into three basic types of climate: cold climates, dry warm climates and wet warm climates, and he stated that two further cases can be added; windy climates, complex climates.

The climate in hot areas can be classified and summarised as follows:

- **Hot-dry (desert climate) climates**: where the main problem is overheating, but the air is dry. Coch (1998) described these regions as having high average temperatures and there is usually a large diurnal (day - night) temperature variation in the daily cycle, very low humidity and very directional solar radiation, no cloud cover and practically no rainfall, and dry winds which are warm and heavy with dust. Day time air temperatures may range between 27°C-49 °C; however, at night it falls to be more or less 22°C. Humidity in general is continuously moderate to low. A sub-climate of this region is maritime desert where the sea is connected to a large area of desert.
- **Warm-humid climate:** where the overheating is not as great as in hot-dry areas, but the temperature is made worse by very high humidity; control of the evaporation and the temperature variation is very small. The range of air temperature is located between 21°C - 32°C with little variation between day and night. According to Koenigsberger (1974) the sub-climate of this region is warm humid island climate which affects islands inside the equatorial belt (an unreal line that goes around the Earth and divides it into two parts).
- **Composite climate** is the combination of warm-humid climates and hot-dry climates. Their characteristics change from season to season. The sub-climate is tropical upland climate.

Koenigsberger et al. (1974) expanded this composite climate to include mountainous regions and big flat area of lands of height more than 900m to 1200m above sea-level.

Evans (2007) summarised the characteristic climatic variables (Table 2.5) with reference to the main seasons using the climate and sub-climate classifications established in subsections.

Table 2. 5: Climate classification. Source: Evans (2007)

Climatic variable		Warm humid	Hot dry	Comfort	Cold	Very cold
Typical temperature °C		20 – 30	15 – 35	15 – 25	5 - 15	< 5
Relative humidity %		> 80 %	< 60 %	60 – 80	-	-
Temperature swing deg C		< 10° C	> 12° C	8 – 12	< 10° C	-
Climate classification	Latitude					
Warm humid	0 -15°	X				
Hot dry	20 - 35°		X	X		
Transition	10 - 30°	X	X	X		
Monsoon	5 - 30°	X	X	(X)	X	
Equatorial upland	0 - 20°			X	(X)	
Maritime desert	20 – 35	X	X			
Subtropical	30 – 40	(X)	X	X	X	
Temperate	40 – 50			X	X	
Alpine-Andean	30 – 50			X	X	X
Cool temperate	40 - 55			X	X	
Cold	> 50°			(X)	X	X
Very cold	> 60°				X	X

Note: (X) indicates short seasons with the defined conditions or possible climate variations.

Pidwirny (2006) cited the factors influencing the world climatic regions as:

1) Latitude and its influence on solar radiation received.
2) Air mass influences.
3) Location of global high and low pressure zones.
4) Heat exchange from ocean currents.
5) Distribution of mountain barriers.
6) Pattern of prevailing winds.
7) Distribution of land and sea.
8) Altitude.

2.5.3 Climatic elements

Hui (1997) sets out the main climatic elements which are regularly measured by meteorological stations; as temperature, humidity, air movement, precipitation, cloud cover, sunshine duration and solar radiation. For the purposes of building design, the four constituents of climate most important are temperature, humidity, solar radiation and air movement (Table 2.6).

Table 2.6: Common climatic elements for building design. Source: After Hui, 1997)

Temperature	Monthly mean of daily maxima (deg C) Monthly mean of daily minima (deg C) Standard deviation of distribution
Humidity	Early morning relative humidity (in %) Early afternoon relative humidity (in %)
Solar radiation	Monthly mean daily total (in MJ/m2 or Wh/m2)
Wind	Prevailing wind speed (m/s) and direction
Rainfall	Monthly total (in mm)

2.5.4 Sources of climatic data

Meteorological stations provide weather data which is usually analyzed and presented in tabular form and/or in graph form. Some design handbooks and standards also provide general climatic data for building design. The statistical analysis of climatic data over the long term will offer a summary of weather information for a particular location (Hui, 1997). The main factor affecting comfort in buildings which climatic design should take it into consideration is thermal comfort. The next section will clarify the importance and effects of thermal comfort in building design.

2.6 THERMAL COMFORT

The primary aim of most buildings' heating and cooling system design is to provide thermal comfort for human occupants. Thermal comfort in buildings is an important consideration in the design of buildings for efficiency and also for the well being of the occupants (Mathur and Chand, 2002). Brage and Cole in their chapter on the 'Historical and Cultural Influences On Comfort Expectation' obtained the answer to the question what is comfort as seen through history as responding to various social, technological, economic and cultural influences, but today the term comfort relates to a physical condition and, in particular, a thermal condition of well- being and satisfaction. It is a complex perception and is the intersection between objective motivation with cognitive and emotional processes (Cole et al., 2003).

The indoor environment should be designed and controlled so that the occupants' comfort and health are assured (CIBSE, 1999). CIBSE (2006:1) explained that "*the primary aim of building services systems is to create, and maintain a comfortable environment*".

Many references define thermal comfort as the state of mind which expresses satisfaction with the thermal environment and is assessed by subjective evaluation (ISO Standard 7730; ASHRAE standard 55-2004; CIBSE guide A. 1999; Panchyk 1984). "*In general, comfort occurs when body temperatures are held within narrow ranges, skin moisture is low, and the physiological effort of regulation is minimized*" (ASHRAE, 2001:81). CIBSE (2006:4) describe thermal comfort as "*where there is broad satisfaction with the thermal environment i,e most people are neither too hot nor too cold*". Similarly, Abdin (1982) defined a comfortable zone for human beings as the situation where no feeling of discomfort is experienced.

CLEAR (2004) state that the thermal aspects of buildings consists of three parts, climate, buildings and people which interact both directly and indirectly. Different elements of the building such as thermal mass, insulation, window size, orientation and shading devices can help to optimise indoor comfort and energy use in different climates. Thermal comfortable conditions are defined to be between the temperatures of 21.1°C in winter and 26.7°C in summer and between humidity of 20% to 80% (Givoni 1976). Vitruvius (1999) explained that 1°C reduction in design air temperature for a heating or cooling system can save up to 10% in energy consumption.

Thermal comfort is an important part of people's overall comfort and thermal discomfort causes people to react in different ways. The next part will illuminate thermal comfort and its relationship to the human body.

2.6.1 Man and thermal comfort

The human body consumes food energy to produce heat energy, which must be released at an appropriate rate to maintain a constant body temperature. Victor Olgyay (1963) defined the comfort zone as the point at which man can spend minimum energy adjusting to his environment.

Most references (such as CIBSE, 2006; Osbourn and Greeno; 2002, Abdin, 1982) state that the human body must maintain an internal organ temperature of 37°C. McMullan (2002: 9) states "*the physical comfort of humans greatly depends upon the physical factors; temperature, quality of air, lighting and the acoustic environment*".

The processes by which the human body exchanges heat with its environment has been defined by many references (such as Olgyay, 1963; McMullan, 2002 and CIBSE, 2006) as the processes of convection, radiation and evaporation (Figure 2.11). Osbourn and Greeno (2002:84) clarified that these factors will "*ensure the physiological and psychological well-being of occupants*".

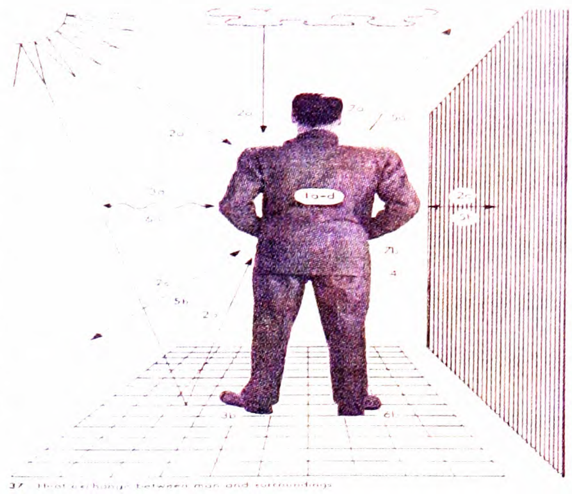


Figure 2. 12: Heat exchange between the human body and its surroundings.
Source: Olgyay (1963)

Fanger (1970: 21) noted that "*man's thermoregulatory system is quite effective and will therefore create heat balance within wide limits of the environmental variables, even if comfort does not exist*". In terms of physical feelings, index PMV predicts the mean value of the votes of a large group of people on a 7-point thermal sensation scale: hot, warm, slightly warmer, neutral, slightly cooler, cool and cold. From the physiological point of view, thermal comfort occurs when there is a thermal equilibrium in the absence of regulatory sweating in the heat exchange between the human body and the environment.

Other climatic factors besides air temperature and humidity that affect comfort level are solar radiation and air movement (Olgyay 1963). On the other hand, Fanger (1986) and CIBSE (2006) identify six factors that affect thermal sensation. These factors can be subdivided into environmentally controlled and individually controlled variables. Personal variables include: activity and thermal insulation of clothes. Environmental variables include: air temperature, air speed, humidity and mean radiant temperature. CIBSE (2006) added another four environmental factors affecting thermal comfort which include: temperature variations in the space; air and radiant temperature differences; localised radiation and warm or cold floors.

Personal variables:

- Activity: Increased activity causes the body to give off more heat, subsequently lower temperatures can be endured. McMullan (2002:66) stated "*the rate of heat emission depends upon the individual metabolic rate of the person and upon their surface area*".
- Clothing: Increased layers of clothing provide improved protection against cold conditions.

Physical variables:

- Air temperature: McMullan (2002: 66) stated "*the inside air temperature is the average temperature of the bulk of air inside a room*". CIBSE (2006) related the level of comfortable temperature to activity and clothing level.
- Surface temperatures: The radiant properties of surrounding surfaces will affect the rate at which heat radiates from a person. The average effect of radiation from surrounding surfaces is called the mean radiant temperature.
- Air movement: McMullan (2002: 68) stated "*the movement of air in a room helps to increase heat loss from the body by convection*".
- Humidity: Moisture in the air causes humidity and the amount of moisture dictates the intensity. McMullan (2002: 69) stated "*relative humidity within a range of 40-70% provides comfortable conditions*"

Accordingly, the environment which is measured using instrumentation (air temperature, radiant temperature, humidity and air movement) and the clothing worn by subjects and their activity and use of controls should noted. The conclusions of tests undertaken by Fanger and others in Denmark were:

- There is no significant difference in comfort perceptions due to geographical location or season (including tropical regions);
- There is no significant difference due to age, sex or body build;
- There is no significant difference due to ethnic origin.

Hedge (2006: 5) confirmed that the effects of age and sex are "*non-significant... and relate to activity and clothing.*" On the other hand, McMullan (2002: 65) states that "*the total quantity of heat produced by a person depends upon the size, the age, the sex, the activity and the clothing of the person*". Similarly, Abdin (1982) clarified that human comfort needs depend on the conditions of the surrounding environment and the way man exchanges heat with it; it differs with individuals, their type of clothing and the nature of their activities. Moreover, it depends on sex as women generally prefer an effective temperature for comfort 1°C higher than men.

There is, however, some debate over the actual influence of age and sex. It is argued that only activity and size actually affect the quantity of heat produced and the other factors are mistakenly interpreted. CIBSE (2006) explained that building designers should provide comfortable conditions for the largest number of occupants by considering comfort requirements and setting appropriate design criteria.

2.7 SUMMARY

Based on the previous classifications, sustainable architecture and building design involves considering the whole life of buildings, taking environmental quality, functional quality and future values into account. It may be defined as design practices which struggle for integral quality, including economic, social and environmental performance in a broad way. This chapter touched on various aspects of sustainable development and the sustainability of buildings, with concentration on those related to environmental performance because these areas are seen as the main building blocks for delivering environmentally sustainable building designs. The chapter raised the important role of architects in protecting the environment by adopting sustainable architecture strategies.

As the environmental impact of buildings becomes more apparent, a new field called 'green building' is gaining drive. Consideration of the climatic influence on buildings and the thermal comfort of the occupants thus plays a vital role in selecting sustainable technologies. The climate has a major effect on building performance and energy consumption.

The most critical part of building design is to identify, understand and control the climatic influences of the building. The key objectives of climatic design include: reducing the energy costs of a building, using natural energy instead of mechanical systems and power, and providing a comfortable and healthy environment for people.

For the efficient thermal comfort of buildings in hot climates, importance has to be given to summer cooling more than winter heating, while the role of natural ventilation and day lighting become fundamental.

Understanding the local climate and its influences on life is essential for the design of a lower energy, lower carbon, and therefore more sustainable future. The current understanding of how to design with climate is summarised in the next chapter.

CHAPTER THREE

CHAPTER ONE:	**INTRODUCTION**
CHAPTER TWO:	**SUSTAINABLE DEVELOPMENT**
CHAPTER THREE:	**CLIMATIC DESIGN**
CHAPTER FOUR:	**LIBYA- GENERAL BACKGROUND**
CHAPTER FIVE:	**RESEARCH METHODOLOGY**
CHAPTER SIX:	**ANALYSIS OF THE FINDINGS OF THE QUESTIONNAIRE, INTERVIEWS AND TEMPERATURE MEASUREMENTS**
CHAPTER SEVEN:	**THE FINAL CLIMATIC DESIGN GUIDELINES FOR HOUSING**
CHAPTER EIGHT:	**CONCLUSION AND RECOMMENDATIONS**

CHAPTER THREE: CLIMATIC DESIGN

3.1 INTRODUCTION

The previous chapters presented the definitions of climate and comfort and man's relationship with climatic conditions. In this chapter, passive climatic design strategies to improve thermal comfort by using the thermal characteristics of the building envelope and other strategies such as ventilation, shading devices and so on, are presented. Climatic design has been promoted as an essential approach in achieving sustainable built environment. Many books, web sites and researchers have tried to define climatic design. This section presents some of these definitions to examine the growing understanding of the issue of climatic design, and reviews some of the literature related to climatic design.

Climatic design is, in essence, to take maximum advantage of nature and the climate in particular to design a built environment. It may seem to be a new trend in building design, but it is an idea that has been with us for a long time. It generally employs a passive approach often referred to as Passive Design. "*Passive design is a process by which the natural environment outside buildings, and the conditioned environments to be created within them, are analysed in parallel with the ways in which the building envelope filters that climate and tempers the internal environment. Passive design works with these analyses and develops ideas/strategies for the design of whole buildings that have minimal reliance on mechanical plant*" (Dowdle, 2003: 3).

Fathy (1973:3) believed that "*Over many centuries, the people in each part of the earth have learned, by trial and error, how to deal with their environment; their solutions to the problem of housing grew out of countless experiments and accidents, out of the experience of generations of builders who kept what worked and rejected what did not, and these solutions were passed on as tradition.*" Arslan and Kumkale (2005) confirm Fathy's opinion that man, in order to survive, observes nature and by imitating and understanding the processes in nature provides solutions for his existence. Cofaigh et al. (1996) stated that climatic architecture has become a concern in the mind of many architects and when the majority of them realise the importance of working with, and not against, the climate the term will change to architecture.

The idea of climatically responsive design is to modulate the conditions such that they are always within, or as close as possible to, the comfort zone (CLEAR, 2004). Foster and Partners define sustainable design as: "Creating buildings which are energy efficient, healthy, comfortable, flexible in use and designed for long life" (Foster and Partners, 1999). The shift towards green design began in the 1970s as a practical response to higher oil prices and from the late 1980s in response to the next big shock of climate change (Roaf et al., 2005).

The importance of climatic design has been declared by many authors such as Roaf et. al., (2003) who has identified 4 main reasons for bioclimatic design:

- The rate of change in the level of climate variability and modification is increasing, requiring human adaptation to a rapidly warming world;
- The fundamental means to this adaptation is the adoption of more effective and widely used methods for passively cooling buildings;
- Air conditioning systems are increasingly seen as a part of the climate change problem, as well as its solution. A problem is not only the rising cost of energy, but the energy used to run these systems is a major contributor to greenhouse gas emissions;
- It is very important to create a new 'cool vernacular' building approach, which matches human and environmental needs.

Hyde (2000) mentioned that climate responsive design is an essential part of the environmental framework that is being developed to reduce environmental impacts and provide for human well-being. Evans (2007) confirmed that the preservation of environmental variables favouring comfort can be achieved through two alternative mechanisms: the use of bioclimatic design resources or by mechanical plant. However, climatic protection and taking advantage of good conditions not only implies the search for comfort and well-being, but also the better use of renewable energies which could help in the reduction of demand for fossil fuels.

3.2 CLIMATIC DESIGN IN ARCHITECTURE

The goal of bioclimatic design in architecture was defined by Szokolay (1995: 71) as the need to "ensure the development and well-being of biological organisms (principally human) subject to specific climatic conditions".

The concept of bioclimatic design is introduced in a large majority of texts. The first documentation of architectural design with climate interests in mind dates back to the fourth century B.C. in Greece (Turner, 2003). The philosopher Vitruvius is quoted as saying, "*We must at the outset take note of the countries and climates in which buildings are built*" (Oktay, 2002). The important references to bioclimatic design have been cited by Evans (2007) as follows:

- Olgyay (1970) developed the sequence **'climate–biology–technology architecture'**, and expanded in the text on the application of the method to cover climate data, biological evaluation of comfort, technological solutions and architectural implementation.
- Koenigsberger et al. (1977) presented the sequence **'climate–comfort–indicators-(design) recommendations'.** At the same time, two application stages are identified: initial design stage and detail design.
- Koenigsberger et al., (1980) also included the sequence developed in the Mahoney Tables.
- Givoni (1978) employed the terms **'climate–comfort–architecture',** used as the title of his book.
- Markus and Morris (1980) identified the elements of the environmental system for buildings without artificial conditioning as: environmental resources (microclimate); protection system (ground, vegetation, building elements); modified climatic system; human system, and the controlled environment.
- Evans (1980) proposed the sequence **'climate–comfort–design'** in his book 'Climate, Comfort and Housing'.

Preliminary design solutions considering the orientation and the aspects of building form can be deduced by analysing annual/seasonal distribution of solar radiation, wind speed, wind direction, air temperature and relative humidity (Mourshed et al., 2005).
Cofaigh et al. (1996) and Givoni (1998) summarised the main objectives of bioclimatic design in hot-humid regions as follows:

- Minimising solar heating of the buildings;
- Maximizing the rate of cooling in the evenings;

- Providing effective natural ventilation, even during rain;
- Preventing entry of insects while the windows open for ventilation; and
- Providing spaces for semi-outdoor activities as an integral part of the living space.

Ahmad et al. (2007) listed a range of issues that can be useful to achieve bioclimatic design such as:

- Climate types and requirements;
- Adaptive thermal comfort;
- Vernacular and contextual solutions;
- Tools and assessment methods;
- Microclimate: sun path, wind and rain;
- Working with the elements, such as passive and active systems;
- Development of a responsive form.

The North Carolina Solar Center, (NCSU, 2002) explained that passive solar homes make efficient use of our energy resources and provide a healthy space for owners. They assumed that a solar home, if it responds well to the climate, can achieve the following: internal comfort; economic, durable and attractive conditions, and be environmentally responsible.

3.2.1 Tools used in pre-design climate analysis:

To successfully create climatic design, architects must consider passive climatic design strategies during the early design stage. Analysing the climate in pre-design stages has been mentioned by many authors. For instance, NCSU (2002) stated that in order for passive solar concepts to be most effective when applied, they needed consideration from the preliminary stages of design. De Schiller and Evans (1996) stated that the ability to design green buildings depends on the building professionals' skills to identify variations of climatic parameters within a site, to develop awareness of possible future modifications produced by the introduction of new built forms and to use this potential during the design process at different scales of application. Hui (1997) clarified that different design situations will require different weather data and climate analysis at the initial design stage which may be used for the following:

- develop design strategies
- check condensation problems in some cases

- optimisation of insulation

The same source stated that calculating load and energy at the outline and detail design stages will require weather data for the:

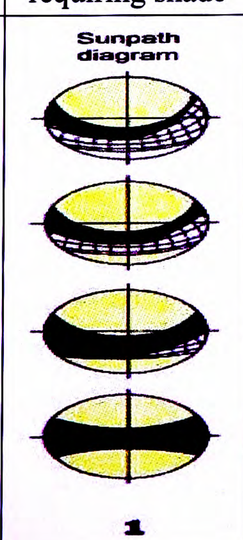
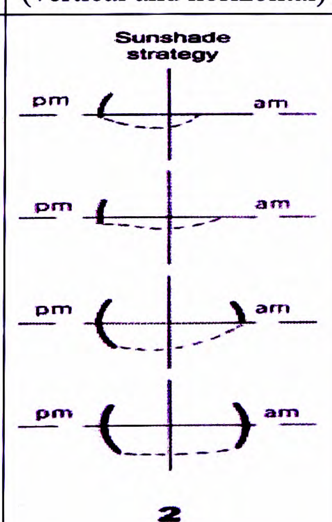
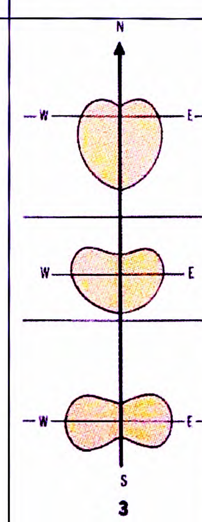
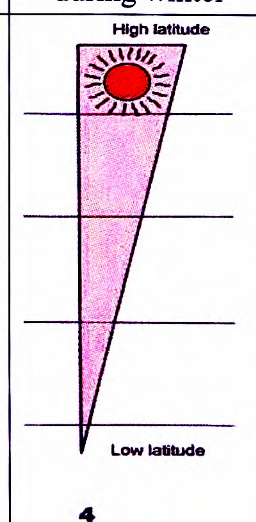
- calculation of cooling and heating requirements
- design of heating, ventilating and air-conditioning (HVAC) systems
- energy estimation of buildings

Many pre-design tools have been developed in order to help architects design buildings in the schematic design stage. Visitsak (2007) listed very useful pre-design tools and methods of climatic analysis and graphical presentations which included the following:

- "Shading Mask Protractor";
- "Timetable of climatic needs ;
- "Horizontal sun path diagrams ;
- "Vertical sun path diagrams";
- "Sundial diagrams".

Sunshade analysis can be used to avoid the inward flow of heat, either direct or indirect. The surfaces on which the sun's rays fall must be protected by solar shading devices which can extensively improve thermal comfort and reduce cooling loads and potential glare problems in highly glazed buildings. Hui (1997) gave an example and explanation of sunshade analysis as shown in (Table, 3.1).

Table 3. 1: Example and explanation of sunshade analysis
Source: Author after http://www.arch.hku.hk/~cmhui/teach/65156-7b.htm

Regions	Solar paths requiring shade	Sunshade analysis (vertical and horizontal)	Insulation	Sun requirements during winter
COOL TEMPERATE ARID TROPICAL				

Some models which have been designed to give advice on climate responsive buildings have been summarised as follows:

- **Building bioclimatic charts**:

"*The building bioclimatic chart indicates that whenever ambient outdoor temperature and humidity conditions fall within the designated limits of a control strategy, then the interior of a building designed to effectively execute that strategy will remain comfortable*" (Watson and Labs, 1983:33)

The charts facilitate the analysis of the climate characteristics of a given location from the perspective of human comfort and refer to the comfort zone, as they present, on a psychrometric chart, the combination of temperature and humidity at any given time (Sayigh and Marafia, 1998). To create the chart, local data should be collected and recorded regularly and then charted based on annual percentages.

The bioclimatic chart is important because it can provide building design guidelines and allows builders and architects to figure out the right specifications for design factors such as orientation, location, size, shading, and form (Turner, 2003). Climatic graphs and charts in architectural design are very useful for climate analysis since they can assist understanding at a glimpse and provide a quick comparison of data (Hui, 1997).

- **Olgyay's bioclimatic chart**:

A bioclimatic chart was one of the first attempts at an environmentally conscious building design. Victor Olgyay developed the first bioclimatic chart (Figure 3.1) in the 1950s to incorporate the outdoor climate into building design (Olgyay, 1963:22). The axis of the chart includes the dry bulb temperature and relative humidity which creates the "zone" in which other important characteristics can be calculated. Olgyay's chart is a "zone of human comfort in relation to ambient air temperature and humidity, mean radiant temperature, wind speed, solar radiation, and evaporative cooling". If the temperature and relative humidity fall below the lower limit, shading is required to maintain comfort and if they rise above the upper limit, then the cooling effects of the wind is usually the only element that can balance the comfort zone (Givoni, 1969:280).

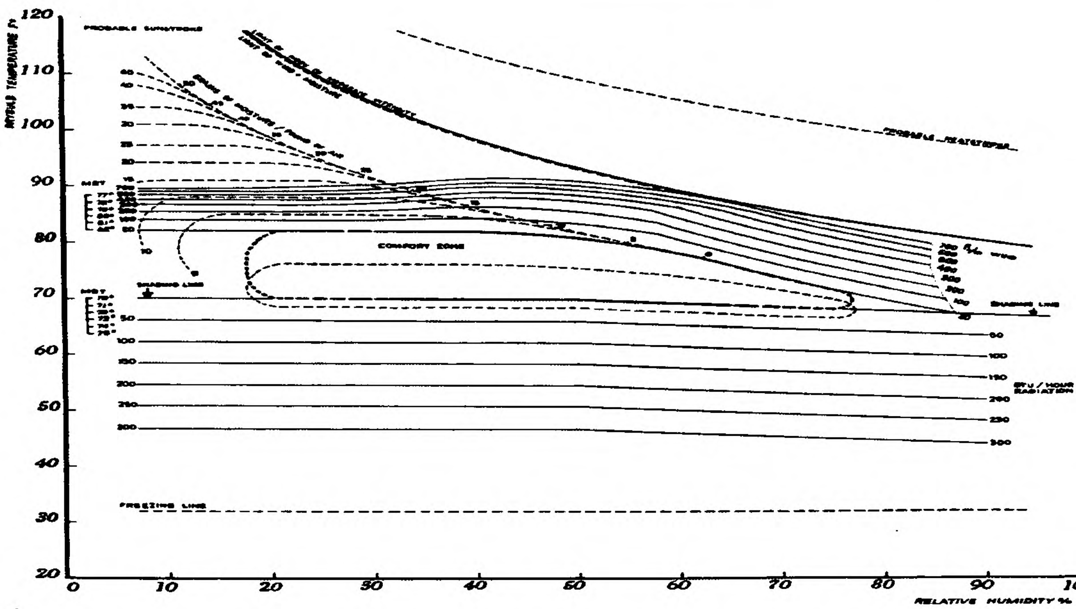


Figure 3. 1: Olgyay bioclimatic chart. Source: Visitsak, (2007:20)

- **Givoni's bioclimatic chart**;

In 1969 a significant improvement of the bioclimatic chart was proposed by Baruch Givoni who examined various thermal indices that affect human comfort and used the results to develop an index of thermal stress I.T.S which was used to develop the comfort chart (Figure 3.2) (Givoni,1976).

The chart aimed at expecting the indoor conditions of the building according to the existing outdoor conditions. The study was based on the linear relationship between the temperature amplitude and vapour pressure of the outdoor air in various regions. In the chart, according to the climatic conditions prevailing outside the building envelope, appropriate passive strategies are defined.

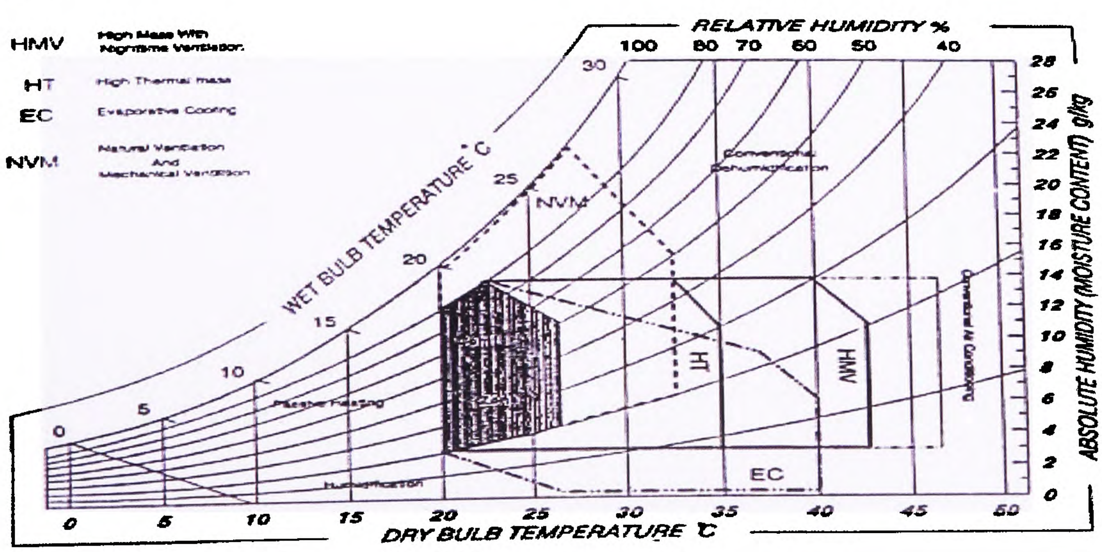


Figure 3.2: Givoni's bioclimatic chart. Source: Givoni (1976)

- **G-M bioclimatic chart:**

In 1979, Givoni and Milne combined the different design strategies into the same chart (Figure 3.3). They determined the limits of effectiveness for each design strategy in order to meet needs of indoor comfort (Visitsak, 2007).

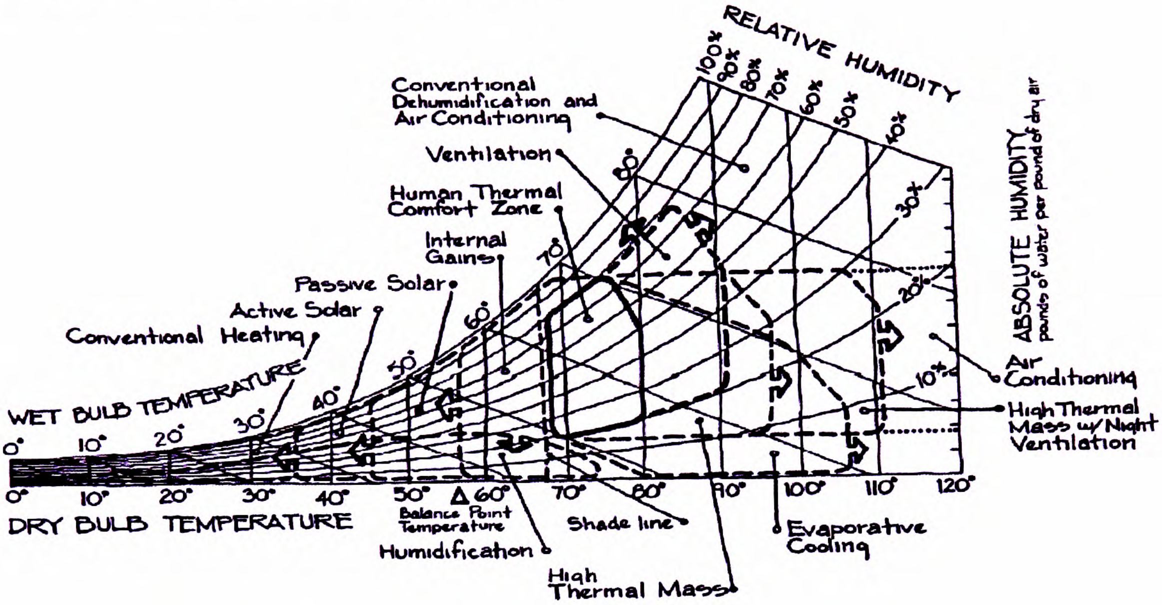


Figure 3. 3: Givoni-Milne bioclimatic chart. Source: Visitsak, (2007)

Visitsak (2007) provided a new bioclimatic chart based on the Givoni-Milne bioclimatic chart. He designed guidelines for a new bioclimatic chart for the hot-humid climate of Houston, Texas (Figure 3.4).

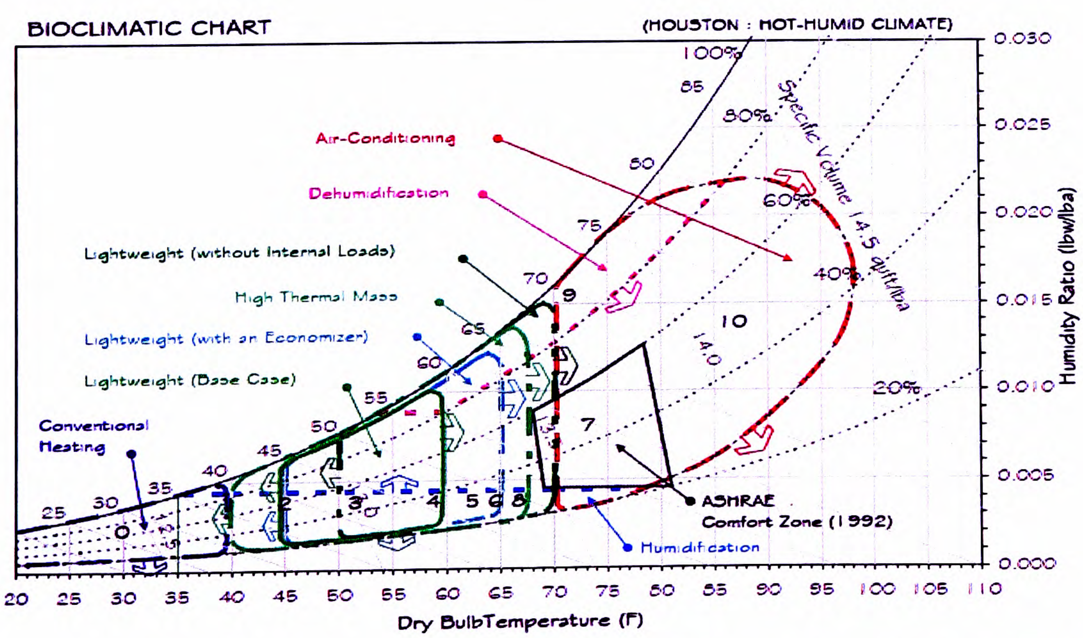


Figure 3. 4: The bioclimatic chart for thermostatically controlled residences in the. hot-humid climate of Houston, Texas. Source: Visitsak, (2007)

- **The Comfort Triangles Chart:**

This chart can be used to compare outdoor conditions with the desirable indoor conditions and to select appropriate control strategies, with emphasis on passive bioclimatic measures, in a similar way to the bioclimatic charts of Givoni (1976) and Olgyay (1963) (Evans 2008). It was developed to indicate the maximum acceptable temperature swings for indoor comfort, based on the average temperature and the daily swing (Figure 3.5). Triangle A shows the comfort conditions for sedentary activity, B for sleep, C for indoor and D outdoor circulation. (Evans, 2003 and 2007).

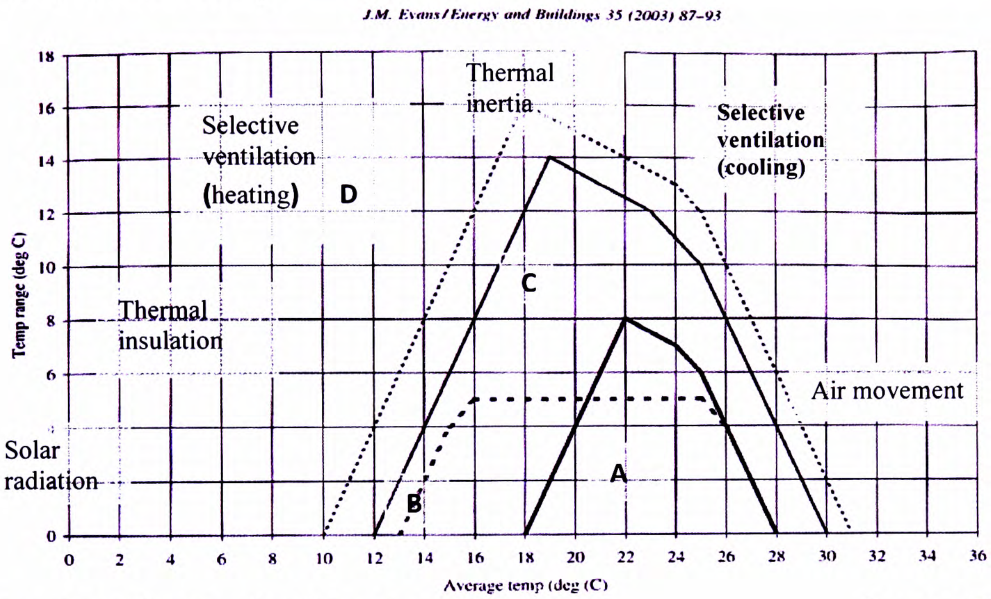


Figure 3. 5: The Comfort Triangles Chart. Source: Evans (2008)

- **The Mahoney model:**

A methodology for building design in accordance to climate has been developed by the Department of Development and Tropical Studies of the Architectural Association in London. They introduced the Mahoney Tables which includes the climatic data used as entry data such as dry bulb temperature, relative humidity, precipitation and wind. The tables are used to analyze the climate characteristics from which design indicators are obtained. From these indicators a preliminary image of the layout, orientation, shape and structure of the climatic responsive design can be obtained (Sayigh and Marafia, 1998).

In addition to above methods and models several other software design tools and methods of climatic analysis and graphical presentations that are very useful have been listed by Haberl (2004) and Visitsak (2007) as follows:

- Solar-2
- Solar-5

- Daylight
- Opaque
- Energy Scheming
- Radiance
- The Weather Tool
- Shaded Fenestration Design

In this thesis, the author used The Weather Tool as a source to provide data related to the case studies in Tripoli, Libya (see chapter 4).

The analysis of synoptic parameters of climate gives an indication of the suitability of bioclimatic strategies in ensuring comfortable living for occupants. The main strategies that should be applied in hot regions are: lowering the indoor temperature, providing natural ventilation, minimizing heat gain and loss, utilization of natural energies for heating and cooling and understanding features affecting climatic design. The next part will clarify factors affecting climatic design.

3.3 FACTORS AFFECTING CLIMATIC DESIGN

Before designing a building in a place, the changes of weather from season to season must be well understood so that the building can be built to shelter people all the year round. Also the actual environmental conditions of the building will be affected by the local micro-climate and site factors (Hui, 1997).

Krawietz (2006) explained that the knowledge of an appropriate climatic response was contained in many traditional ways of building and of living. He identified that the performance of a building, whether it does well or badly, depends on the design of its form, its plan, section, height, the size and layout of internal and external openings and connections, the thermal inertia and transparency of its construction, the orientation of its spaces, and finally in physical terms on the design of the building's immediate external environment. He also stresses the importance of considering the use of renewable energies, integration of the newest technologies (e.g. Photovoltaic, BIPV) and energy efficient overall design concepts.

Muhaisen (2006) stated that the first rule of thermal comfort in summer is shading to avoid heat gain, whereas the opposite is true in winter in any of the investigated locations. Without shading, building surfaces absorb heat, raising that surface temperature above that of the ambient air and adding to the cooling loads due to air temperature and humidity.

Cofaigh et al. (1996: 161) confirmed that the simplest way of cooling a dwelling is by natural ventilation which can be achieved by using the benefits of cool night-time air and by the evaporation effect of water such as using fountains and pools. They gave five cooling strategies:

- Control external gain in summer time;
- Minimise internal gains by using energy-efficient appliances;
- Ensure there is adequate cross-ventilation for the dwelling;
- Provide adequate cut-off between sunspaces and the dwelling;
- Use vegetation and water for positive cooling.

The factors influencing solar gain were identified by McMullan (2002:78) as:

- The geographical latitude of the site
- The orientation of the building on the site.
- The season of the year.
- Local cloud conditions.
- The angles between the sun and the building surfaces.
- The nature of the glazing.
- The nature of the roof and walls.

As stated before, architects can achieve passive design buildings by studying the macro-and micro-climate of the site, applying bioclimatic architectural principles to combat the adverse conditions and taking advantage of the desirable conditions. Some common design elements that directly or indirectly affect thermal comfort conditions and the energy consumption in a building, as collected from many sources such as The State of Queensland (2008); Muhaisen (2006); Krawietz (2006); CLEAR (2004); Hui, (1997) and Givoni (1998) are as follows:

- Building layout;
- Site landscaping;
- Landscaping of adjacent ground to provide shading;
- The plan shape and orientation of the dwelling;
- Orientation of the main rooms and the openings;
- Location and shape of openings;
- Size and details of windows and doors;
- Organization and subdivision of the indoor space;
- Shading of openings and walls;

- Protection of openings against excessive solar access and rain penetration.
- Provision of verandas and balconies;
- Location of internal walls with respect to cross-ventilation;
- Roof type and details;
- Roof form;
- Ceiling heights;
- Thermal and structural properties of walls and roof;
- Location of particular rooms;
- Materials used for construction, and
- Insulation.

To sum up: the design variables in architectural expression that are important for the aim of this study (as collected from different references) including the major factors that should be taken into consideration to control the thermal environment in buildings can be summarised as follows:

3.3.1 Buildings' layout

From the urban point of view, it is very important to achieve climatic design as Evans (1980) explained that the design of dwellings and the spaces around them can increase or reduce the incidence of solar radiation. Hyde (2008) who inspired the Mediterranean urban characteristics from traditional architecture stated that in hot temperate climatic conditions, cities and building textures are traditionally well organised and focussed on:

- Open spaces such as streets, squares and courtyards;
- The main issues of bioclimatic efficiency are providing ventilation and sun protection with appropriate materials and construction;
- Greater density means the lower solar energy contribution and ventilation capacity.
- Urban structure should be oriented to take advantage of the fresh breezes from the sea; this strategy of climate control can be used as the foundation of cities.

Givoni (1998) stated that the higher the density of the buildings in a given area, the poorer will be its ventilation conditions; high buildings block the wind as the first row of buildings acts as a wind barrier. He also added that, the lower the ratio between the building size and the width of spaces, the lower temperature in buildings and outdoor spaces.

3.3.2 Landscaping

Landscaping is an important element in altering the microclimate of place. It is affected by two main elements:

- Topography - elevation, slopes, hills and valleys, ground surface conditions.
- Vegetation - height, mass, shape, texture, location, growth patterns.

Good landscaping could help in providing the following advantages:

- Reduces heat gain by conduction from striking and heating up of building surfaces;
- Prevents reflected light carrying heat into a building from the ground or other surfaces;
- Creates different airflow patterns that can be used to direct or divert the wind advantageously by causing a pressure difference;
- Creates shade by trees and the effect of grass and shrubs reduce the air temperatures adjoining the building and provide evaporative cooling; and
- Properly designed roof gardens help to reduce heat loads in a building.

In addition to the above benefits of landscaping the National Renewable Energy Laboratory (NREL) (1995) stated that landscaping may be the best long-term investment for reducing heating and cooling costs, while also bringing other improvements to the community. They added that some of the benefits of landscaping if it is well-designed are as follows:

- Cuts summer and winter energy costs dramatically.
- Protects the home from winter wind and summer sun.
- Reduces consumption of water, pesticides, and fuel for landscaping and grass maintenance.
- Helps control noise and air pollution.

Arias (2005) stated that vegetation with its various aesthetic benefits in the urban landscape have other useful factors summarised as follows:

- Trees and other plants provide a natural protective element against solar radiation as well as wind control.
- In warm and humid microclimates, where the greater part of the year requires protection from extreme solar radiation (and at the same time requires the free passage of air) vegetation may be used like a sunshade, such as palm trees, whose permanent leaves are able to block solar radiation and their tall trunks will easily allow unimpeded ventilation.

- Providing a degree of privacy for inhabitants, plantings could create screens or curtains of trees which have the advantage of permitting the flow of air, unlike constructed walls which completely prevent the passage of wind.

NCSU (2001) clarified that well-planned landscaping can reduce energy requirements during all four seasons, by preventing the hot summer sun, allowing warming solar radiation in winter, deflecting cold winter winds and channelling breezes for cooling in spring, summer and autumn. They provided three principal strategies to reduce heat gain: (1) shading the house with trees, shrubs or vines; (2) shading the area around the house to lower the temperature of its surroundings and (3) covering the ground to reduce the sunlight reflected into the house. (Figure 3.6) shows the kind and distribution of trees in North Carolina 'which located in a hot region' that can assist in shading and not preventing the access of sunlight when needed.

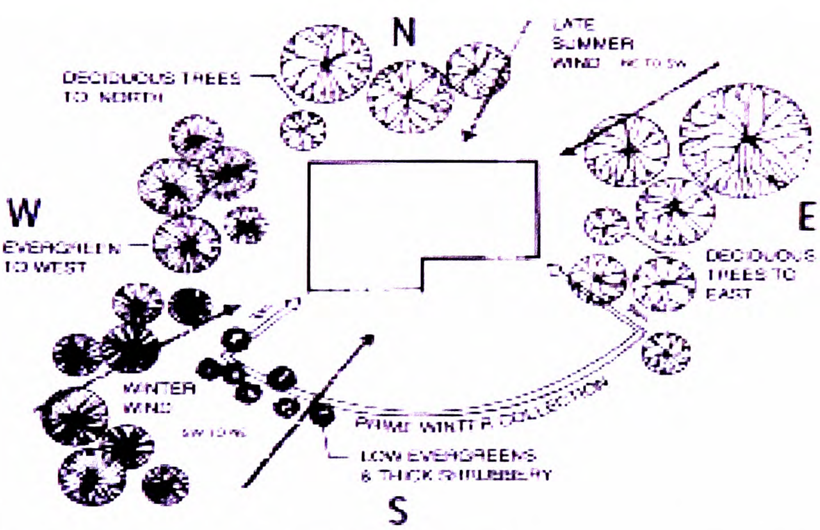


Figure 3. 6: Distribution of trees on a North Carolina site. Source: NCSU (2001)

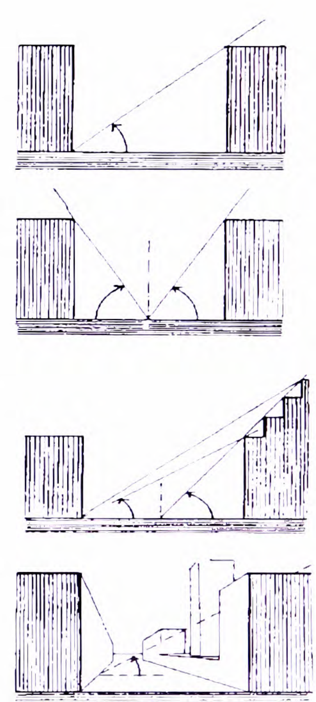
NCSU (2000) clarified that using natural vegetation such as trees, shrubs and vines offer some of the best exterior shading. A deciduous tree or vine shades a home from the summer sun, and then, when the leaves fall, allows winter sunlight inside the house. They are most effective when planted on the south, east and west sides. Evergreens provide shade and offer protection from the wind on the north side.

According to Givoni (1998) the most appropriate plant combination in landscaping in hot-humid climates is a mixture of grasses, low flower beds, and shade trees with high trunks. In addition, there are other components related to local micro-climate and site details which will affect the comfort of the building. The important factors which should be considered are: site topography (slopes, hills and valleys, ground surface conditions); the kind of vegetation (which includes height, mass, shade and shadow, texture, location, growth patterns) and finally, built shapes which consists of the relationships between buildings (attached – separated) and surface conditions.

3.3.3 Ratio of built form to open spaces

Surface-to-volume ratio is the area of the envelope and its relationship with the volume of space inside a building that needs to be heated or cooled and which can affect the thermal performance of the building.

For any given building volume, the more compact its shape the less wasteful it is in gaining or losing heat. Also, the building form determines the airflow pattern around the building, directly affecting its ventilation. Givoni (1998) stated that from the climatic point of view, the distances between buildings affect the solar and wind exposures of the walls; in hot regions a special importance is attached to the distance between buildings in the east-west direction. Heine (2010) confirmed and clarified that the building form and its compactness are relevant to the amount of heat transmission losses, which are relative to the insulating quality and to the heat transmitting surface. Evans (1980) explained that the proportion of the space between buildings will determine the quality and quantity of light and breeze; it will also affect the amount of sun on the facades on the surrounding buildings, pergolas and vegetation can provide protection of external spaces (Figure 3.7).



- The spacing angle used to control the proportion of streets and external spaces to safeguard environmental standards.
- The traditional form of building control; angles measured from the central axis of the street.
- The second method may give lower standards if 'set-backs' are allowed.
- Buildings may receive sun, light and ventilation around the sides of opposite buildings rather than over the roof.

Figure 3. 7: Spacing between buildings. Source: Evans (1980)

The effect of interior height on internal thermal comfort (Figures 3.8) has been clarified by Evans (1980) as follows:

- Lowered ceilings will increase radiation from the ceiling to the body, but the difference is not noticeable.
- The change in temperature gradient will usually be less than 1°C at body level, which is not noticeable.
- Increased ceiling heights will not give 'sensible' air movement due to the stack effect under normal conditions.

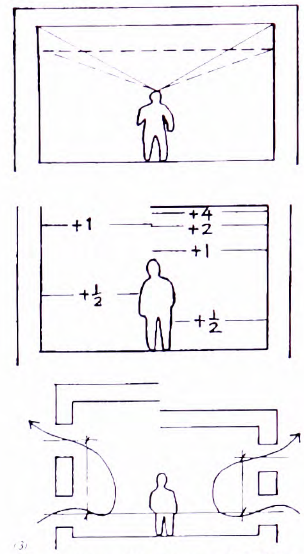


Figure 3.8: Effect of interior height on internal comfort. Source: Evans (1980)

3.3.4 Orientation

Building orientation is an important design consideration, mainly with regard to solar radiation and wind. Sartogo (2008) clarified that, in order to enhance natural ventilation and to control solar heat gain, it is very important to site the building to capture the prevailing breezes and ensure that the location does not restrict the airflow to other buildings within the site or create wind shadows. Heine (2010) provided some rules for solar orientation and factors that need to be considered are:

- Horizontal surfaces receive the greatest intensity of solar radiation.
- On vertical surfaces, the greatest intensity of solar radiation is on the morning eastern elevations and on the afternoon western elevations.
- South-eastern surfaces get less radiation during the hot season and more radiation during cold seasons. The radiation increases in northerly latitudes.

Givoni (1998) explained that the main aim of orientation in hot regions is to minimize the impact of the sun and provide cross ventilation. Evans (1980) confirmed and clarified that orientation and the arrangement of buildings and external spaces can be designed to admit cooling breezes.

The best street and building orientation in hot regions has been clarified by Baccoush (2006) as shown in (Figures 3.9, 3.10).

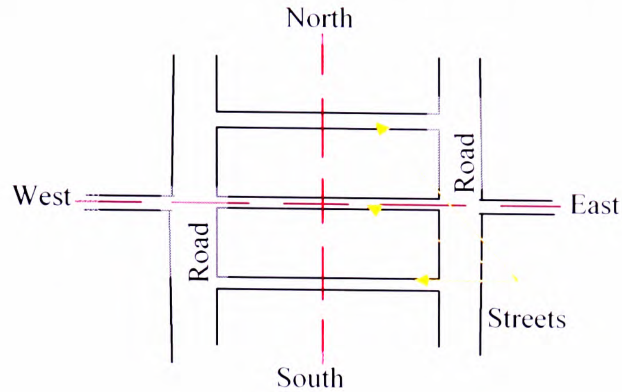


Figure 3. 9: Best streets orientation. Source: After Baccoush (2006)

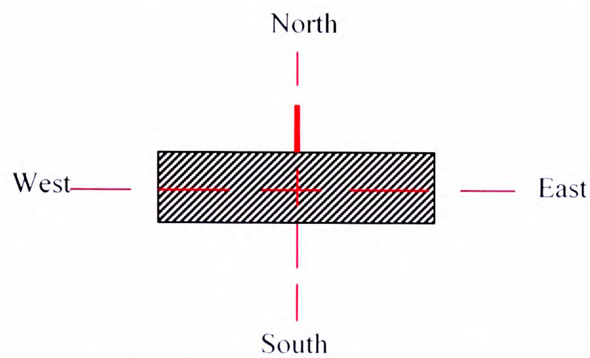


Figure 3. 10: Best building orientation. Source: After Baccoush (2006)

Holmes and Hacker (2007) suggested that low-energy buildings have been described by designers in a number of different ways. They cited some of them as:

- Naturally ventilated building: ventilation controlled by the occupants opening windows;
- Advanced naturally ventilated building: using natural forces and use of ventilation pathways other than windows to control the flow and direction of the air ventilation;
- Mechanical ventilated building: provide the ventilation air by using some kind of fans;
- Mixed-mode building: using one of the types described above and also using mechanical cooling systems;
- Air-conditioned building: This has preserved windows and cooling is available at all times of the year.

For several design purposes, the position of the sun on a given date at a given time has to be known. This enables the building designer to calculate the best orientation of the building; to calculate the shadow cast around the building, the patches of sunlight on floors, walls, etc. Also the altitude and the azimuth of the sun enables the designer to calculate the intensity of solar radiation for specified space and time coordinates. This understanding influences the choosing of the building size, volumetric proportions, orientation, fenestration details, shading devices, ventilation, building materials, etc (CLEAR, 2004).

Baccoush (2006) presented the main techniques which can be used to reduce direct heat gain in hot regions in (Figure 3.11).

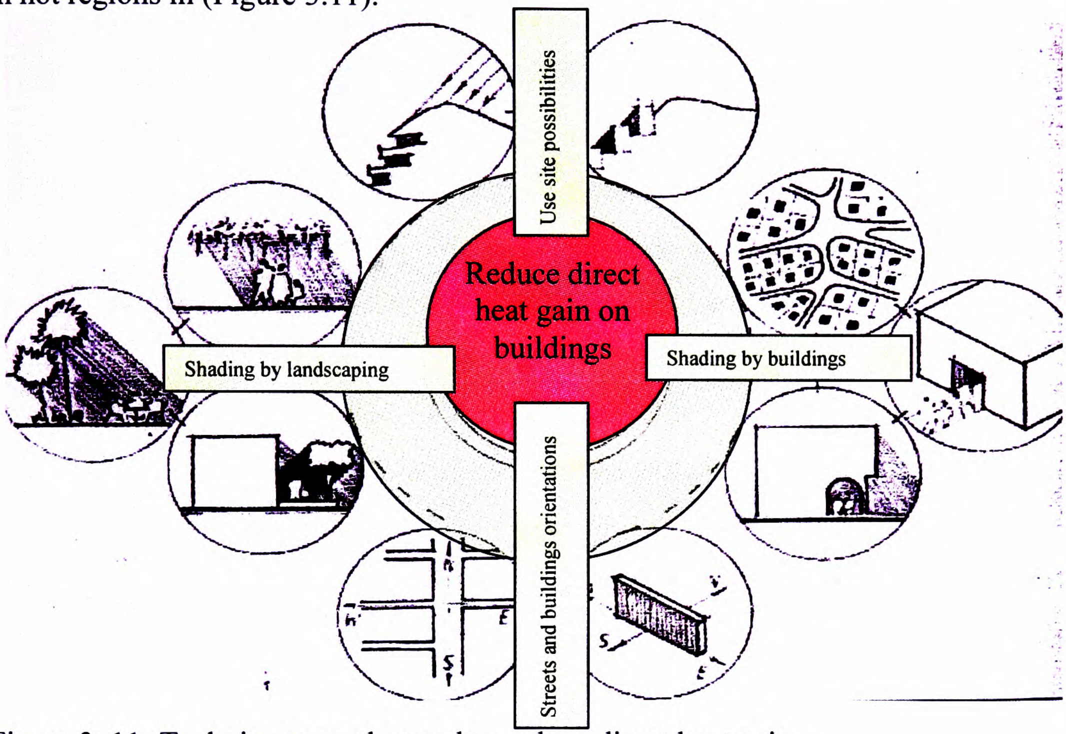


Figure 3. 11: Techniques can be used to reduce direct heat gain.
Source: After Baccoush (2006)

3.3.5 Building envelope and fenestration

The building envelope and its components are key determinants of the amount of heat gain and loss and of the amount of wind that enters inside. Olgyay (1973) calculated the thermal stress on the surface of a square plan building for four different climatic zones - cool, temperate, hot arid, and hot humid. The optimum plans recommended for the four climatic zones have the following percentages: cool = 1.1; temperate = 1.6; hot arid = 1.3; hot humid = 1.7. Therefore the square house is not the optimum form for any location. Elongated shapes on the north-south axis are less efficient than the square house, while the optimum lies in a form that is elongated east-west.

Cofaigh et al. (1996) stated that the design of the envelope elements (walls, roofs, floors) and the transparent elements (such as windows and sunspaces) can play a major role in heating or cooling a dwelling.

According to Givoni (1998) the appropriate layout of buildings in hot-humid regions are as follows:

- for those who are using air conditioning, the building should be compact to minimise the surface areas of its envelope and thus reduce the heat gain;
- For those who are dependent on natural ventilation to achieve comfort, a spread-out building with large windows enables more natural cross ventilation.
- The ideal building plan is a detached elongated building with a single row of rooms with openings in the two opposite walls;
- Raising the building off the ground can greatly improve the potential of ventilation;
- The rooms should have direct access to open balconies or verandas on one or two sides;
- The balconies provide protection to walls and windows from sun and rain.

The same author suggested that the optimal interior design in hot humid regions is to have an open plan for the dwelling unit to enable free flow of air through it; privacy can be provided by designing doors made like shutters blocking the view but giving passage to airflow He also recommended leaving the upper part of a room-height door open via hinges at the top. Evans (1980) explained the effect of external design on internal air movement (Figure 3.12) as follows:

1) Walls and vegetation close to buildings can divert wind away from openings;
2) Air movement in rooms on different levels can vary, even when windows are identical;
3) Dark and dusty surfaces outside windows cause discomfort inside; and
4) Rooms raised off the ground receive better air movement and less dust.

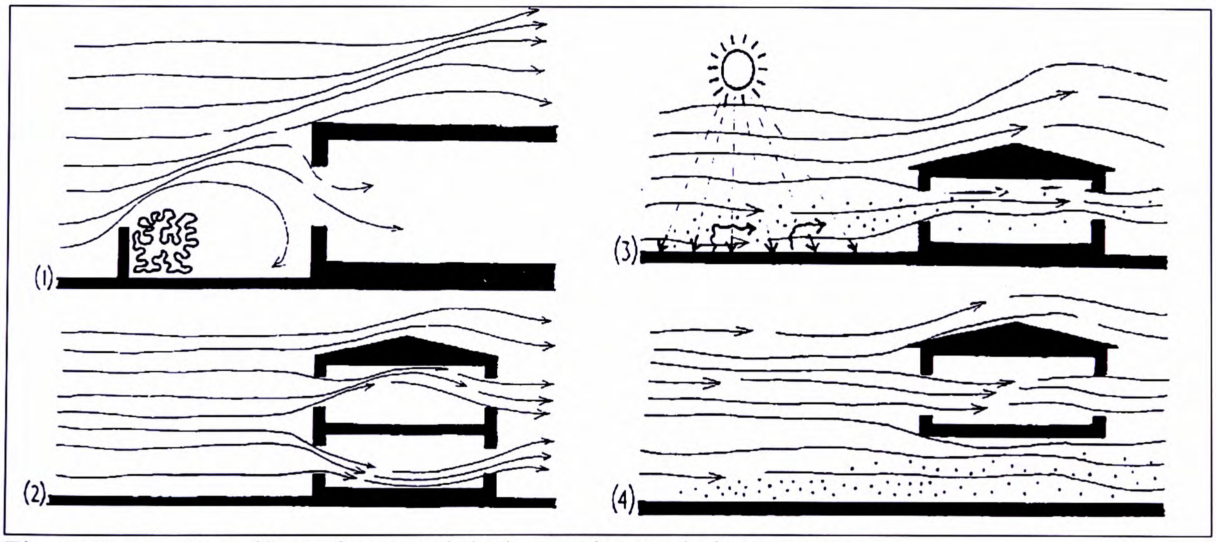


Figure 3. 12: The effect of external design on internal air movement.
Source: Evans (1980)

The same author explained the effect of the inlet and outlet positions on internal air flow (Figures 3.13) as follows:

1) High inlet and outlet do not produce good air movement at body level.
2) Low inlet and outlet produce a good pattern of air movement, when it is required for cooling.
3) Low inlet and high outlet also produce a low level wind pattern.
4) The air flow at ceiling height produced by a high inlet is hardly affected by an outlet at low level.

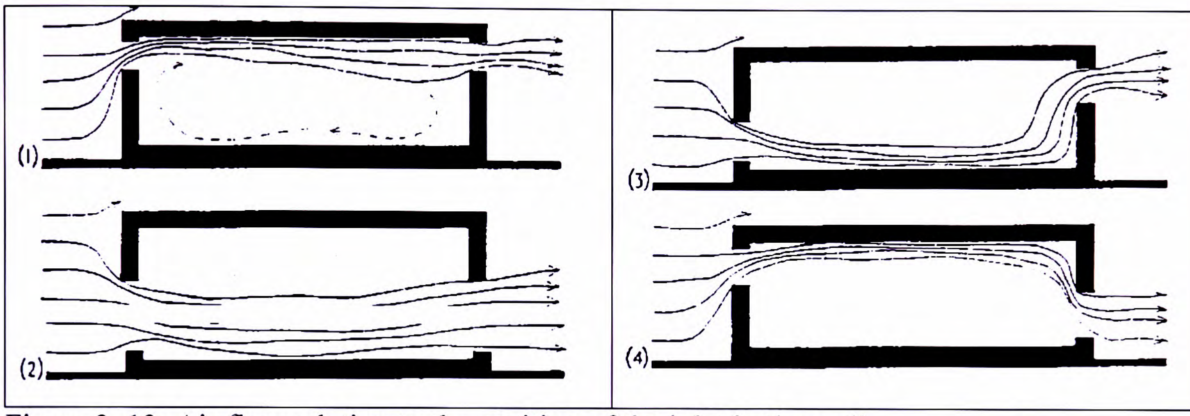


Figure 3. 13: Air flow relating to the position of the inlet in the wall.
Source: Evans (1980).

The effect of the external sunshade shape and position on the internal ventilation has been explained by Evans (1980) (and presented in Figures 3.14) as follows:

1) Projection shading devices produce an air flow in the room.
2) A slot between the wall and the shade results in a more direct flow of air.
3) Moving the position of the shade has the same effect, but a larger shade is required.
4) Louvres in the window give a more direct flow, but the sun may heat the louvre and the louvere may heat the air as it enters the room.

All the sunshades shown are equally effective at shading 45° angle sun

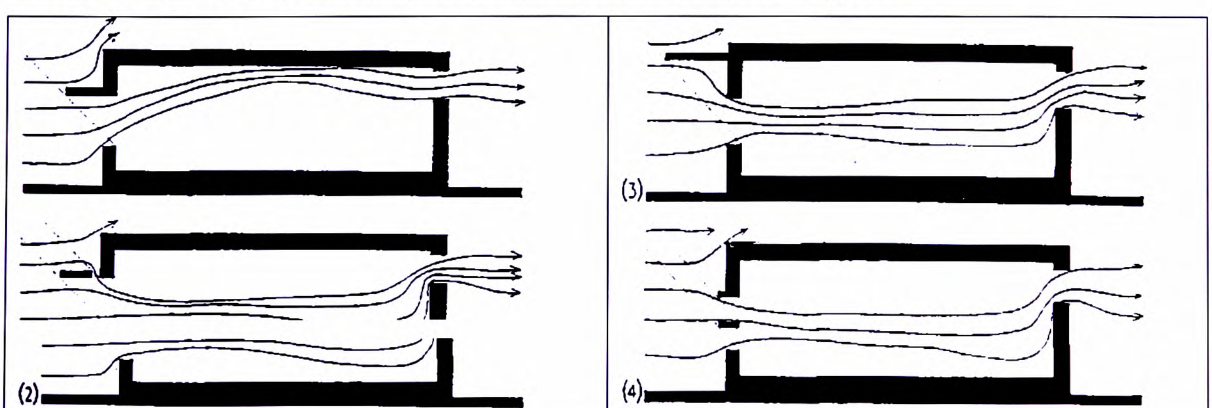


Figure 3. 14:The effect of an external sunshade on the internal ventilation.
Source: Evans (1980)

The primary elements affecting the performance of a building envelope can be summarised as follows:

3.3.1.1 Materials and construction techniques

The choice of building materials is very important in reducing the heat gain or loss of buildings. Efficient structural design and good thermal insulation can increase the thermal time lag (Figure 3.15) and reduce the quantities of high-energy building materials. As Evans (1980) has stated, the appropriate properties of walls and roofs can help to achieve comfort or reduce the amount of energy used.

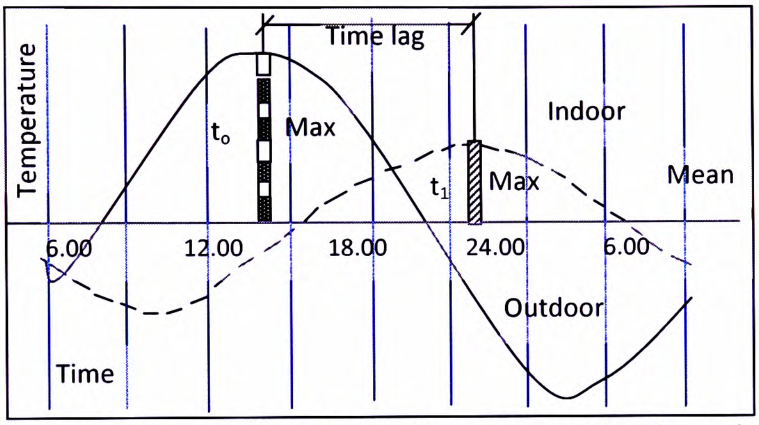


Figure 3. 15: heat transfer from outside to inside through the wall (Thermal time lag).
Source: After Baccoush (2006)

Many authors have put forward the best building materials that can be used in hot regions and some can be summarised as follows:

Elkhalifa and Balila (2010) found that brick, as a material used for walls and roofs, emerges as the best material in terms of loosing heat through the fabric, while cement blocks tend to have small percentage of heat loss attributed through the fabric. Corrugated iron sheets in roofing perform well with all wall materials if a false ceiling is used. They advised that more consideration should be taken when selecting cement blocks for walls` construction.

Ahsan and Svane (2010) found that the cooling load can be reduced by 7%-10% when the thickness of an external wall is doubled (229 mm concrete hollow block instead of 114 mm concrete hollow block). They found that the U value of 250 mm hollow concrete block whitewashed externally is 1.7 W/m2. The U value of a 280 mm brick wall (115 mm brick + 50 mm air gap + 115 mm brick) including an air cavity of 50 mm and whitewashed externally is also 1.7 W/m2. Accordingly, 280 mm brick walls including an air cavity of 50 mm can be used instead of hollow concrete blocks on east and west facades to reduce energy use. They agreed with used hollow clay tiles (HCT) in place of a weathering course for roofs and that can save 18% - 30% of energy used in an air conditioned building.

3.3.1.2 Roof design

The roof receives significant solar radiation and plays an important role in heat gain/losses, day-lighting, and ventilation. Ahsan and Svane (2010) confirmed that the roof is an important element of design when it comes to conserving energy because the heat entering into a building structure through the roof is a major cause for discomfort in the cases of non air-conditioned buildings.

In her experimental investigation on studying the possibility of reducing air temperature in buildings through roof design, Ben Cheikh (2010) proposed building roof components by using a metal plate ceiling over which lies a bed of rocks in a water pool; an air gap separates from the external environment by an aluminium plate painted with a white titanium-based pigment to increase the radiation reflection process during daytime. The results show that the air temperature can decrease by 2 to 3°C if night natural ventilation of buildings is allowed.

3.3.1.3 Walls

Walls are a major part of the building envelope and receive large amounts of solar radiation. The heat storage capacity and the heat conduction property of walls are key to meeting desired thermal comfort conditions. The wall thickness, material, and finishes can be chosen based on the heating and cooling needs of the building.

Ahsan and Svane (2010) stated that doubling the thickness of the external walls on the east and west of the building can reduce the solar radiation heat gain, and the use of hollow clay tiles and appropriate horizontal overhang ratios for all four orientations can reduce the cooling load by 64% and thus reduce the total energy use of the building by 26%. Baccoush (2006) provided three solutions to walls design suitable for hot regions shown in (Figure 3.16).

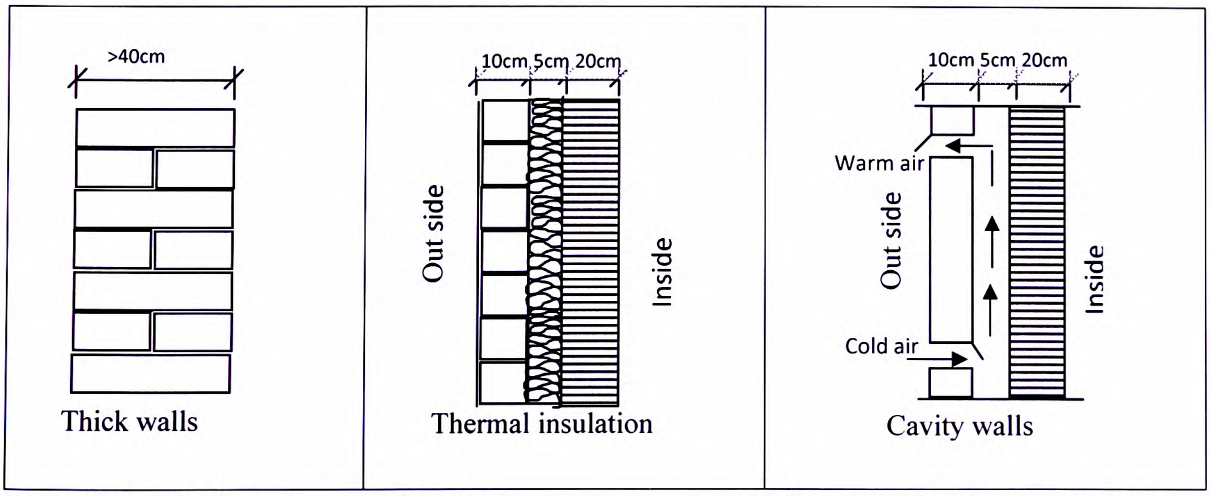


Figure 3. 16: Different types of walls. Source: After Baccoush (2006)

3.3.1.4 Fenestration and shading

Windows and other glazed areas are most insubstantial when looking at heat gain or losses. The proper location, size, position and orientation of windows, window glass materials, external and internal shading devices and shading; these all form an important part of bioclimatic design as they help to keep the sun and wind out of a building or allow them in when needed (Figures 3.17).

The need for shading devices, as suggested by Watson and Labs (1983), is when outdoor air temperature exceeds the lower limits of the comfort zone (68 °F-20°C). Similarly, the shade-line in the Givoni-Milne chart is approximately 70 °F- 20.6°C) (see Figure 3.3). Therefore, if the outdoor temperature is above the shade line, then the windows need to be shaded. Visitsak (2007) confirmed that the functional advantages and aesthetic benefits of shading devices should be considered; he cited the ASHRAE recommendation to use shade line factors for windows facing various directions in residential buildings in different latitudes.

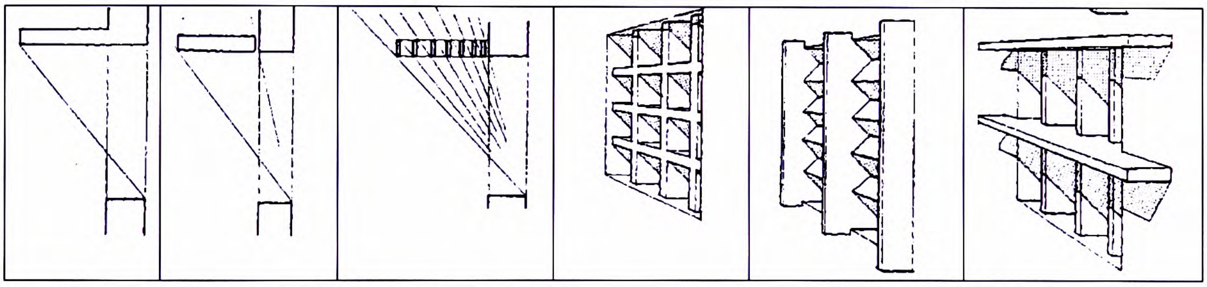


Figure 3. 17: A series of shading devices. Source: Evans (1980)

Givoni (1998) clarified that, for providing indoor comfort in hot-humid regions, ventilation issues and the effective prevention of solar heating of the building are very important. He suggested shading walls and windows by wide verandas and vegetation. Panchyk (1984) stated that minimizing heat gain by choosing effective shading devices can significantly reduce the cooling requirements of a space; where some shading devices do no more than cast a shadow upon a window area, others contribute to the insulation of the window surface. (Figures 3.18) clarify the relationship between shading devices' shape and size and the shading provided.

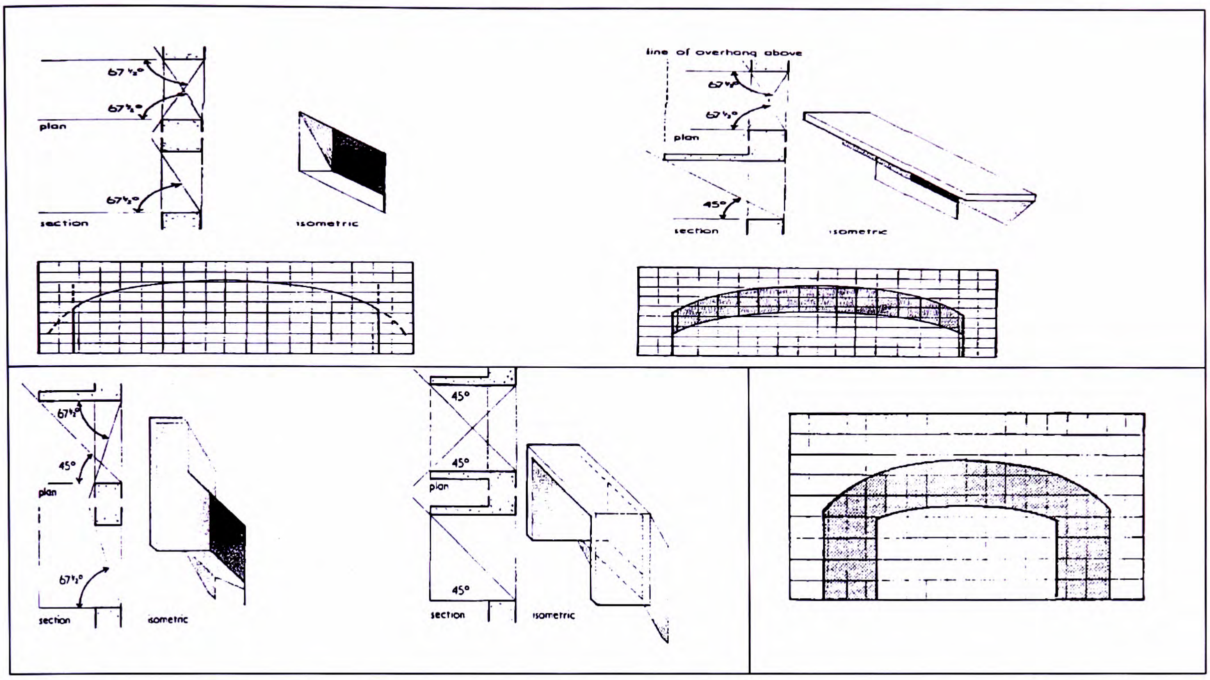


Figure 3. 18: The shading characteristics of a simple window. Source: Evans (1980)

The location of openings for ventilation is determined by the prevalent wind direction. Openings at higher levels naturally aid in venting out hot air. The size, shape and orientation of the openings moderate air velocity and flow in a room; a small inlet and large outlet increases velocity and distribution of airflow through a room. When possible, a house should be positioned on a site that takes advantage of prevailing winds.

Ossen et al. (2005) (in Ahsan and Svane (2010) found that horizontal overhang ratios of 1.3, 1.2, 1 and 1 for east, west, north and south orientations respectively have optimum total energy savings of 14%, 11%, 6% and 8%. They concluded that to optimize total energy use in hot and humid climates, external solar shading is the best option, considering the trade off between total heat gain and natural light penetration.

The North Carolina Solar Center (NCSU, 2000A) clarified that a roof overhang is a simple architectural feature that can be used to block direct sunlight in summer without reducing the available sunlight in winter. It can be a permanent part of the building's structure, or may be used seasonally. For overhangs to be fully effective, they should be used in conjunction with some other cooling strategies, such as interior shading. They provided simple calculations on different size overhangs (located on the south side of a building) for different sites' locations as presented in (Figure 3.19).

NCSU (2000A) explained that in southern overhangs, a 1 foot (0.3m) overhang would shade 3.3 feet (1.01m) down a wall; however, each foot of an east or west overhang will only shade about 0.8 feet (0.24m) down a wall. Accordingly, an east or west overhang would have to extend out several feet to provide shade, which would require extra support. North Carolina is located in a similar climatic region to that of Tripoli. Accordingly, it can be assumed that south overhangs in Tripoli of the length of 0.80m would shade about 2.70m down a wall.

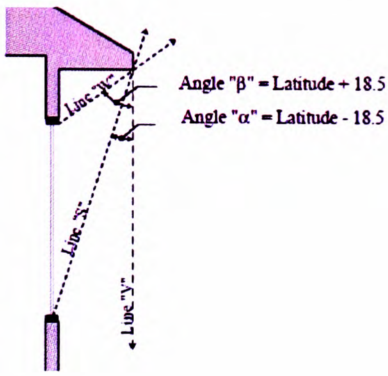


Figure 3. 19: calculating southern overhangs.
Source: NCSU (2000 A)

NCSU (2000) stated that orientation is a main factor in choosing window insulation and shading. They showed that well-insulated windows can upgrade the energy performance in various ways, summarised as follows:

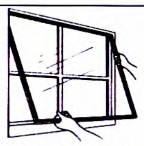
- **Window orientation**:

➢ South windows are the best for winter solar gain; they can be shaded by a roof overhang. Windows on the south side will always be net energy gainers in the winter. This is because they receive sufficient radiation during the day to offset heat losses through the same windows at night.

➢ Windows on the north side of the house are usually net energy losers. They do not gain enough direct solar radiation during the day to offset night-time heat losses. Keep north windows to a minimum and insulate in the winter.

➢ East and west windows can cause overheating in the summer and need seasonal shading. Because it is difficult to design an overhang deep enough to block the late-afternoon sun, it may useful to use awnings, shutters, window films or screens.

- **Interior window options to reduce winter heat losses:**

➢ An interior storm panel can be used with skylight and awning windows that are difficult to fit with exterior storm panels (Figure 3.20).	 Figure 3. 20:An interior storm panel.

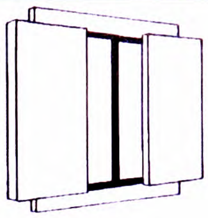
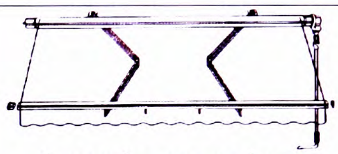
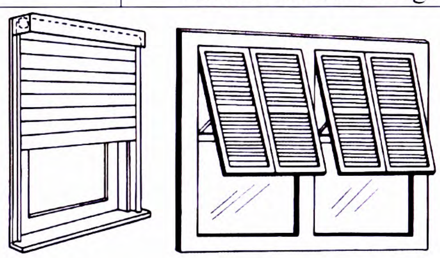
• **Exterior window options to reduce summer heat gain**: (Figures 3.21) ➢ Exterior thermal shutters should have a core of insulation to reduce heat loss. They should fit tightly over the window when closed. ➢ Roof overhang is one of the most effective forms of shading exterior glass. It is easily included in the design when the house is under construction.	 Exterior thermal shutters
➢ Awnings reduce summer solar heat gain up to 65% on south-facing windows and up to 77% on west-facing windows.	 Lateral arm awnings
➢ Louvred shutters can block direct sunlight and reduce solar heat gain by 80% when used properly. Light-coloured shutters will be most effective. ➢ Tinted or reflective films are usually attached to the inside of a window. ➢ Exterior rolling shades and shutters can also provide summer shading.	 Exterior rolling shutter and shutter combines natural ventilation with awning-like shading.

Figure 3. 21: Exterior window options to reduce summer heat gain.
Source: NCSU (2000).

3.3.1.5 Finishes:

The external finish of a surface determines the amount of heat absorbed or reflected by it. A smooth and light colour surface reflects more light and heat in comparison to a dark colour surface. Givoni (1998) confirmed this and suggested that white is the appropriate colour in a hot-humid climate.

This part of the study can conclude with the philosophy of a famous American landscape architect, James Rose, who explored the role of landscape as a place for thought and self-discovery intended to establish spiritual links between people and nature. He urged mankind to create environments in which man, nature and shelter are the same thing. He believed that protection from solar radiation and unfavourable wind movements by vegetation is of great importance and contributes to improving the internal microclimate of residences along with the landscape features of interior courtyards, garden, landscape units and small pools; all these make the landscape richer visually and they assist in keeping people cool. Moreover, his architectural expression is strongly related to the construction of spaces of high energy efficiency by reducing the necessity for mechanical systems, and where the most important task is to work in harmony with what the environment offers, adapting as much as possible the building to the local climate (Vissilia, 2009).

In summary, the major factors which should be taken into consideration when controlling the thermal environment in a building can be listed as follows:

- The form of the building which includes: surfaces-to-volume ratio, orientation and the height of the building. Also the size, position, orientation of windows and window glass materials and external and internal shading devices play a major role in controlling the internal environment.
- The kind of materials and construction, thermal insulation, surface qualities, shading and sun control.
- Control of air: outdoor fresh air, cross ventilation and natural ventilation.
- Landscaping: vegetation, paths, shaded open spaces, water.

Ozay (2004) clarified that many climatic design consideration lessons in hot regions can be learned from previous periods and these can be listed as follows:

- Use the concept of open and semi-open spaces such as courtyards, verandas, balconies and terraces;
- Use local materials such as adobe, yellow stone or the proper use of new systems and materials;
- Use thick thermal insulating walls and high ceilings;
- Ensure that maximum attention is paid to the sun orientation and prevailing wind direction;
- Use sloped roof structures with attic space and overhangs instead of using flat reinforced concrete roof covers;
- Use careful landscape design, especially choosing trees that provide shade during the hot summer time. Grapevines are the most common and traditional plants used for pergolas;
- Use proper design for the special building elements that provide climatic solutions such as canopies, overhangs and sun devices, wooden shutters with louvres; and
- Use pure forms and light colours such as white to reflect the heat.

Baccoush (2006) summarises the previous principles to reduce direct heat gain in the internal spaces in (Figure 3.22).

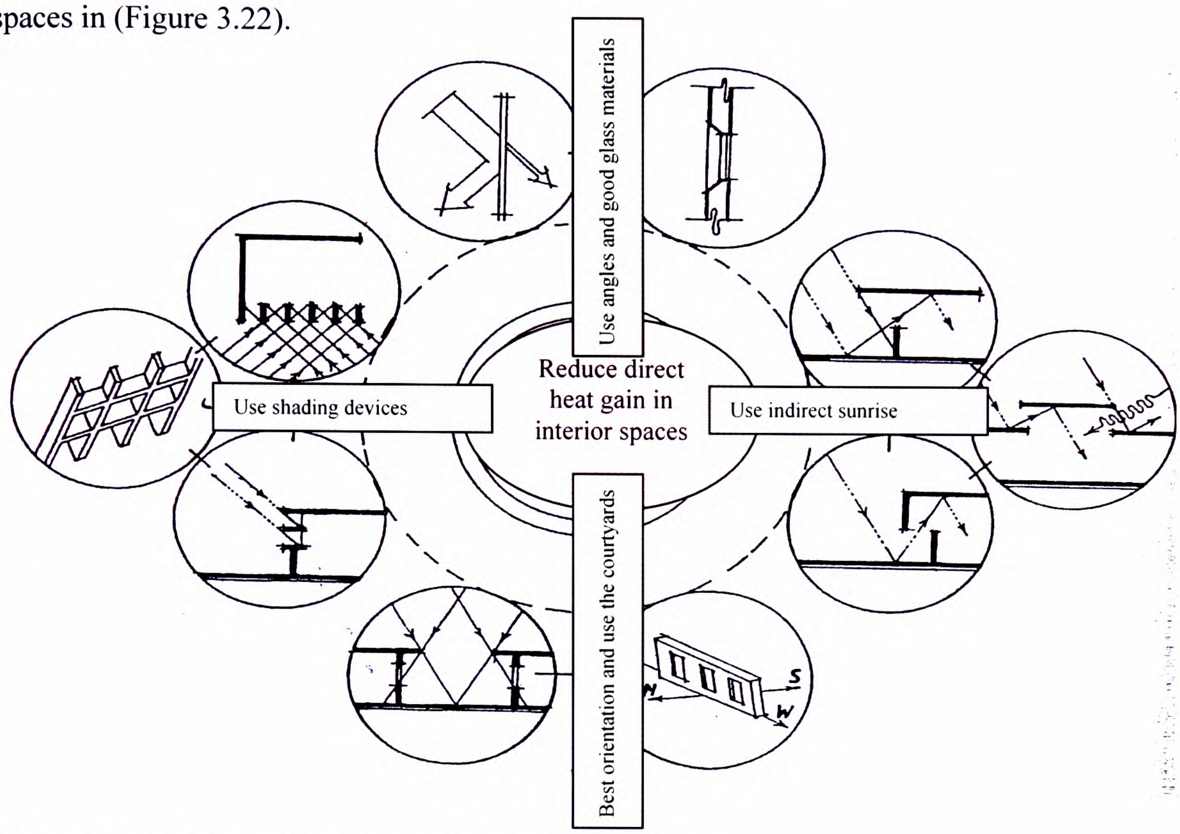


Figure 3. 22: Reduce direct heat gain in interior spaces.
Source: After Baccoush (2006)

To understand the climatic design strategies in hot regions (taking into consideration the factors affecting climatic design) it has been seen that understanding vernacular architecture and contemporary passive design strategies in hot regions should be the main guides to achieve the aim of this research. The next section will identify some techniques which can be used to achieve climatic design starting by clarifying the relationship between climatic design and vernacular architecture.

3.4 CLIMATIC DESIGN AND VERNACULAR ARCHITECTURE

The phrase "vernacular" or "traditional" in architecture means buildings that are produced by a cultural group for itself which serves as a framework for its daily life. Roaf et al., (2001) has stated that before the last century buildings were passive and low energy in their design. They were built to suit a local climate, culture and environment and built of local materials. Traditional builders had to design with respect to nature and local climate. For thousands of years, people operated under these vernacular premises because it was the most logical way to build and to live. Hassan Fathy explains how "the vernacular architecture of the Arab world and neighbouring regions not only solved the climatic problems but did so with a combination of beauty and physical and social functionality" (Oliver, 2003: 11).

These ancient principles were used extensively until the early 1900s, when cheap energy and technological advances in the 1950s and 1960s(such as the development of compact heating and air-conditioning equipment) ensured that a high degree of comfort in buildings was achievable even in adverse climates (Almansuri et al., 2009B). As a result, the wisdom of designing with climate in mind was too often ignored. The industrial revolution enabled environmental engineering to create a comfortable situation in almost any building in any climate (Randall, 2001).

Park (1998) stated that vernacular architecture is by its very nature "green" because it is deeply joined to the land. The use of locally available materials; good orientation of buildings taking advantage of natural prevailing winds and sun patterns; using natural systems of solar heating and ventilation; and the use of durable materials means that many historic buildings already meet many of the principles outlined for new structures intended to be of a sustainable design. He argued that most research and product development for sustainable design has been for new construction with little attention given to the rehabilitation of existing or historic structures and that modern designers should not ignore the role of historic features, such as overhang, sunshade, large windows, skylights, roof ventilators, deep projecting overhangs, and deciduous shade from trees.

Traditional building is explained by Dincyurek and Turker (2006) as the use of past experiences to suitably respond to the cultural and environmental needs of the context. Hence, climatically responsive, environmentally sensitive, socio-economically adaptive, culturally conscious building forms can be created and designers should find ways of analysing and understanding traditional housing for the continuity of tried, tested, developed and evolved design principles in traditional architecture.

Gedik (2004) believed that climatic design can be learned and inspired by the observation of old traditional buildings. Evans (1980) indicated that the role of architects in providing a comfortable building as, architects should pay maximum attention to designing buildings adapted to local climatic conditions in order to provide residential comfort while using minimum artificial energy.

Vernacular buildings often provide the most tangible evidence of how people lived in the past or how they live today. Presented fairly and with strong interpretation, they can be an effective means of education and a most engaging medium for public history. Ultimately, they can raise issues that transcend the particularities of any single site (Chappell, 2007).

Hyde (2000) clarified that it is appropriate to think in particular of the nature of traditional buildings and their environment. It summarizes thousands of years of unconscious research into the connection between building and climate and represents more holistic models for the development of a climate responsive architecture. These traditional models can be examined as examples, which inform the architecture, rather than providing a set of ready-made solutions. Also he argued that buildings should be assessed and designed by a broad set of criteria which forms the following framework:

- The geography of the site;
- The degree to which the building fabric has embodied energy;
- The climate at the site and operational energy demands;
- The potential for reuse and/or recycling of materials (Hyde, 2000).

Roaf et al. (2003 and 2005) maintained that there is much to learn from traditional buildings about how to design regionally appropriate structures. They explained that buildings have been traditionally designed using accepted principles, which are: design for climate, design for a physical and social environment and design for time. McDonough confirmed that world history offers many examples of societies with environmentally sustainable structures and communities which have endured for thousands of years. However, we have also pursued other paths which have led to economically unsustainable practices. For the development and improvement of humankind, it is very important to renew a commitment to living as part of the earth by understanding development and growth as processes which can be sustained, not exploited to impractical limits. He explained that no simple return to vernacular architecture can help us now because we know too much about the global and interrelated aspects of the world's problems. Therefore, any local land use plan will have global implications, and these need to be investigated (McDonough, 2000).

Hyde (2008) who was inspired by vernacular architecture when designing for warm climates stated that examining the historical architectural character of the Mediterranean can identify simple solutions that give efficient thermal control, and traditional building solutions have shown how important efficient climate regulation was for early house builders. For instance, the author provided details of the courtyard house as an important solution for this climate as the courtyard typology can provide good lessons for architects if a cooling objective is important, and he indicated that the advantages of the courtyards are as follows:

- During the day time, there is minimal solar penetration which limits the heating of walls surrounding the courtyard. Accordingly the temperature of the courtyard is lower than the external temperature; and
- During the night, the courtyard retains a pool of cool air which can be used for cooling the adjacent building.

He clarified that vernacular solutions with the addition of double-façade systems and solar roofing can contribute to new solutions for housing in a Mediterranean climate.

Despite all the more recent recommendations, it is still clear that Hassan Fathy's work (from 1945 when he started the Al Qurna village project on the west bank of the Nile in Luxor, Egypt until he died in 1989) still provides the clearest insight into climatic design. In his book 'Natural Energy and Vernacular Architecture: Principles and Examples with Reference to Hot Arid Climates' (1986:37) he explained the possibilities of vernacular architecture in improving future architecture "*Before inventing or proposing new mechanical solutions, tradition solutions in vernacular architecture should be evaluated, and then adopted or modified and developed to make them compatible with modern requirements*". He stated that the main problems facing architects in designing and planning for hot regions are protection against heat and providing adequate cooling, and he recommended that great care must be taken in the choice of building materials especially in the choice of the wall and roof materials. According to experiments undertaken in 1964 in the Cairo Building Research Centre, Fathy was the first to identify that mud brick walls prove the most appropriate in achieving thermal comfort. Fathy provided a bioclimatic guideline in hot regions which will be addressed in section 3.6.1.

Vernacular architecture is an effective teaching tool as well as a vast research resource. It can be a powerful instrument for teaching public history because it presents evidence, however skewed and edited, for how people lived. Clarifying the features of vernacular architecture can be useful to understand the importance of this architecture and how to improve these features to meet today's needs. The next section addresses the main features of vernacular architecture in hot and hot humid regions.

3.4.1 The main features of vernacular architecture in hot-humid regions

3.4.1.1 Courtyard houses:

The courtyard is defined by the Oxford English dictionary (2000:156) as "*an area of ground, without roof, that has walls or building around it, for example in a castle or between houses or flats*". Courtyard houses have been used by many urban civilizations for hundreds of years. It is still the traditional house type of many Asian, North African, South American and European countries (Almansuri et al., 2009A). Fathy (1986) stated that the courtyard concept is universally applied in both rural and urban housing design in the traditional architecture of countries in hot arid regions stretching from Iran in the East to the shores of the Atlantic Ocean in the West.

Almansuri et al., (2009A) explained that the nature of the courtyard as a space seems to be well defined as an open space that is surrounded on all sides by buildings. Its design is slightly different in its details from one country to another, but the main concept of design remains the same. The courtyard has become a flexible space where most of the activities of the family happen. It provides security and privacy for the residents and daylight for the rooms that are built around them. Usually it includes planted trees and a shallow pool in the middle of the yard. Edrees (2001) (cited by Amer, 2007) stated that the courtyard is a space where a family gathers after sunset, where the family members enjoy cheerful social interchange in comparatively fresh and cool air. Theories have confirmed that there is a strong relationship between the courtyard and sustainability. Edward et al., (2006: 222) defined this relationship thus "*the courtyard house is a model of low-energy design, of built form which supports rather than destroys family and community life, and is a unit which creates the essential building blocks for the making of sustainable cities*".

Despite the huge belief by the specialist and professional architects that the courtyard house is the ideal solution for achieving thermal comfort in the hot climate regions, some authors argue that the success of the courtyard depends on the integration of other factors. For instance, The Centre for Desert Architecture and Urban Planning (CDAUP, 2008) stated that the conclusions of a number of studies have indicated that internal courtyards as thermal modifiers in the built environment of hot regions are not necessarily appropriate. They suggest that the success of such courtyards in creating a good microclimate depends to a great extent on their detailed design, requiring careful attention to a range of factors including geometry, finish materials and the use of vegetation. Muhaisen and Gadi (2005) maintained that special arrangements are required at the design stage to achieve a suitable and satisfying courtyard building. This includes the internal envelope's finishing and materials, as well as the proportions of the physical parameters of the courtyard form. Similarly, El-Dars and Said (1972) explained that the court house in Libyan contemporary housing must undertake certain further development to accommodate social change and the progressive modern requirements of the Libyan family, together with new advances in building technology. Swan (1991) stated that, if the walls surrounding the courtyard are thick and of adobe, they store the night's coolness and gain heat slowly during the day, releasing their stored heat many hours later, when it is needed. Plantings cleanse the air further, protecting dwellers behind courtyard walls from the foul-smelling fumes of car infested streets.

The importance of studying and searching for the benefits of vernacular architecture especially the courtyard house typology has been clarified by many authors; for instance, Gianni (1988) mentioned that insufficient quantitative work has been done to understand the thermal behaviour of the courtyard type as a system in different climates and cultures. Fathy (1986) stated that new science can develop human abilities to use natural sources of energy which can be achieved in vernacular architecture. He argued that if science and technology are to regenerate architecture through a logical and comprehensive comparison of new and traditional structures, the principles that created the solutions must be respected. This is the only way to improve human and ecological quality whilst also retaining the achievements of traditional architecture in the hot regions of the world.

El-Fortia (1989, 110) wrote that "*it would not be unreasonable to consider that a form of housing that has been adaptable to the changing need of people through many centuries could not be adapted yet again to meet the requirements of today's society and its new lifestyle, at the same time giving a sense of identity and continuity*." And finally Edwards et al. (2006, 231,22) argued that climate is not the underlying reason for the courtyard house and gave examples from Milan and Aleppo that share the same building types but not the same climate. However, they stated that "*The courtyard is after all a tradition which over the past century has come under three great threats - war, earthquake and globalization - yet remains vibrant and relevant*". They confirmed that the traditional courtyard house was the invention of many different influences and outlined six functions of the courtyard as follows:

- The demarcation of limits of the property;
- The definition of a place of privacy for the family;
- The unification of spaces and elements in a house;
- The provision of circulation elements;

- The creation of a garden or cool place; and
- The promotion of ventilation.

3.4.1.1.1 The courtyard house concept design

The concept of the courtyard house is dependent on the enclosed space being open to the sky and surrounded by rooms on all sides. The courtyard is slightly different in its details from one country to another, but the main concept of design remains the same including its building materials and low height. It is characterised by being inward looking with a few high outside windows to respect socio-cultural traditions as well as to suit the climatic conditions.

3.4.1.1.2 The courtyard house and climate

Many studies have been conducted on the performance of the traditional courtyard house in modifying climate. For instant, Swan, (1991) in his study of Hassan Fathy, stated that the central courtyard of a house is the most efficient air conditioner as it traps the cold of the desert night air, releasing it gradually during the day to adjoining rooms through in-built cluster. Edwards et al., (2006) confirmed that the courtyard provides a climatically controlled space from many of nature's unwanted forces, such as wind and storms. El-Fortia (1989) stated that there are two important aspects of the courtyard; it modifies the climate of the living spaces and provides light and air to the rooms, also it plays a main role in the social life of the family.

Bukamur (1985) stated that courtyard houses, in addition to their flexibility of orientation, are well protected from hot, sandy winds and outside air pollution. Gianni (1988) explained that the Arab courtyard house considered as an example is diffused in many variations throughout Arabic and Islamic countries. It creates a complex regulating system that creates a microclimate in a passive way where heat transfer processes naturally. In this sense, the courtyard house is the end product of a complicated historical procedure of unconscious climatic design.

To provide more details on the style of courtyard houses, Evans (1980) stated that rooms are built around the central courtyard, which provides a relatively cool private out-door space for family activities. To increase the ventilation inside the house and reduce the temperature, the height of the ceiling is usually increased to 4m. This feature is associated with housing in hot climates, providing openings at the top of the wall that helps the hot air ascend and escape.

Rajapaksha et al. (2003) clarified that in order to minimise indoor overheating conditions the inclusion of an internal courtyard in the building design should be qualified to the optimization of natural ventilation. However, the efficiency of this strategy greatly depends on the design details of the building composition in providing an appropriate airflow pattern to the courtyard.

Safarzadeh et al. (2005) and Fathy (1986) stated additionally that courtyards provide security and privacy for the residents and daylight for the rooms and basements which are built around them. Also that they provide other benefits in hot climates; with their tall walls, the rooms (built around the courtyard) provide wind shading effects for one another, thus reducing the infiltration of hot and often dusty winds to the rooms. With their trees, flowers, shrubs and a pool of water, the courtyards create a micro-environment, a few degrees lower in air temperature and slightly higher in relative humidity. Furthermore, the tall trees in the courtyards shade the walls and the ground from the intense direct solar radiation of the sun. All these features reduce the heat gains of the building.

3.4.1.1.3 Principles of the courtyard

There have been many studies conducted on courtyard housing with each giving a detailed explanation about its importance and principles (Amer, 2007; Edwards et al., 2006; Muhaisen, 2006; Cofaigh et al., 1996; Roaf et al., 2007; Fathy, 1986; Golany, 1980). Depending on the fact that, in hot zones, air temperature drops considerably after sunset from re-radiation to the night sky, Hassan Fathy (1986), as a pioneer in this field, explained in his book "Natural Energy and Vernacular Architecture" how the cooling system used in a courtyard house works and how convection currents generate a flow of air. It is dependent on the idea of air movement by convection, where warm air is less dense than cool air and therefore will rise in an environment of cool air. As the warm air rises, it must be replaced by cooler air from the surroundings. Fathy divided the air movement processes inside the courtyard into three cycles as follows:

The first cycle depends on the cool night air falling into the courtyard to replace the warm air that rises to escape outside the house. This cool air gathers in the courtyard in laminar layers and seeps into the surrounding rooms, cooling them. This coolness is effective until noontime (Figure 3.23).

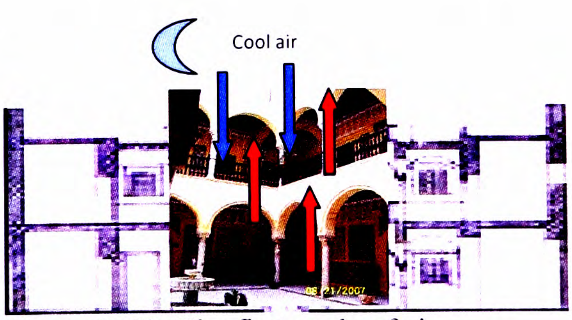


Figure 3. 23: The first cycle of air movement.

The second cycle happens in the morning when the air of the courtyard, which was shaded by the surrounding rooms, and the cool air stored in the rooms at night, filters out to the courtyard which heats slowly and remains cool until late in the day when the sun shines directly into the courtyard (Figure 3.24).

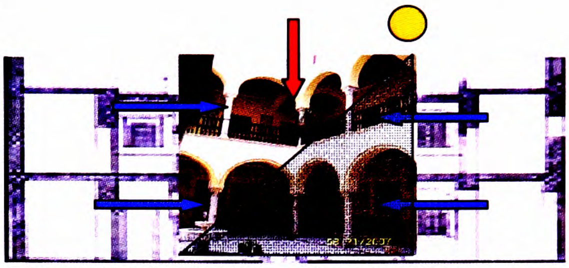


Figure 3. 24: The second cycle of air movement.

The third cycle starts when the sun's rays fall vertically on the courtyard, the warm air begins to rise up where it is replaced with cooler air, this cycle continues into the night until the first cycle starts again (Figure 3.25).

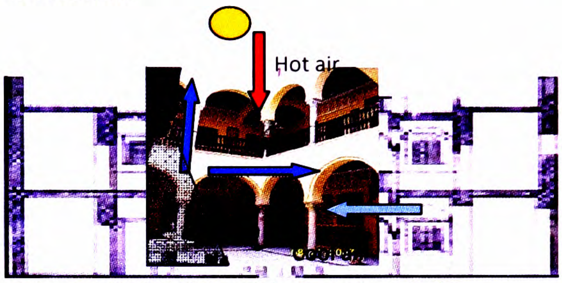


Figure 3. 25: The third cycle of air movement inside the courtyard.

Source: Almansuri et al., (2009 A)

Amer (2007) stated that the courtyard as an architectural element is functionally based on aspects of the climate, demonstrating its suitability for hot weather, because it helps circulate the air and stimulates the required air currents. He concluded that the main two functions of the courtyard in relation to climatic conditions are:

- During day time, the courtyard is cool because of the shade offered by the walls and surrounding houses;
- During the night, the courtyard is also cool because of the cold air layers on the floor.

- **The fountain: as a part of the courtyard.**

The advantages of a fountain are to display water and mix it with air to increase humidity and to cool the air by evaporation. Fathy (1986) stated that a fountain is an architectural element occupying a privileged place in the house plan.

- **The salsabil**

This replaced the fountain where there was not enough pressure to allow the water to spout out of the fountainhead (Fathy, 1986). It is a marble plate located at an angle which allows water to drop over its surface, to flow into a marble channel until it reaches the fountain located in the courtyard, in order to increase the humidity of the surrounding air (Mohamed, 2010).

- **Porch:**

Manríquez et al. (2006) stated that a porch or portico is an excellent feature in a hot climate. To provide shade in the summer time and to allow low angle winter sunbeams, the location of the porch can be in the south, southeast or east (Figure 3.26).

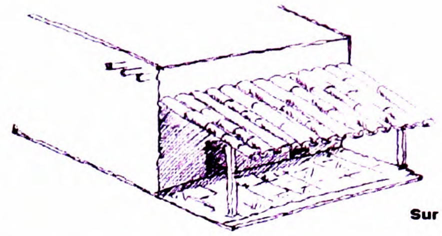


Figure 3. 26: The porch as a solar control device.

Source: Manríquez et al. (2006)

3.4.1.2 The *malqaf*

The *malqaf* or wind tower is a traditional architectural element that forms mainly part of residential houses. The function of this tower is to catch cooler breeze that is located at a higher level above the ground and to direct it into the interior of the buildings. This feature is used in many countries around the Arabian Gulf (Figures 3.27 and 3.28).

Fathy (1986) explained that the *malqaf* or wind-catcher was invented to satisfy a need for ventilation. It is also useful in reducing the levels of sand and dust. It can be incorporated into modern buildings aesthetically. The Badger is a kind of developed *malqaf*; it has a shaft with a top opening on two or four sides (Figures 3.29, 3.30). A Badgir which is made of mud-bricks gets cool by radiation and convection (A'zami, 2005). Fathy (1973) stated that in Gourna school, the wind catcher produced a drop in temperature inside the classroom of 10°C.

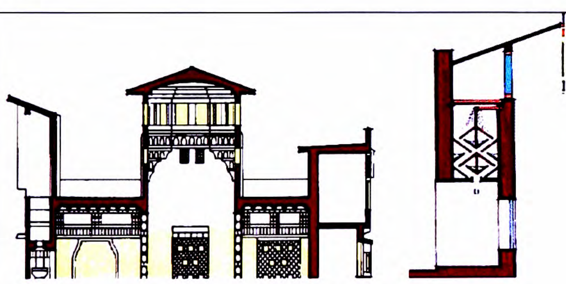


Figure 3. 27: Kinds of wind-catchers.
Source: After Fathy (1986)

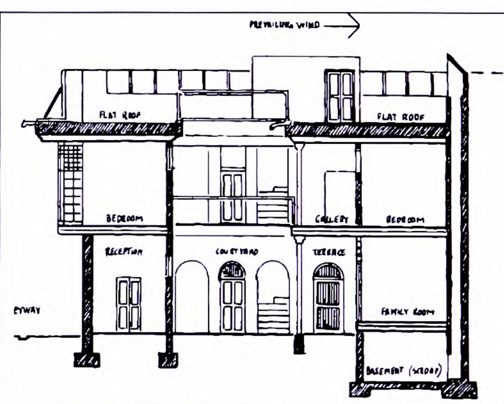


Figure 3. 28: Cross section of the Baghdad house. Source: Stead (1980)

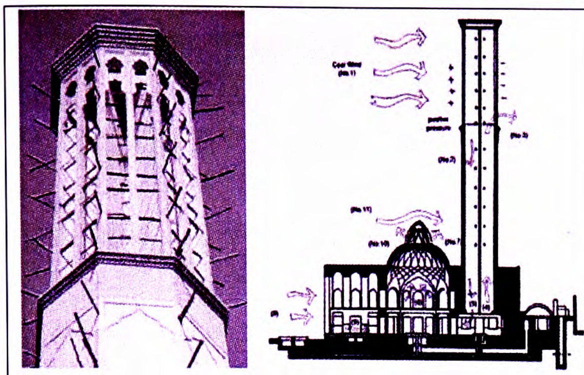


Figure 3. 29: Wind-catcher at Dowlat-Abad Garden in Yazd (Iran).

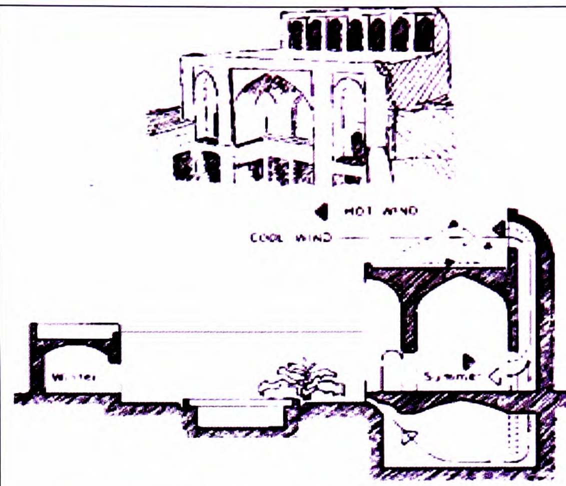


Figure 3. 30: Persian house showing a unidirectional badgir (Egypt).

3.4.1.3 Openings

The kind of windows that should be used in hot climates as suggested Givoni (1998) is to use small windows with a total area of about 5 to 10% of the floor area. However, large windows can be used by adding some features such as insulated controllable shutters and screens. In addition, a movable *Shesh* can be added directly to the window to block the sun's rays but not prevent access by the breeze. There is also another kind of opening that can be used to improve internal ventilation which is called a *Taka*; it is located higher than the window and faces it (Mohamed, 2010).

Mashrabiya is the name of a typical type of wood carving particular to the Arab East mainly used for windows, which allows cool breezes to enter homes in the heat of summer (Figures 3.31, 3.32). Kamel (1996) stated that *mashrabiya* is a most sophisticated type of woodwork and is used mainly in decorating the windows from the outside; it can be used on the inside the house as well.

The *mashrabiya* allowed people inside a building to look out without being seen. It is frequently used to cover the windows of the women's quarters within homes. Fathy (1986) stated that the *mashrabiya* has five functions: (1) controlling the passage of light, (2) controlling the air flow, (3) reducing the temperature of the existing air, (4) increasing the humidity of the existing air, and (5) ensuring privacy. In addition, using a ventilation blind is useful in regulating solar radiation and wind flow into rooms. Also, a sun-breaker can be used to protect whole facades of glass-wall and concrete or steel frame buildings.

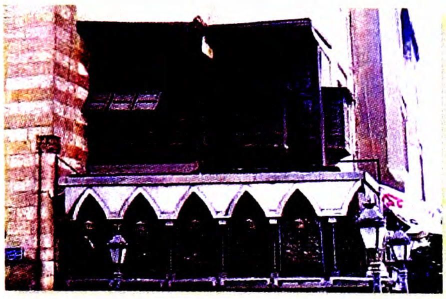


Figure 3. 31: Using mashrabiya in elevations.
www.touregypt.net/featurestories/mashrabiya.htm

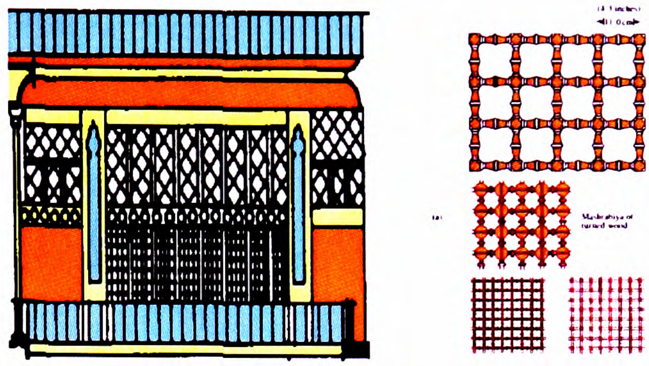


Figure 3. 32: Different forms of mashrabiya.
Source: After Fathy (1986)

3.4.1.4 Roof construction

The shape of the roof is very important in sunny climates because it is the surface that is most exposed to temperature in the building. Kennedy (2004) stated that roofs need to prevent unwanted heat loss or gain. As roofs are exposed to the sun, they must keep out the sun's heat through insulation or radiant barriers. In the Middle East, domes and vaults are common and are made with materials such as bricks, stones and earth that is strongly compressed. Fathy (1986) confirmed that curved and pitched roofs are the most useful way to adapt to hot climates and the combinations of vaults and domes can be infinitely varied and extremely beautiful (Figures 3.33). The importance of using domed roofs near a wind catcher has been clarified by Kazemi (2006) as the low pressure created by the wind passing over the dome leads to the sucking out of the warm air trapped in the inner part of the dome (Figure 3.34).

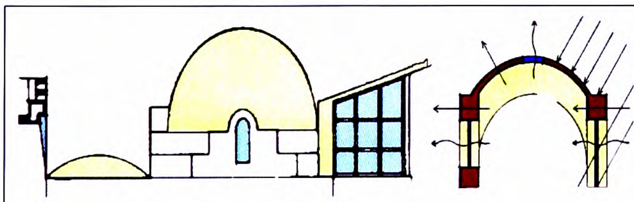


Figure 3. 33: Domed roofs.
Source: After Fathy (1986)

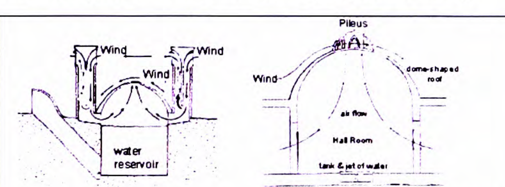


Figure 3. 34: The wind passing over the dome. Source: Kazemi (2006)

Although traditional buildings used the best techniques available at the time, these are not necessarily the best solutions for current needs. Current methods and materials have the potential to improve functionally, cleanliness, indoor climate and provide even greater energy efficiency. Consequently, the key factor for this research is what lessons can we learn from the past in terms of how to work with the climatic conditions of the location, in combination with the use of local materials and traditions of construction and their direct connection into 'modern' architecture with the application and integration of appropriate modern technologies.

For more understanding of vernacular architecture, see Edwards et al., (2006). Also, section 3.5.3 provides applications of some of the features of vernacular architecture. The next part provides explanations of passive climatic design solutions used in contemporary architecture.

3.5 PASSIVE CLIMATIC DESIGN AND CONTEMPORARY ARCHITECTURE

Passive design (in essence taking maximum advantage of nature and the climate in particular to designing built environment) may seem to be the latest trend in building design, but it is an idea that has been with us for a long time. Many authors, researchers and institutes have paid attention towards the importance of passive design in designing the built environment without using mechanical heating or cooling equipment. Evans (2008) stated that indoor temperature comfort can be achieved through two different methods: (1) the use of passive controls by avoiding excessive internal heat gains, incorporating solar protection for glazed openings, night ventilation and thermal mass. Dense and high heat capacity internal walls and ceilings reduce peaks and maintain the lower temperature achieved with night ventilation; (2) mechanical cooling can be used to remove heat from indoors and leave it outdoors.

Several theoretical and experimental studies have demonstrated the usefulness of passive design techniques. In the context of cooling buildings in hot-dry and warm-humid climates, passive techniques mainly aim towards reduction in heat infiltration through the building envelope and the provision of fenestration for inducing desired natural ventilation indoors (Mathur and Chand, 2002).

Littlefair (1998) believed that it (passive design) is increasingly unlikely to make a major impact on the future; he believed that passive solar has to move into the city (previous studies on passive solar design have concentrated on the use of "green field" rural or suburban sites). Solar design needs to come to terms with environmental awareness as well as low energy and resource consumption by making the most of obstructed urban sites rather than using up scarce open land.

Passive design is a process to develop ideas and strategies "*for the design of whole buildings that have minimal reliance on mechanical plant*", it works with the building envelope which filters the climate and tempers the internal environment (Dowdle, 2003:3). Reardon (2005) confirmed that passive design is design that does not require mechanical heating or cooling; dwellings that are passively designed take advantage of natural energy flows to sustain thermal comfort.

According to the U.S. Department of Energy (2004) passive solar design or climatic design is designing the components of the building such as windows, walls and floors to collect, store, and distribute solar energy in the form of heat in the winter and reject solar heat in the summer. Likewise, Panchyk (1984) confirmed that the structure of a building (including walls, floors and ceilings as a part of passive solar systems) functions as a heat-collecting and storage element or thermal mass and often becomes the radiant heating surface within.

Passive climate control is a design principle where it is important for the architect and engineer to be aware of how the building is used. At the same time it is important for the user to understand the building and to be aware of any activities that could possibly have an unintended and inappropriate effect on the indoor climate (René et al., 2001). National Renewable Energy Laboratory (NREL) (2001) explained that the difference between a passive solar home and a conventional home is design. The key is to take advantage of the local climate when designing a passive solar home.

The main principles of passive design in homes are:

- Provide acceptable levels of comfort.
- To be as low energy as possible (reduces heating and cooling bills).
- To be as self sufficient in renewable energy as possible.
- To have as little impact on the environment as possible by reducing greenhouse gas emissions

For hot regions, natural cooling is very important in order to achieve comfort. Cofaigh et al. (1996) clarified that the heat accumulated by the building envelope during the day may be lost by night-time radioactive heat loss to the sky, or by ventilation with the cooler night air. They provided a set of cooling strategies as follows:

- Control external gains in summertime, by screening where necessary;
- Use energy-efficient appliances to minimise internal gains;
- Ensure that there is adequate cross-ventilation to the dwelling, and that sunspaces can be vented to outside;
- Provide adequate cut-off between sunspaces and the body of the dwelling;
- Use vegetation and water for positive cooling.

To sum up, the concept of passive climate control is completely in line with the notion of sustainable building. It provides an alternative to a mechanical air-conditioning system and, as such, is an essential part of low energy solutions. Passive climate control implies that a building is constructed and arranged in such a way that the thermal and hygroscopic properties of the building and its contents create a good stable indoor climate. It concentrates on building physics and as an underlying principle accepts that although the temperature and relative humidity may be maintained within acceptable ranges these parameters may stray outside the design code requirements for limited periods.

3.5.1 Passive design techniques

Most references state that every passive solar building should include five different elements (Figure 3.35) which are:

- **The Collector**: collect the sunrise through windows which should face the south.
- **Absorber**: This is the storage element which could be walls, floors, or partitions. Sunlight hits the surface and is absorbed as heat. Evans (2007) explained that, in buildings with a well insulated external envelope, the addition of internal mass can reduce the temperature swing by up to 80% of the external swing.
- **Thermal mass**: These are the materials that store the heat produced by sunlight. It is the material below or behind the absorber (exposed surface).
- **Distribution:** This is the method by which solar heat circulates from the collection and storage points to different areas of the house.
- **Control:** These are the elements which could control under or over heating during the summer time such as using roof overhangs to provide shaded areas during the summer months.

These elements are very important in places which need heating more than cooling, but in the hot desert regions, which need cooling more than heating, the fifth principle (control) should be the main principle to avoid the overheating.

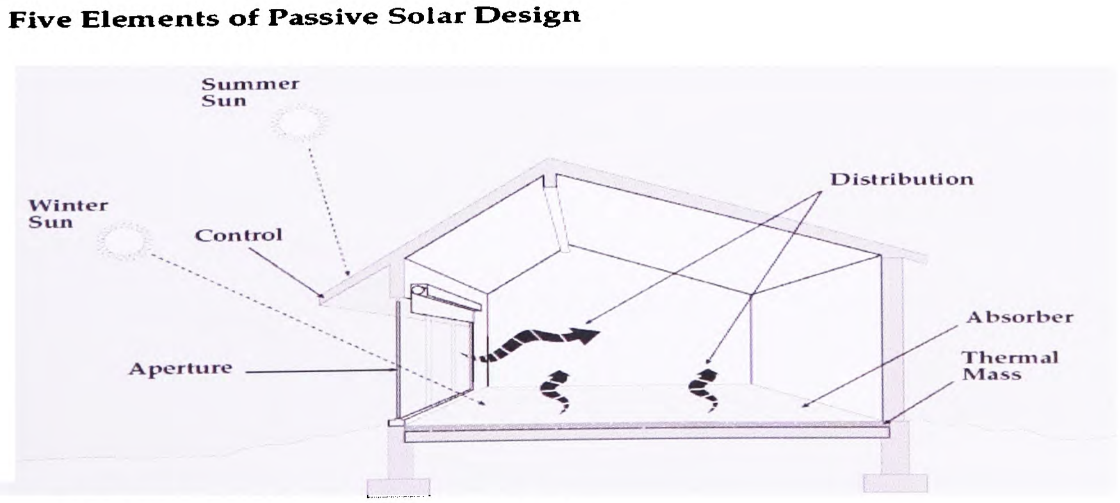


Figure 3. 35: Five passive solar design elements.
Source: Energy Efficiency and Renewable Energy (2008)

Many references set out the basic passive solar design techniques. For instance, the U.S. Department of Energy (2004) and Christensen (1994) stated that there are three basic types of passive solar design: direct gain, indirect gain, and isolated gain, and some others give two other types: composite and combined. All of these types are explained by Christensen (1994), Evans (2007) and Roaf et al. (2003) as follows:

3.5.1.1 Direct heat gain

South facing glass admits solar energy into the house where it strikes directly and indirectly on thermal mass materials in the house such as masonry floors and walls (Figures 3.36).

The thermal mass will temper the intensity of the heat during the day by absorbing the heat. At night, the thermal mass radiates heat into the living space.

Figure 3. 36: Direct heat gain in winter. Preventing direct sunlight in summer

Source: After Panchyk (1984)

3.5.1.2 Indirect heat gain

In the indirect heat gain system, thermal mass is located between the sun and the living space. The thermal mass absorbs the sunlight that strikes it and transfers it to the living space by conduction. There are two types of indirect heat gain systems:

- Thermal storage wall systems (The Michell-Trombe wall (Figures 3.37). Evans (2007) explained that the 'Trombe wall' or 'ventilated accumulator wall' achieves a favourable modification of the outdoor conditions in a series of steps, using the different thermal properties of glass, surface absorbance and thermal mass in following layers of the construction.
- Roof pond systems, using water pipes in the roof to heat water in morning and distribute heat at night (Figure 3.38).

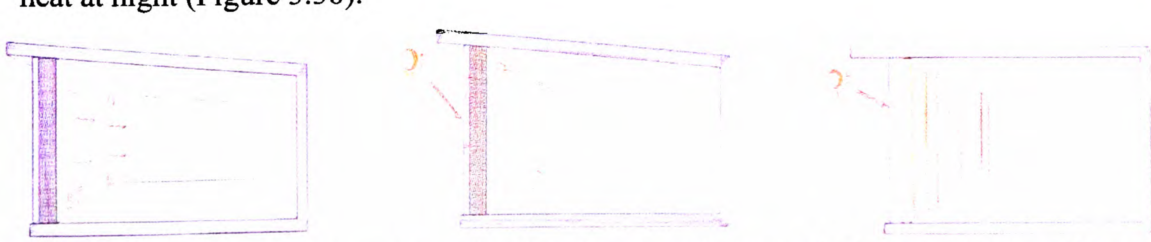


Figure 3. 37: Using the storage wall with closed and open windows and using the water pipes wall as a thermal storage wall. Source: After Panchyk (1984)

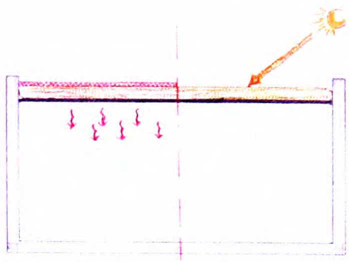


Figure 3. 38: Using water pipes in the roof to store heat in morning and distribute it at night.
Source: After Panchyk (1984)

3.5.1.3 Isolated system

An isolated gain system has its integral parts separate from the main living area of a house. Examples are a sun room (solar greenhouse) and a convective loop through an air collector to a storage system in the house (Figures 3.39). It employs a combination of direct gain and indirect gain system features.

Figure 3. 39: Direct heat gain to sun room and indirect heat gain to living room.
Source: After Panchyk (1984)

3.5.1.4 Combined system

This system is more flexible than the others because it depends on mixing more than one type of system (Figure 3.40).

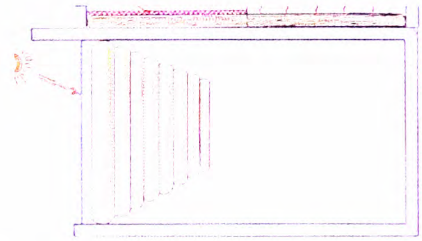


Figure 3. 40: Using a Trombe wall and water pipe roof at the same time.
Source: After Panchyk (1984)

3.5.1.5 Mixed system

This kind of system depends on using one of the previous systems in addition to using mechanics to increase the benefits; it can be created by mixing passive and active systems (Figure 3.41).

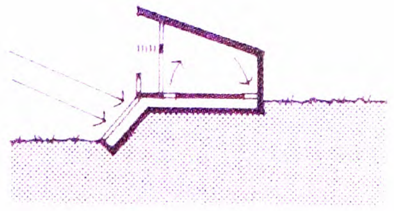


Figure 3. 41: Using direct heat gain and a solar collector. Source: Ebrahem (1987)

These modifications of the indoor conditions in buildings can be achieved by the use of the characteristics of the building skin, building materials, cross-ventilation and by the use of available technologies.

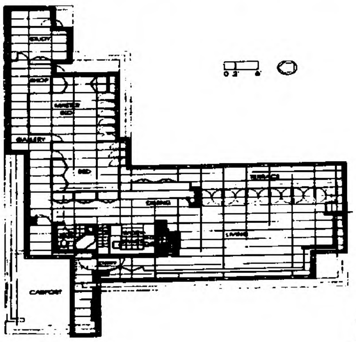
Therefore, in the next section, a series of examples are presented, based on passive design solutions. These demonstrate the potential of the building design to modify the internal conditions through strategies of natural conditioning.

3.5.2 Examples of passive climatic design techniques

Many architects paid attention to climate in their work from the early years of the last century. They adapted for climate in different ways and for different reasons such as reducing energy consumption, benefitting from sun and weather to provide comfort and lately most of them are working with climate to help in reducing environmental impacts. Most architects believe that vernacular architecture gives the best examples of climatic design and a great variety of devices such as sun-breakers have been added to the vocabulary of architectural features in hot zones. The works of many architects in the late 20th century heads towards ecological sustainability in the built environment. This section will give examples of buildings which show some of the general climatic solutions in the work of 20^{th} century pioneers.

- **Jacobs' house**:

The Jacobs' house was designed by Frank Lloyd Wright and is located in Madison, Wisconsin. It was built during 1936-37. It is well oriented to use solar gain to heat the house. However, it was not insulated. It was one of the first buildings in the United States with radiant floor heating. The original radiant floor heating system had the pipes located underneath the floor slab in a layer of sand. The entire roof of the house has also been insulated. It had single glazed windows and doors, wood sandwich walls and radiant floor heating (Figures 3.42) (Sturgeon and Porges 1998).



L-shaped plan

The north view

Internal photograph of the living room

The south west view

Figure 3. 42: The Jacobs' House. Source: Sturgeon and Porges (1998)

- **Maison Clarte building**:

According to Gallo (1996), Maison Clarte was designed by Le Corbusier in 1932 in Geneva. Le Corbusier studied the sun path (Figures 3.43 and 3.44) and solved the heat problems by extending the floors to provide a one and half meters deep balcony with a parapet. Also sliding shutters were added in front of the parapets because of the summer heat, thereby casting a shadow and establishing a very satisfactory condition of sun penetration in the winter and giving a sun barrier in the summer.

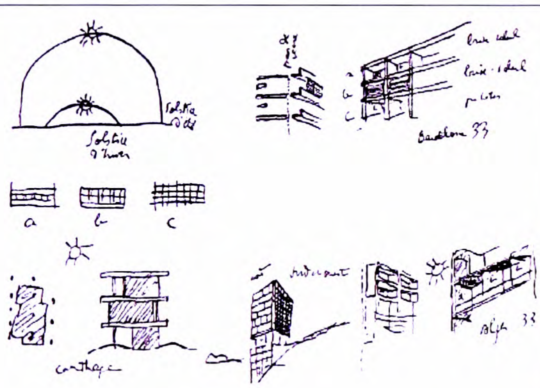


Figure 3. 43: Sun path studies.
Source: Gallo (1996)

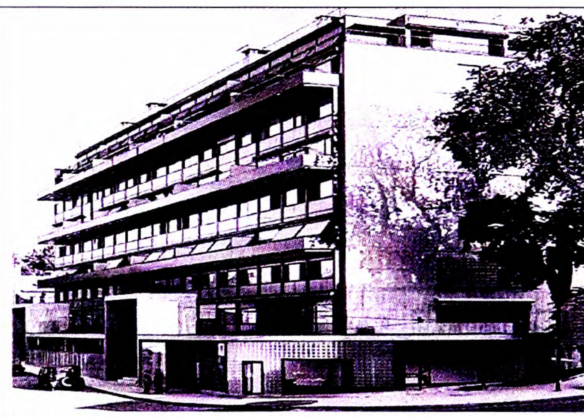


Figure 3. 44: Maison Clarte building.
http://www.galinsky.com/buildings/clarte/

- **The Tower of Shadows**:

Le Corbusier designed the Tower of Shadows in 1960 in Chandigar. The orientation of the building is north-south, making a deliberate break with the balance of the huge path. The northern side is completely open, while the other three sides are equipped with brise-soleil. (Figures 3.45).The course of the sun during all seasons has been very carefully studied and annotated at the Atelier Le Corbusier in order to determine the location and orientation of the various brise-soleil (Gast et al. 2000).

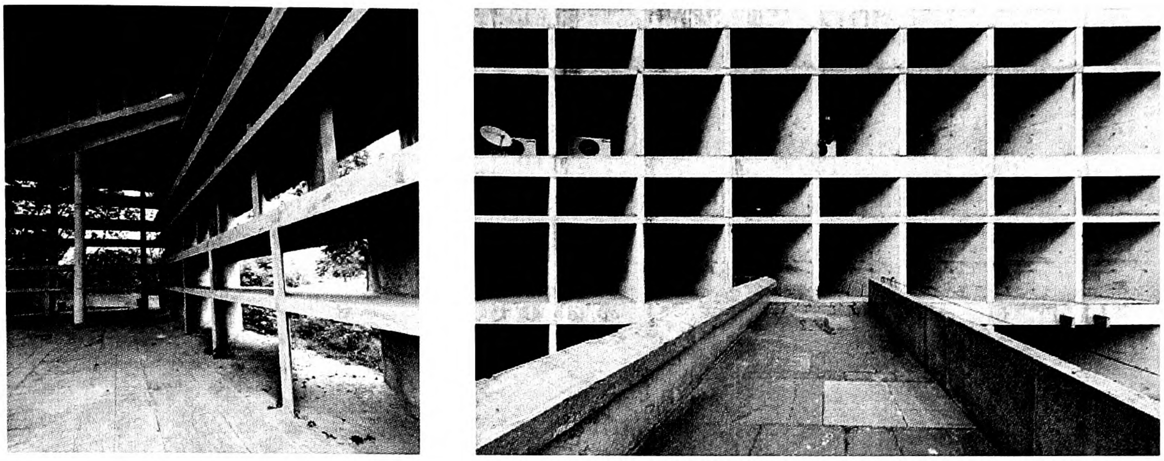


Figure 3. 45: The Tower of Shadows, Chandigarh.
http://www.flickr.com/photos/manuelasiener/tags/chandigarh/

- **Tunisia - Carthage villa:**

While reviewing some of Le Corbusier's work, it is important to mention that Le Corbusier was affected by the vernacular architecture of Mediterranean and Arabic countries when he designed two villas in Tunisia. Gaber (2001) stated that Le Corbusier looked outside his own context for new approaches to design by studying the vernacular architecture of Tunisia and improving it. He extracted the dominant form of Tunisian buildings which had not changed in typology since the 16th century and which incorporated the courtyard, the open floor plan, the simple second story and the shield-like elevation. These elements inspired Le Corbusier to reinterpret their functional and structural roles and use them as a framework for new design.

The courtyard assumes a more dominant position in his other project but at the Tunisia - Carthage villa that built in around 1967 (Figures 3.46) the courtyard is figurative. The villa was divided into three main terraces; ground, first and roof, each of these was a central gathering space of kinds and divided according to function but not as an open courtyard. The development in interior design was the sectional flow of rooms where the ground floor flows volumetrically into the other levels not just for attractive architectural innovation, but to act a wind catcher, which managed to circulate incoming air currents throughout the house (Gaber, 2001).

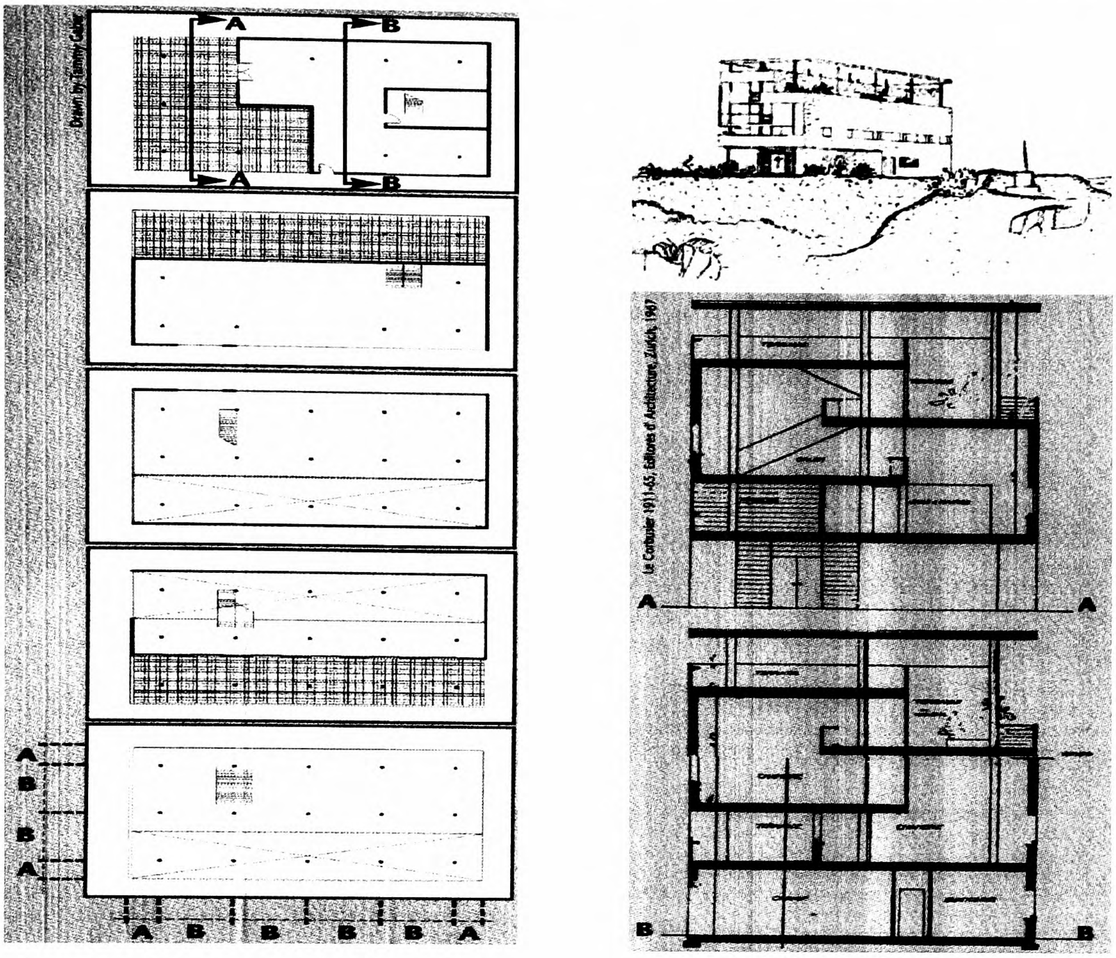


Figure 3. 46: Tunisia - Carthage villa. Source: Gaber (2001)

- **Roof-Roof house**:

According to KBDA (1995), Ken Yeang designed this house in 1984 to be used by himself and his family. He used structure as environmental filters, which also determined the form, language and configuration of the building. He extracted climatic function from the vernacular style in Malaysian architecture and used the idea of the roof and veranda serving as a form of umbrella to protect the interior from direct solar gain. It is the enclosure systems that operate as environmental filters within the landscape where the planning of the internal spaces follows a radial configuration along an East-West axis and in this way integrates the spaces between the building and the site boundary walls as mini-courtyards (Figures 3.47). Hagan (2001) stated that this house does not look like its vernacular antecedent in form or material but it looks like an international style and the louvred sunshade over house and pool provides what Yeang calls a 'solar filter' suitable for warm-wet tropical climates. It is the first step towards developing a fully fledged bioclimatic architecture that attempts to assimilate western building style types such as high rise buildings with traditional passive cooling strategies taken from vernacular Malay houses.

As to the functional aspects, it has satisfied the need of the users. Yeang stated that the house had been effective in its role as an experimental design using a systemic approach in generalizing the building form, configuration and spatial organization based on climatic factors (KBDA, 1995).

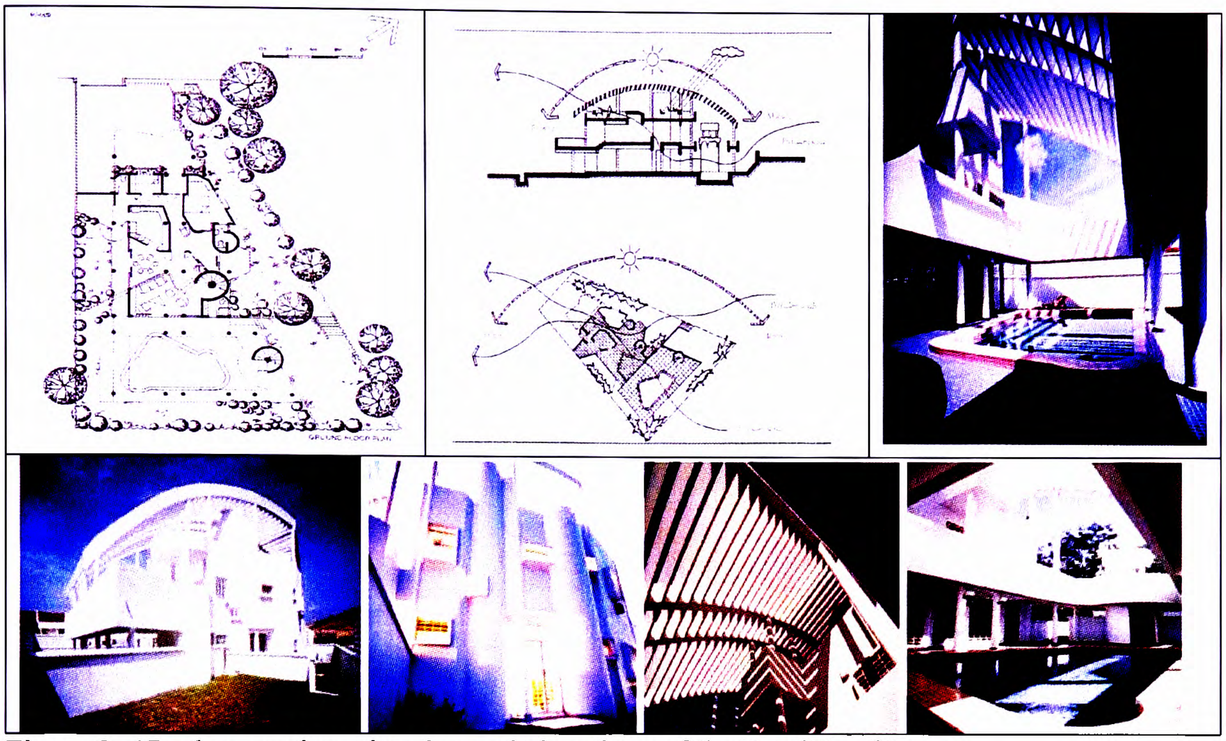


Figure 3. 47: plan, section, site plan and elevations of the Roof-Roof house.
Source: KBDA, (1995)

- **The Oxford Solar House**:

One of the important examples of eco-housing undertaken in the late 20th century was designed and occupied by Susan Roaf (Figure 3.48). It was built in 1994. It was one of the first low energy houses in the UK with a fully integrated photovoltaic roof to explore what PV cells could do. It has been so successful that it is both a net exporter of electricity and Susan manages to run her car off the roof as well. The house is designed to use the minimum of energy for heating, cooling and lighting. The house is laid out with rooms arranged around a central core incorporating a service duct, it has stairs to the first floor and a lobby to the covered entrance. The front and back doors are protected by buffer spaces (Figure 3.49 and 3.50). Triple glazed windows are used throughout the house except in the sun spaces and in order to reduce the pipes in the house, the position of the bathrooms are over the kitchen (Fuentes et al., 1996).

Figure 3. 48: Solar house main elevation.

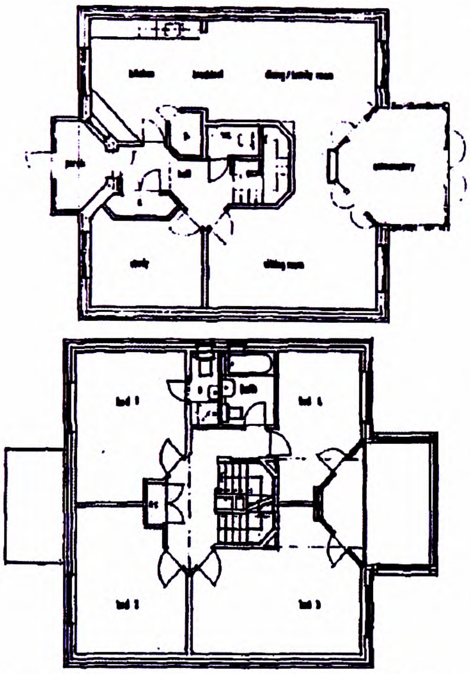


Figure 3. 49: Plans of the solar house.
Source: Fuentes et al., 1996.

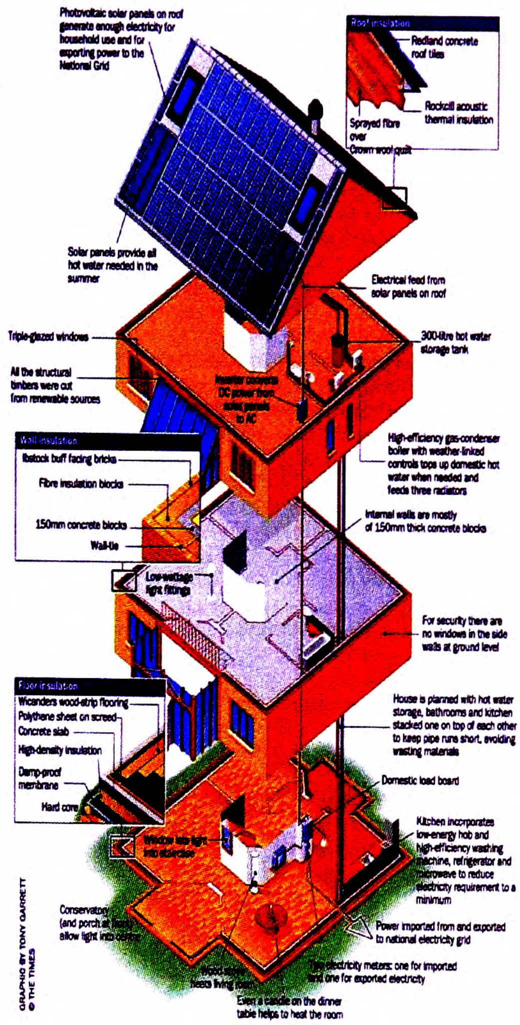


Figure 3. 50: Cross section showing the different functions.

The examples above and others which have not been addressed in this research, show that the importance of climatic design is not a new innovation and it is not impossible to create a comfortable environment by using passive solutions. The next section provides examples of new vernacular architecture in hot regions which have achieved passive climatic design by improving vernacular features and using technology.

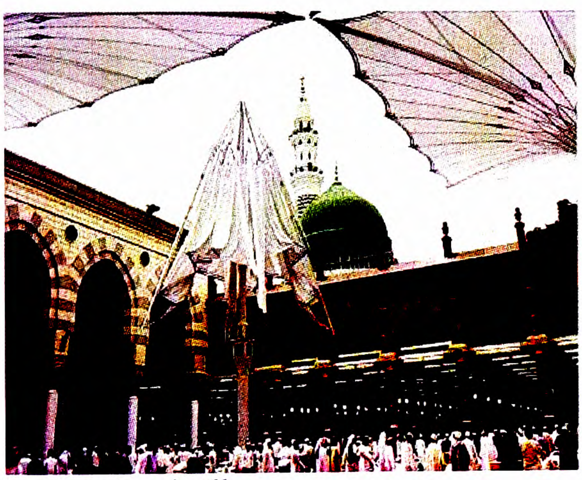
3.5.3 Examples of new vernacular architecture in hot regions

This part of the study presents examples of what we call 'new vernacular' which aims to use some vernacular solutions in ways that can meet the needs of today.

The examples have been chosen for different functions and from different locations in hot and hot-humid regions.

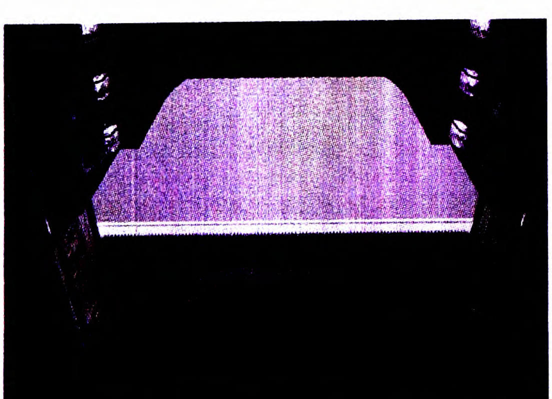
- **Holy Mosque in Medina** [Saudi Arabia]:

An Egyptian architect, Kamal Ismail, designed the extension to the Holy Mosque in Medina. He used a mixture of technology and vernacular solutions such as using 27 courtyards to let in natural light and ventilation. For the two large inner courtyards (17m x 18m) he used six convertible umbrellas with cone-shaped membranes with a height of 14m. These were developed to provide shading without destroying the character of the courtyards (Figures 3.51) (Ashour, 1998). When they are opened the umbrellas reveal their gathered membranes to create a lightweight vault. When closed, the umbrellas take on the classical image of domed minarets. In the same mosque to ensure environmental control during summer and winter they incorporated some of the latest technology to deal with some environmental problems in a covered extension to the existing mosque measuring 450m x 250m. To light and ventilate this area 27 open courts are distributed within it and each court is covered by a sliding steel dome which rolls on rails to a park position over the roof (Ashour, 1998).

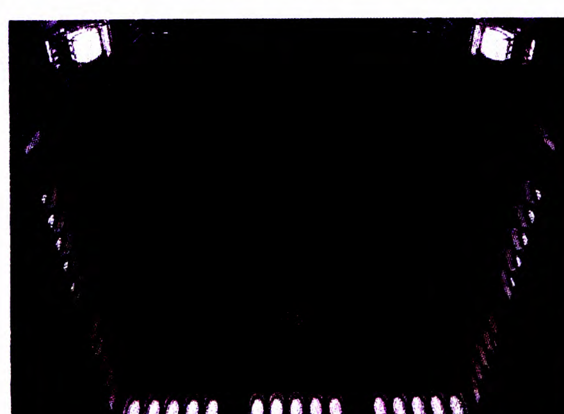


The closed umbrellas
www.geocities.com/sjalam/gif/covemad.jpg

The opened umbrellas.
www.jannah.org/articles/madinah.html



The dome while covering



The covered dome

Figure 3. 51: The Holy Mosque in Medina. Source: Ashour (1998).

- **The Hajj terminal in Jeddah** [Saudi Arabia]:

This project won the Aga Khan award for the best Islamic design in 1985. The project incorporates 210 tents and forms the roof of the terminal. It is only used during the month of the El Hidja, when nearly one million Muslims pass through this terminal. The plan of this terminal consists of two halves each consisting of five equal modules. Each module comprises twenty one tent units suspended from tapering steel pylons. The use of a vast tent sitting in the desert was a practical answer with great visual strength (Figures 3.52 and 3.53).

The designer had been inspired by the Bedouin tent and the design was not a copy of tents of the past but it is a form for the future. The open structure allows the air to circulate. The roof reflects heat and lets the air circulate keeping an even temperature of 33.5°C while the thermometer outside soars to 54.4°C (Abderezak and Tahar, 2004).

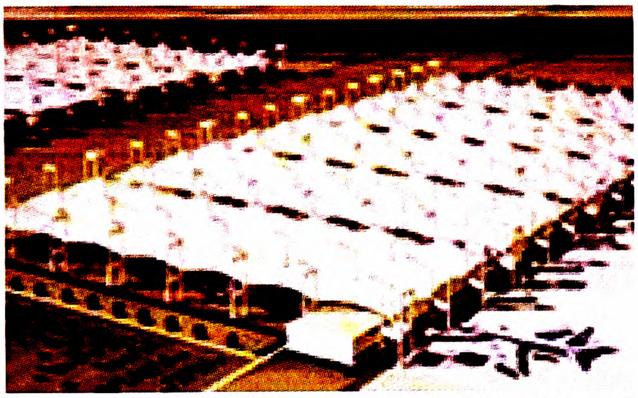


Figure 3.52: The structure adapted from the traditional tent. tradearabia.com/news/ttn_174548.html

Figure 3.53: Internal view of the terminal. Source: Abderezak and Tahar, (2004).

- **Qatar University:**

Ashraf, (2008) stated that Qatar University was built in 1973. To control the harsh climatic conditions an Egyptian architect, Kamal Kafrawi, integrated modern technology with traditional elements of Arabic Islamic architecture. He developed some vernacular elements as follows:

1. Wind tower structures: these are one of the most outstanding features of the university and are used to provide cool air and reduce humidity; also to provide cover for the university buildings (Figure 3.54).
2. Protected courtyards: with their gardens and fountains, the courtyards provide pleasant areas of coolness and shade, both open and partially covered. They provide connection and circulation spaces within the university complex. Towers of light are also introduced and are intended to control the harsh sunlight, and abundant use of *mashrabiya* and some stained glass also serve to mediate the environment (Figure 3.55, 3.56).

3. Geometric forms: the octagonal shape of the modular unit was derived from traditional principles which enhances ventilation through wind towers and provides lighting through indirect sunlight.

Figure 3. 54: Emphasizing natural ventilation by using wind towers in the education technology centre.

Source: Mcmorrow, B. (2010)

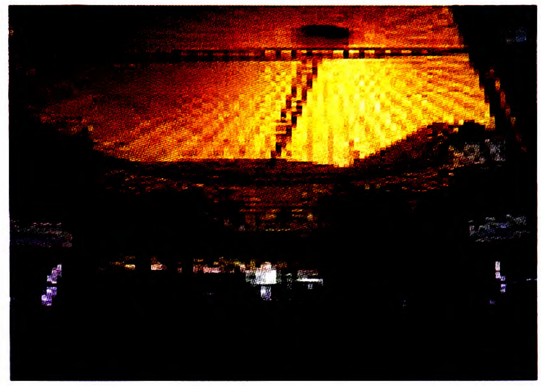


Figure 3. 55: The covered courtyard.

http://commons.wikimedia.org/wiki/File:Doha_Shopping_Centre.jpg

Figure 3. 56: Using Mashrabiya in the university buildings and using fountains to provide humidity. Source: Ashraf, (2008)

- **The Maadher Project** [Algeria]:

The most advanced articulation of Algerian contemporary architecture can be found in buildings and projects by Hany and Abderahman El Miniawy who partly collaborated with the architect Aly Seradj. Their works are closely connected to the Islamic past without contradicting present day conditions. Abderezak and Tahar (2004) stated that this project helped to redefine architecture as it attempted to resolve the most basic and critical issues confronting the poor people of Algeria. They described the main features of the village: it is built of mud bricks made on the site and consists of four houses grouped around a shared courtyard, each house having in addition its own private courtyard. Each house is covered by simple vaulted forms (Figure 3.57, 3.58). They believed that the project responds to the harsh climate and that it provides an environment in which people can live and work comfortably.

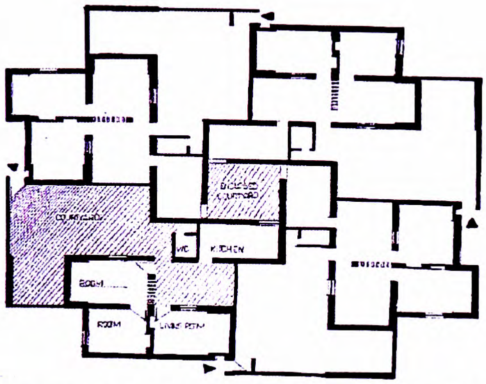


Figure 3. 57: Plan of four individual houses.
www.planum.net/topics/themesonline-arabarchitecture.html

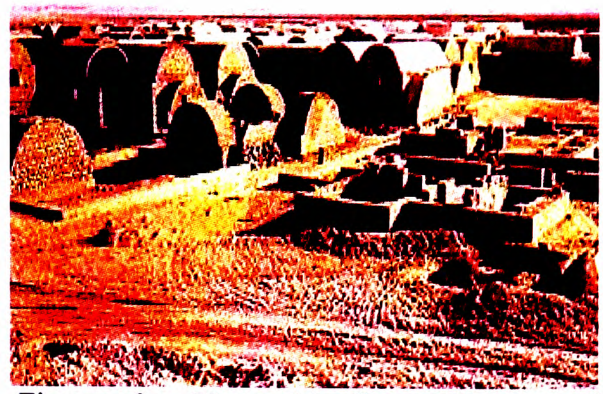


Figure 3. 58: Maadher village under construction, the vaults are used for roofs.
Source: Abderezak and Tahar (2004)

Mosaad (2005) stated that the architects Hassan Fathy and Ramses Wissa Wasef were forerunners in the use of new vernacular architecture and their influence is felt by younger architects all over the world. Fathy was more directly influenced by the vernacular architecture of the Nubians as well as being inspired by Egyptian architectural heritage and adopted it in a new context and in doing so he himself influenced several architects throughout the world.

Technology in the view of Hassan Fathy has been clarified by Steele (1989) as Fathy placing an early emphasis on appropriate technologies, on local materials and construction techniques and on social co-operation chime with contemporary, environmentally conscious architecture, in which architects have tried to work with the environment instead of changing it, exploring the renewed use of traditional materials and techniques and having a more modest understanding of their social and cultural roles. El-Rashidi (2000) cited the opinion of architect Ahmed Hamed on Hassan Fathy saying that he was not, as many believed, rejecting modernity lock, stock and barrel, but rather globalisation and industrialisation as homogenising concepts that strip humans of their individual qualities, cultures and values. Hamed explained that, many people believe that Hassan Fathy was against technology. In fact, he was not against technology and he used appropriate technology.

It is useful to explore some of the works of Hassan Fathy in different countries. These houses all incorporate trademark Fathy elements such as the domes that he adopted from vernacular Nubian architecture and the use of *mashrabiya* and other traditional materials.. He also reproduced the traditional Cairo house inner courtyard and the division of private and public domestic space.

- **Emir's house project in Kuwait** (Al-Sabah House)

Steele (1989), Abderezak and Tahar (2004) and Serageldin (2007) described the house as genuine and authentic modern Arab architecture which was designed by the champion of indigenous buildings Hassan Fathy and was built in 1978. This house belongs to Sheikha Hussa, daughter of the late emir, and her husband Sheikh Nacer who has struggled to preserve some of Kuwaiti heritage.

The building was made in traditional mud brick, all hand made on site. The project gave an idea of the charm, dignity and intelligent arrangements of a traditional house. It included inner courts which is essential for the Arab way of life and the spaces complement and enhance each other, each having its own social function, eg, for men to gather, for women to look after the children. In this project Fathy proved that the graceful mud brick structures were both economical to build and admirably suited to the climate (Figure 3.59 and Figure 3.60).

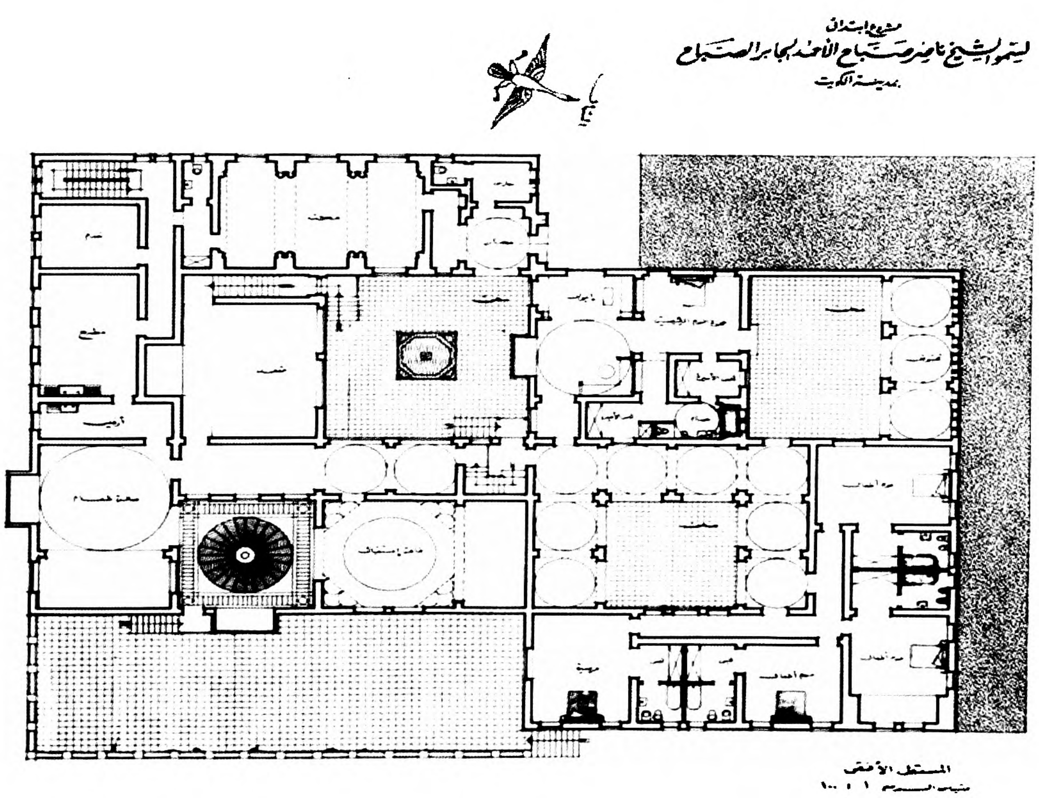


Figure 3. 59: Plan of Al-Sabah House. Source: Steele (1989)

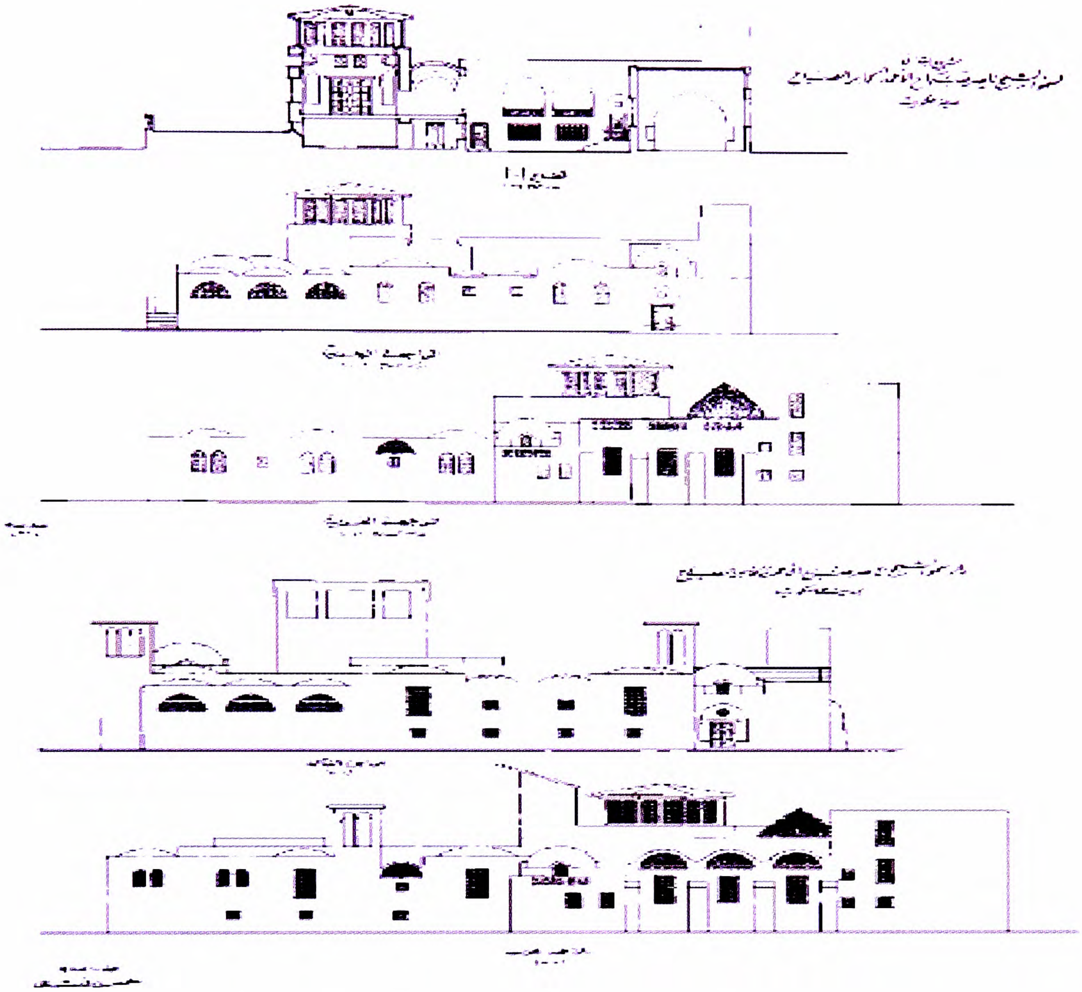


Figure 3. 60: Section and elevations of Al-Sabah House. Source: Serageldin (2007)

- **Saudi Arabia project** (Abdul Rahman Nassief house):

Hassan Fathy was involved in several residential projects in the Kingdom of Saudi Arabia between 1973 and 1975. One of these houses belongs to Dr. Abdul Rahman Nassief. It was built in 1973 and is located in Jeddah. The philosophical direction of this house is most controversial today (Steele, 1989). Serageldin (2007) stated that the house was built with stone block recovered from damaged traditional tower houses in the old city. Rather than using the familiar dome over the guest area, he found that an octagonal shukshieka would be more regionally appropriate. (Figures 3.61, and 3.62).

There are two similar rooms (*qa'as*) linked by a passageway. This passageway serves as a spine that links an open, central courtyard and a large public *majlis* with its related dining area.

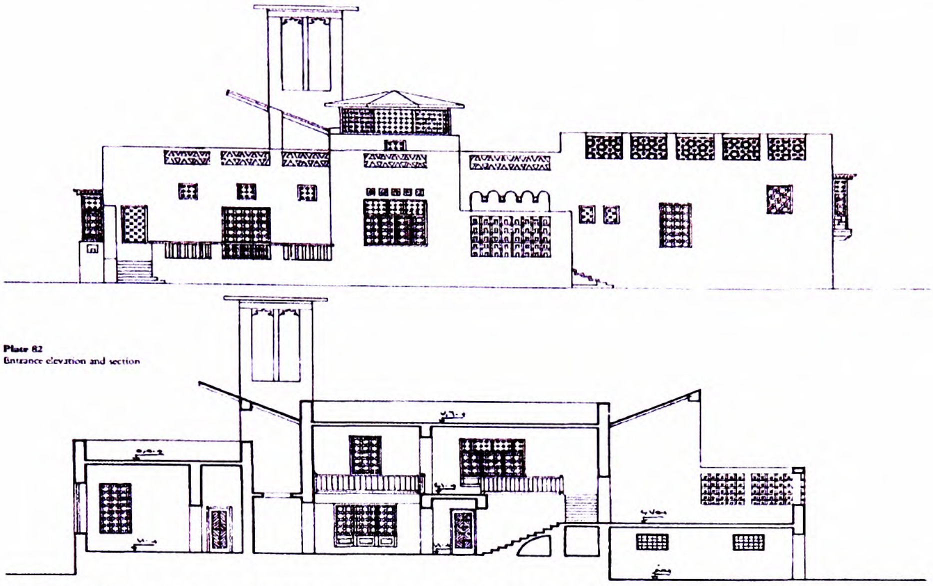
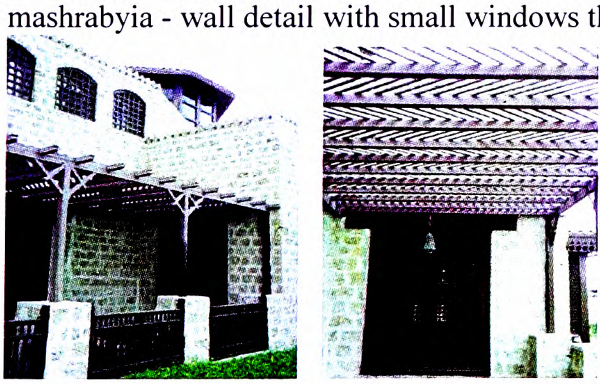


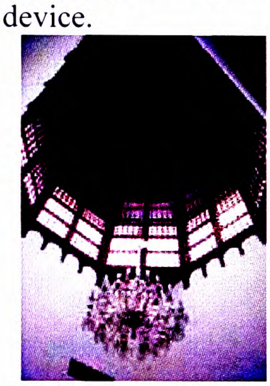
Figure 3. 61: Elevation and section of the Abdul Rahman Nassief house.
Source: Rastorfer (1985)

Elevations showing the use of local materials such as stone and the parapet wall with mashrabyia - wall detail with small windows that protected by shading device.



Using the entry porch to provide shade.

Using *mashrabyia* to achieve privacy and provide ventilation.



Using octagonal *shukshieka* instead of dome

Figure 3. 62: Abdul Rahman Nassief house.
All images Source: http://archnet.org/library/images/thumbnails.jsp?location_id=1545

- **Fouad Riad house, Giza –Egypt:**

According to Steele (1989), this house, one of Fathy's "stone period" houses, which was prompted by a governmental ban on the use of mud brick. The Fouad Riad house design sets out to solve all of the client's functional needs.

The house appears to be almost insignificant from the public side and only reveals itself from the interior or from the private gardens that join it to the oasis beyond. The house is located in the middle of palm green fields in total unity with its surroundings (Figure 3.63).

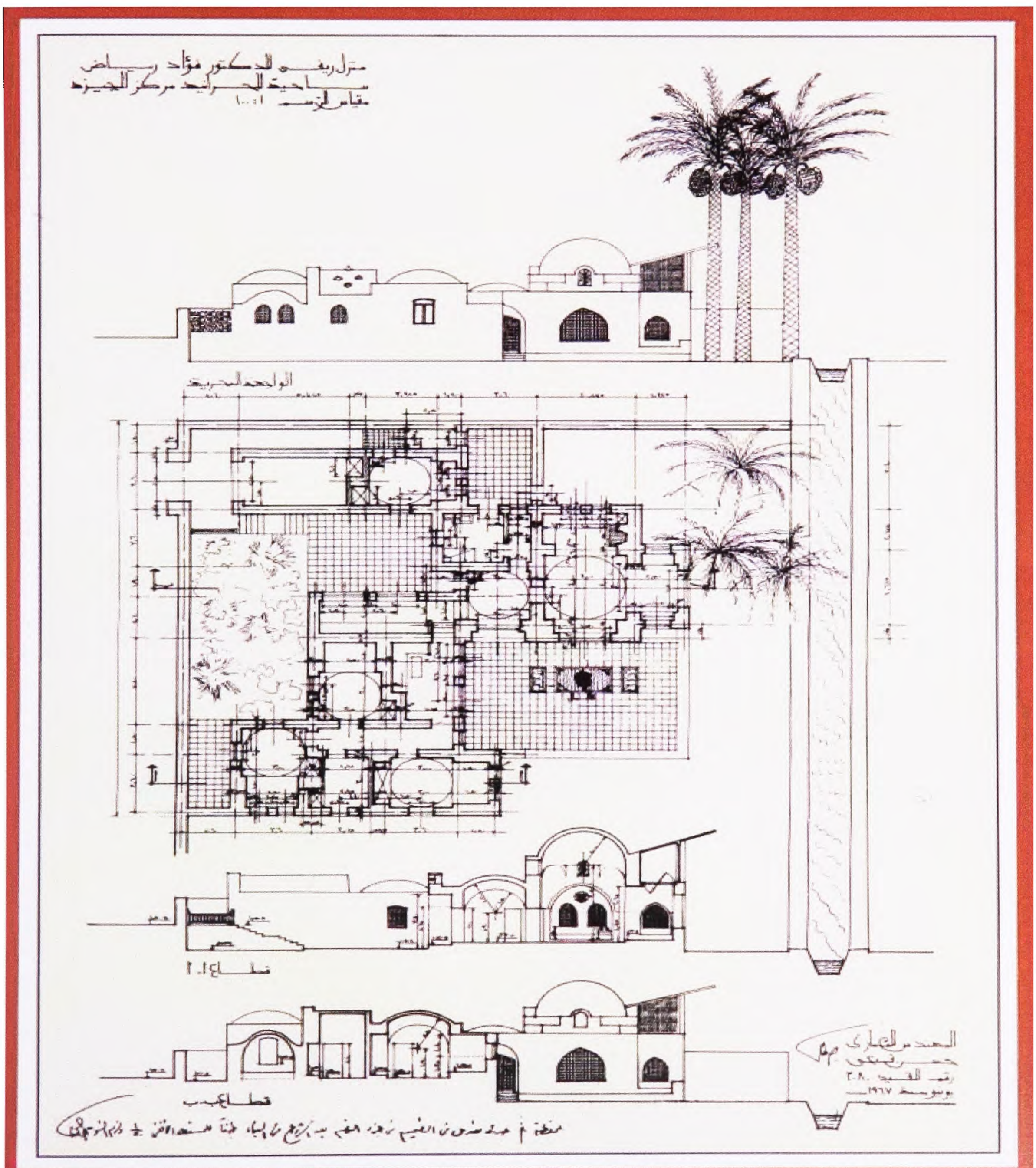


Figure 3. 63: Drawings of Fouad Riad house. Source: Steele (1989)

A very recent study by Almansuri et al., (2010 A) entitled 'Designing a dwelling unit in Tripoli – Libya by using sustainable architectural principles' shows the possibilities of implementing sustainable principles in designing houses in Tripoli taking into consideration social, economic and climatic factors. The house designed shows how traditional values can be incorporated into a contemporary design that meets current needs for modern living in Libya (Figures 3.64, 3.65, 3.66, 3.67 and 3.68). Almansuri et al. clarified that the suggested design did not give a detailed form and elevations; it is a concept design that shows the possibilities of designing a dwelling unit taking into consideration most of the sustainable housing principles. Accordingly, it is a suggested concept design aimed at providing a flexible guideline and applicable ideas, which can be amended according to site location, user's needs and the creativity of the architect.

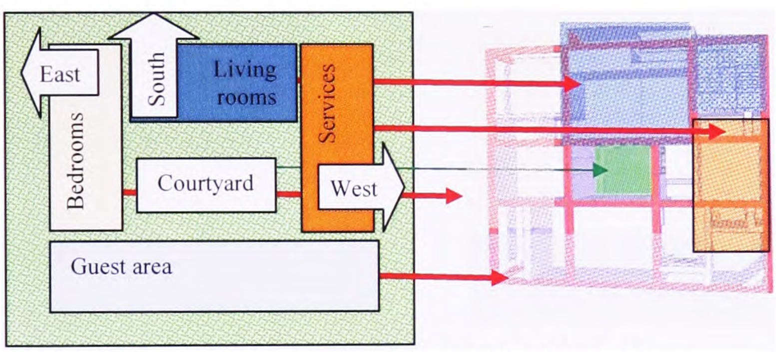


Figure 3. 64: The main design concepts of the Tripoli model.

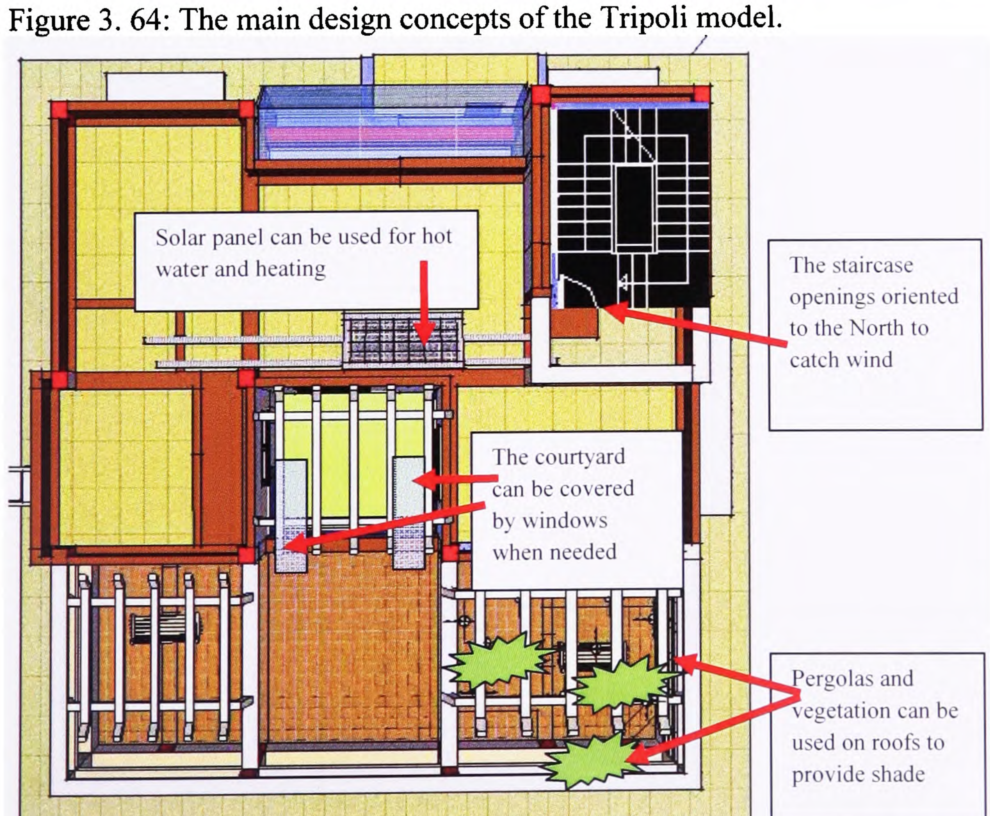


Figure 3. 65: Showing the roof plan with an explanation of the main features.

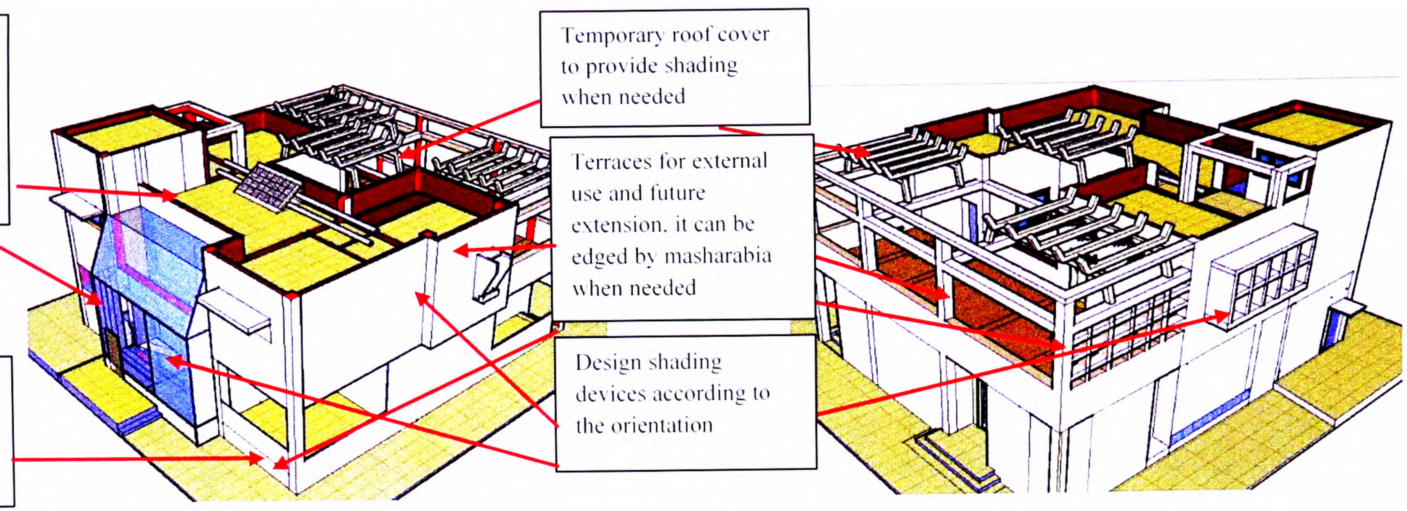


Figure 3. 66: Perspectives showing the main external features in the designed model.

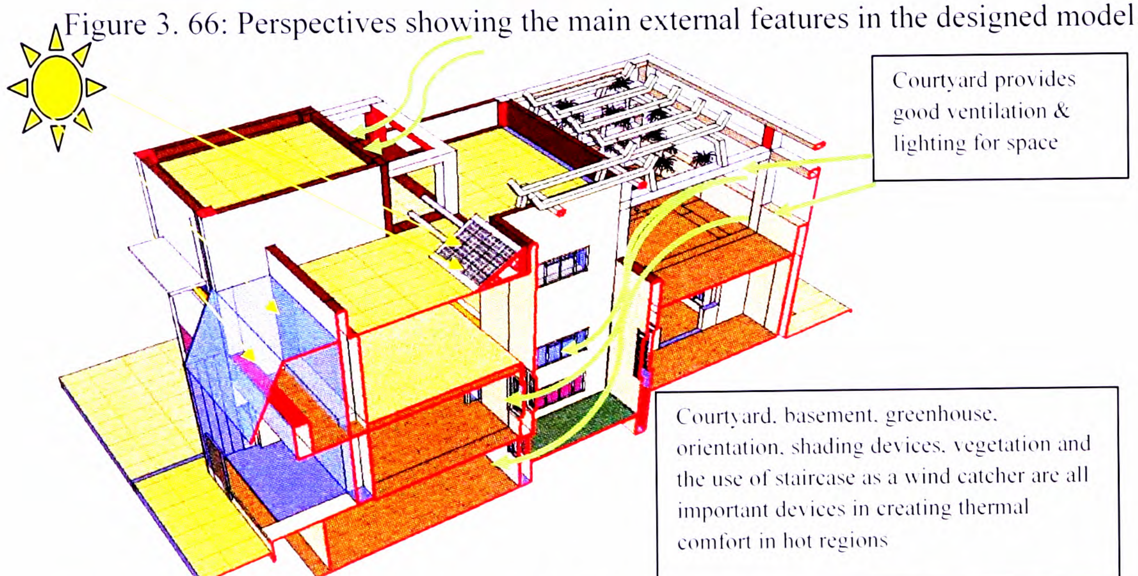


Figure 3. 67: Sectional perspectives shows the relationship between the courtyard and other functions.

Source: Almansuri et al., (2010 A)

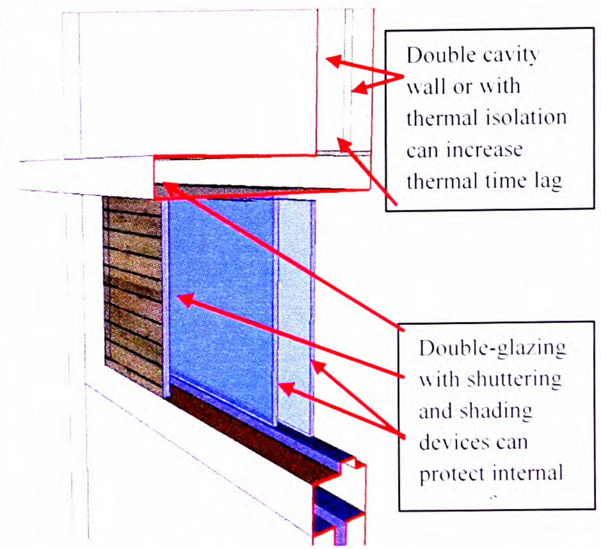


Figure 3. 68: External wall and windows design.

To sum up, it is clear that modern problems need modern solutions and many architects try to solve the problem of how to accommodate local traditional environments with the modern way of life and techniques. The earlier examples can be seen as part of a continuing tradition, choosing locally available materials and methods of construction and thus combining excellently with their surroundings. Some of them accommodate local traditions with modern technology and hence produce an environment that the community can identify with. The examples are suitable to the climate, culture, life style and economy of their particular places and can be admired for the creative and generative process, in which the imagination of the architects, the skills of local craftsmen, the needs of individuals and communities, and an understanding of the environment must work together.

The next part section will show the way in which the passive climatic design concept can be used to achieve a favourable modification of the external climate and approach or achieve conditions in the comfort zone without recourse to artificial conditioning or energy resources.

3.6 CLIMATIC DESIGN STRATEGIES

Evans (1980) stated that the shape of dwellings can be designed to obtain advantage from the useful aspects of climate and to reduce the impact of adverse aspects. Factors that should be controlled in relation to the needs of the climate zone are: the form, layout, orientation and scale of dwellings and dwelling-groups. Oliver (2003: 130) highlighted the relationship between building and climate as '*Dwellings are built to serve a variety of functions, but one of the most important is to create living conditions that are acceptable to their occupiers, particularly in relation to the prevailing climates*'. Paraphrasing Oliver, buildings do not control climate, which, apart from the wind or the sun shadow that they cast, remains largely unaffected, but they filter the climate, to provide more moderated internal conditions. "*The materials that are used, the forms they take, the volumes they enclose, and the services that are installed may all contribute to the 'micro-climate' that the house generates. This is not always precisely what the occupants require in temperature, ventilation or relative humidity.*" Similarly, Evans (2007) confirmed that building design (through the use of building form, grouping of volumes facade orientation, design of openings, colour selection, and thermal characteristics of building elements) can offer the possibilities of both protection from unfavourable aspects and the optimisation of favourable ones. It is argued that each and all of these aspects require design decisions that can promote the creation of favourable comfort conditions, or approach acceptable levels of habitability and energy efficiency.

A primary strategy for cooling buildings without mechanical assistance (passive cooling) in hot humid climates is to employ natural ventilation and provide shading. The North Carolina Solar Center (NCSU, 2000A) stated that a strategy for reducing cooling energy in the home is as follows:

- Block heat from entering
- Minimize heat generated
- Ventilate to remove heat and move air
- Air condition only when needed as a supplement to low-energy cooling strategies.

The following strategies cited by Greenbuilder.com (2007) can be used to achieve helpful solar gain and ventilation:

- The building should be elongated on an east-west axis.
- Use shading to prevent summer sun entering the interior.
- Place windows on the south exposure.
- Skylight windows offer the best airflow. Canopy windows should be fully opened or air will be directed to ceiling. Awning windows offer the best rain protection and perform better than double hung windows.
- Use two widely spaced windows if a room can have windows on only one side.
- A thermal chimney employs convective currents to draw air out of a building. Green rooms can be designed to perform this function, also thermal mass indirect gain walls can be made to function similarly.
- Make the outlet openings slightly larger than the inlet openings.
- Place the inlets at low to medium heights to provide airflow at occupant levels in the room.
- Keep a high mass house closed during the day and opened at night.

Key sustainable design features include lighting, materials and layout has been given by Yudelson (2008:131) as follows:

- ❖ Low energy lighting design features included the following:
  - Window placement designed to minimise need for artificial lighting;
  - Energy-efficient florescent lighting.
- ❖ Eco-friendly materials include the following:
  - Renewable, recyclable materials such as bamboo flooring;
  - Water-saving fixtures in the bathrooms such as dual-flash toilets;
  - Formaldehyde-free cabinets and energy-smart appliances in the kitchen;

- Nontoxic paints used for the walls of the house;
- On-demand (tankless) water heater; and
- Radiant heating system.

❖ Sustainable design layout features include the following:

- Cross-ventilation in all major rooms;
- Large, operable doors in breeze-Space designed to maximize breezes for cooling;
- Stone floor in breeze-Space for efficient thermal mass heating;
- Sloped roof with panels using the butterfly roof configuration; and
- Spread-in insulation in roofs for energy-efficient envelope.

At the urban planning level, Edwards and Hyett (2001) clarified some strategies that can be useful in hot and cold regions such as:

- From a sustainable development perspective, the compact city is the ideal city form; the best configuration is high density, mixed-use. However, the benefits from the compact form are limited and vary according to climate, land use type, culture and latitude;
- Medium- rise buildings. This is because tall buildings require energy for lifts;
- An ideal city contain leafy squares and tree-lined streets to bring nature into the heart of the city;
- Green spaces will help to stitch together the urban fabric.

Coch (1998) provided general guides for each climatic region as follows:

- ***Cold climates***: keeping the heat trapped inside the buildings is the most important aspect. To reduce heat loss the surfaces exposed to the outside should be at a minimum; this leads to a preference for compact built forms.
- ***Hot-dry climates***: an attempt is made to take advantage of the great temperature variation during the day-night cycle, delaying the infiltration of heat as far as possible by using materials of great thermal inertia. Buildings should be arranged in compact patterns to reduce the surfaces exposed to solar radiation and increase shaded areas. To reduce the effects of the sun on buildings the outside walls should be painted in white or in light colours to reflect the radiation as much as possible; also using eaves, blinds and lattices in the openings helps in reducing heat gain. The openings should be few and of a small size. Other very important resources are the presence of water and vegetation.
- ***Warm-humid climates:*** protection against intense radiation is very important. Ventilation is also very important in order to dissipate the heat in the interior and to reduce the humidity of interior spaces.

Evans (2007) gave some useful strategies in hot regions as follows:

- There are two systems to achieve comfort in hot conditions: produce a drop in air temperature or an apparent drop in temperature. Air movement is an example of the second system, where the air temperature is not reduced, but a cooling effect due to improved heat dissipation and evaporation of transpiration on the skin can produce a cooling effect.
- Using solar protection is very important to avoid an increase of average indoor temperatures, because radiation through glazed openings can increase the average indoor temperature up to 10°c or even more in bad design situations.
- The indoor temperature swing can be reduced by using high thermal mass inside buildings. It acts as a 'thermal sponge' absorbing heat as the temperature rises, while releasing heat as the temperature falls.
- The external envelope with high thermal mass will delay and reduce the transmission of heat to the interior of the building by day and also reduce the night time losses. Usually, heavyweight walls and roofs can reduce the internal surface temperature swings by 70%.

Askar et al., (2001) listed different building and environmental features which can be used to achieve desirable benefits as follows:

- Ensuring that the building is of high thermal-mass.
- Sizes and locations of the openings through the outer walls and roof should be optimised with respect to the heat and light transfers through them, and for defensive reasons.
- Shading by natural means (e.g. via trees) reduces the insulation entering adjacent buildings and the effects of wind. This can also be achieved in urban environments with shaded alleys providing some thermal protection.
- Reducing the ratio of the external-surface area to the contained volume of the building.
- The pergola system (i.e. the repetition of shaded and sun-lit zones) inhibits the rate of heat gain and reduces diffuse reflection to surrounding dwellings.
- Narrow streets can behave as cooling ducts by venting away hot dusty air.
- Increasing the wind-exposed surface areas of the external walls and other building elements enhances the rate of heat loss via winds to the ambient environment.
- The reflective properties of a facade with respect to insulation can be increased by painting it white or by utilising glazed brick-facings.
- The rates of heat transfer through the facades of buildings can be reduced by employing low-thermal-conductivity building materials as well as designs that incorporate walls with cavities that act as air ducts for heat-exchange purposes.

Rapoport (1969) provided some strategies to reduce solar radiation such as:

- Minimize the area and the number of windows;
- To block floor radiation, windows can be located at a high level;
- Minimize the absorption by the facades by white or light colours;
- Provide natural ventilation especially at night;
- Construct a part of the house into the ground, which will always be cooler than the outer ambient temperature in summer.

The objective of this part of the study is to identify bioclimatic design strategies in general in order to understand how these strategies can modify the external climatic conditions in order to improve indoor comfort. The next section will provide more design strategies in hot and warm-humid climates.

3.6.1 Design strategies in warm-humid climates

A number of researchers (found in a wide number of sources) have explored design strategies in warm-humid climates, some of which are reviewed below.

Manioğlu and Yılmaza (2007) clarified that, in hot and dry climates, the high heat capacity of the building envelope can be minimized by using materials with high thermal mass that can increase the thermal time lag of the building envelope. It can delay the heat transfer through the envelope and therefore higher day temperatures will be reached indoors when the outdoor air temperature is much lower. High thermal mass with higher surface temperature on the outer side will rapidly lose heating energy to the atmosphere by radiation at night to start the next day from a cooler level. Therefore, the preferred materials in this climate can be combinations of calcareous rock, stone and mud. The same authors suggested that the thermal performance of a building should be evaluated by a dynamic model of heat transfer calculations during the design stage, taking into account the heat capacity of the building envelope.

Olgyay (1969) noted that the optimum shape is that which loses the minimum amount of outgoing temperature in winter and accepts the least amount of incoming temperature in summer. He gave some general strategies related to the form of a building as follows:

- The square house is not the optimum form in any location;
- All shapes elongated on the north-south axis work both in winter and summer.

Hyde (2000) described climatic design strategy as the basic direction that can be taken with regard to producing the best climatic performance of the building. He thought that the key factors in warm climates are as follows:

- The optimum orientation: a building should be positioned to receive the cooling breeze in summer;
- The building fabric and the fenestration should be designed to be in harmony with the climatic conditions;
- An analysis of the building process identified the roof as a dominant element; it demonstrates the climate control features in the building, in particular ventilation, solar access and lighting;
- The importance of the external walls: the problem with the external walls is complex because there is a need to maximize transparency for light and ventilation and a need for closure and shading to prevent solar gain;
- Adding semi-outdoor areas such as verandas and courtyards to the basic building form: these spaces can provide privacy and a degree of shading to the building as well as reducing glare.

Looking at the on-line programme at the University of Hong Kong (arch.hku.hk), most of the design strategy cited by Hyde is confirmed except one point which relates to the use of lightweight building. This programme suggests that the design strategy in warm-humid climates should be as follows:

- The whole building should be lightweight to allow rapid cooling down at night.
- East and west walls should have minimum or no windows in order to exclude the low angle east and west sun.
- The walls should be reflective and/or well insulated.
- To provide cross ventilation, north and south walls should be as open as possible.
- The spacing of buildings should be carefully considered to avoid obstruction of the wind.
- Openings should be protected from the sun and heavy rain; also from mosquitoes and other insects which abound in these climates (Hui, 1997).

Many other authors state that the use of high weight construction can perform much better than lightweight such as Ficarelli (2010) who stated that using high thermal mass construction can secure the day heat through the night in winter, and night cooling during the day in summer. Also, Mohamed (2010) confirmed the importance of using high thermal mass and clarified that achieving high thermal mass was traditionally by thick walls made by heavy materials.

The recommendations from the Australian state government, (Commonwealth of Australia 2005, Northern Territory Government 2006, Commonwealth of Australia 2007 and The State of Queensland 2008) can be similarly summarised as follows:

- The plan shape and orientation of the dwelling and location of particular rooms: orienting the long axis of the house should ideally be east-west because the long north- and south-facing walls can easily be shaded by the eaves;
- Location and shape of openings: minimise windows on the east and west walls and using vertical wing walls to shade windows and walls from the low west-southwest and east-southeast sun;
- Protection of openings against excessive solar access and rain penetration: shading the walls and windows by using shutters, verandas, canopies and/or eaves and fixed overhangs;
- Using light colours for walls and roof, to reflect the heat of the sun;
- Reflective foil insulation is good, because it reflects incoming sunshine, but bulk insulation is not desirable, because it prevents the house cooling down at night;
- Roof form: choose roof and wall types with high insulating properties (R-values)
- Ceiling heights: ventilation of the roof space is recommended, to reduce heat build-up there. The increased heat loss in the cooler season is not important;
- Location of internal walls with respect to cross-ventilation;
- Metal roofs which cool rapidly at night. Daytime heat gain can be minimised by using sheeting with a reflective coating on its underside;
- Landscaping of adjacent ground to provide shading. Outdoor living areas (using vegetation, water, verandas or under an elevated house) will be particularly useful. Shelter from the rain is needed in summer; shade is also wanted and evaporative cooling from pools and water features;
- Windows' positions should be opposite each other to allow cross-ventilation and all windows should have curtains;
- Insulation: using wall materials with good insulation properties;
- Open-plan living areas with high ceilings to maximise air movement and reduce radiant heat to occupants;
- Earth-sheltered and underground housing are ideally suited to this climate.

These guidelines raise the issue of the pros and cons of lightweight versus heavyweight construction.

Evans (1980) had already addressed all of these recent strategies with more explanations. Evans clarified some points which are not addressed above as follows:

- Shade the roof with suspended reed matting or timber boards or by vegetation above the roof;
- To reduce the roof area, a two story building can be used;
- Using an insulation layer on the outside of a concrete slab can increase a thermal time lag of eight hours;
- To achieve good ventilation windows should be located on both sides of the building;
- Avoid openings in west elevations and if windows are poorly oriented or are too large, external shading devices with additional shutters can help to reduce the heat gain;
- Light internal walls are preferable in rooms which are used by day such as the living room and kitchen;
- A suspended floor with a large well ventilated under-floor cavity will give a quicker response when temperatures drop slightly in the evening than a floor directly in contact with the ground.

Ahmad et al. (2007) and Hyde (2008) adapted sets of bioclimatic solutions for a detached house in the Mediterranean climate as illustrated in Table 3.2

Table 3. 2: Solution set for the Mediterranean climate: detached house.

Characteristics	Solutions
Form	Compact for air conditioning to minimize surface area of envelope; spread-out building for natural ventilation
Floors	Two to three maximum
Dimensional ratio (length/width)	1– 3 maximum
Orientation	(0° = south): 0° and 180°
Roofing	Pitched, ventilated attic, reflective foil under roof, separate and insulated ceiling
Solar protection	Façade-shadowing systems
Active systems	Photovoltaic (PV) collectors on roof
Passive systems	Cross-ventilation, shading, orientation
Glazed/opaque surfaces ratio	South and north 30%
Thermal time lag	8 hours
Ambient air exchange	>10 in summer (V x hour)

Maximum yearly heating energy consumption	0kWh/m²
Reference U value	0.3–0.6W/m²K
Living-room orientation	South and north

Many authors argue that the best strategies and solutions can be inspired by vernacular architecture. Some of these strategies are illustrated as follows.

Meir and Roaf (2007) in their paper entitled 'The Future of the Vernacular Towards New Methodologies for the Understanding and Optimisation of the Performance of Vernacular Buildings' stated that traditional and vernacular housing has been considered as naturally adapted to the control of the natural environment. They set out four facts that resulted from a review of vernacular architecture in warm regions as following:

- Courtyard houses are ideal for dry lands.
- *Windcatcher*s in the Middle East have developed in size as the technology has become more elaborate.
- Vaults and domes are climatically superior to flat roofs.
- Adobe buildings are better suited for hot regions.

They also presented some of the results of their research project in the deserts and dry lands of the Middle East and the Mediterranean:

- Extreme thermal mass (typical of stone and mud) can have an important effect on the thermal performance of buildings;
- Vaults and domes have the potential to perform better than flat roofs; their orientation makes a difference;
- Lightweight roofs have important effects on the thermal performance of buildings (even with extra-heavy walls);
- Lightweight structures provide comfort in summer only in terms of lowering the operative or SolAir temperature;
- Lightweight structures are extremely cold on winter nights. Open combustion used for heating raises the probability of respiratory complications and cancer by 1000 times compared to outdoors' open combustion;
- Internal and semi-enclosed courtyards can prove a liability under hot arid conditions; orientation and proportions matter;
- Insulation can improve indoor conditions provided thermal mass is not excessive;
- Fenestration alterations and roof insulation and/or shading can improve indoor conditions significantly.

Muhasien explained that the courtyard building form can be an efficient modifier of the hot-humid climatic conditions if special arrangements are made at the early stages of the building design. This includes the internal coverings and finishing materials, as well as the proportions and physical parameters of the courtyard form (Muhaien, 2006).

In her presentation in Alfateh University in Tripoli on '*Windcatcher*s of Change Building for the Future: Learning from the Past?' Roaf (2007) stated that *windcatcher*s can be "*Mushrabiyeh, Room in the wind, a tent flap raised to catch the wind, a door opened to collect the breezes from the Sea, a hall of opposing Orsi Windows, Malqaf*". She argued that the *windcatcher* is an ancient technology, and explained that although the *malqaf* is more suitable to catch wind because it rises up high in the air, the other *windcatcher*s could also provide good ventilation.

Hassan Fathy (1986) confirmed most of the strategies cited previously above and added some further details which help to understand some specific points:

- **Elevations:**

- The north facade is least exposed to the sun, the lighting in rooms located in this facade is always evenly distributed, therefore it is ideal for hospitals and school classrooms;
- The advantage of the south facade is that the sun is high over the horizon in summer and can be shaded using a relatively small overhang, and in winter the sun is low which allows the sunshine to infiltrate when it is most desirable.
- The sun's rays are on the eastern facade in the early morning and the walls cool down considerably by evening, making this exposure more suitable for bedrooms.
- Avoid openings in the western facade because it is the worst elevation in both summer and winter times.

- **Openings:**

- Ventilation blinds are useful in regulating solar radiation and wind flow into rooms;
- A sun-breaker can be used to protect whole facades of glass-wall and concrete or steel frame buildings;
- The *mashrabiya* has five functions: (1) controlling the passage of light, (2) controlling the air flow, (3) reducing the temperature of the existing air, (4) increasing the humidity of the existing air, and (5) ensuring privacy.

- **The roof:**

➢ The roof is the surface most exposed to temperature in the building and the reflectivity of the outer surface of the roof and the thermal resistivity of its materials are of primary importance.

➢ Shading the roof is very useful initiative. It has two functions: (1) shading the roof during the day and (2) providing physiologically comfortable living and sleeping spaces at night.

➢ The shape of the roof is very important in a sunny climate. Pitching or arching the roof has several advantages over a flat structure: (1) increasing the height the interior, (2) increasing the total area of the roof, (3) during the day part of the roof is shaded from the sun, (4) domed and vaulted roofs increase the speed of any air flowing over their curved surfaces.

- **The *malqaf*:**

➢ The *malqaf* or wind-catcher was invented to satisfy the need for ventilation. It is also useful in reducing the levels of sand and dust;

➢ It can be incorporated into modern buildings aesthetically;

➢ The *badgir* is a kind of developed *malqaf,* it is a shaft with the top opening on two or four sides.

- **The courtyard:**

➢ The courtyard serves as a reservoir of coolness;

➢ The *takhtabush* is a development of the courtyard concept to ensure a steady flow of air by convection. It is a covered outdoor sitting area, located between the courtyard and the back garden.

- **The fountain**

➢ The fountain plays its water and mixes it with air to increase humidity and to cool the air by evaporation;

➢ The *salsabil* is the replacement for a fountain where there is not enough pressure to allow the water to spout out of the fountainhead.

3.6.2 Summary of the main passive design strategies captured from the literature

From the analysis of the literature conducted to date, the following points can be drawn out that are important in this research project to adapt passive design to develop better strategies of design with the climate, which will affect the comfort of the building:

- **Local micro-climate and site details:**
  - Site topography: slopes, hills and valleys, ground surface conditions.
  - Landscaping and type of vegetation: height, mass, shade and shadow, texture, location, growth patterns.
  - The form of the building which includes surface to volume ratio, orientation and height;
- **Built form: controlling the thermal environment in the building:**
  - The size, position & orientation of windows and window glass materials;
  - Design and position of external and internal shading devices;
  - Air movement; outdoor fresh air, cross ventilation and natural stack ventilation;
  - Selection of materials and construction, thermal insulation, thermal mass, surface qualities, reflection coefficients;
  - Develop the available vernacular solutions;
  - Include the relationship between buildings (attached –separated) and surface conditions.
- **Integration of new technologies:**
  - Use solar water heating.

As provided in the literature, the main strategies as agreed by the majority of the sources has been collected and presented in Table 3.3 and discussed with the Libyan professionals' group to explore their suitability to be adapted in the Libyan context in general and in Tripoli specifically.

Table 3.3: The main strategies captured from the literature

Principles	Component	Strategies
Local microclimate	Building size and location	•Reduce the surfaces exposed to solar radiation and increase shaded areas. The compact city is the ideal city form. •Narrow streets can behave as cooling ducts by venting away hot air. •The spacing of buildings should be carefully considered to avoid obstructing wind flow around buildings. •The lower the ratio between the building volume and the width of spaces, the lower the temperature in buildings and outdoor spaces.
	Landscaping and kind of vegetation	•Green squares and tree-lined streets get nature into the heart of the city. •Green spaces will help to stitch together the urban fabric. •Shading by natural means (e.g. via trees) reduces the radiation entering adjacent buildings and the effects of wind. •The pergola system restrains the rate of heat gain and reduces diffuse reflection to surrounding dwellings. •Provide open spaces such as streets, squares and courtyards. •Trees create different airflow patterns and can be used to direct or divert the wind advantageously by causing a pressure difference. •The shade created by trees and the effect of grass and shrubs reduce air temperatures adjoining the building and provide evaporative cooling. •Trees and other plants represent a natural protective element against solar radiation as well as wind control. •Vegetation may be used like a sunshade such as palm trees whose leaves are able to block solar radiation and their tall trunks will easily allow unimpeded ventilation. •The most appropriate plants for landscaping in hot-humid climates is a mixture of grasses, low flower beds and shade trees with high trunks.
Building deign	Plan design Concept	•Open-plan living areas with high ceilings maximises air movement and reduces radiant heat to occupants.
		•Earth-sheltered and underground housing are ideally suited to this climate.
	Patio/ courtyard	•A courtyard house is an ideal solution for hot climate regions. •Internal and semi-enclosed courtyards can prove a liability under hot arid conditions; orientation and proportions matter. •The courtyard serves as a reservoir of coolness.
	Building heights	•Ceiling heights - ventilation of the roof space to reduce heat build-up there. The increased heat loss in the cooler season is less important. •Two to three floors maximum.

	Building form	•The building should be elongated on an east-west axis. •The square house is not the optimum form in any location. •The whole building should be lightweight to allow rapid cooling down at night. •To reduce the roof area, a two storey building can solve the problem. •Raising the building off the ground can improve the potential for ventilation. •To reduce the size of any air conditioning equipment, the building should be compact to minimise the surface areas of its envelope and thus to reduce the heat gain. •For natural ventilation, a spread-out building with large windows enables more natural cross ventilation. •The ideal building plan is a detached, elongated building with a single row of rooms with openings in two opposite walls.
Room orientation		•The living room and the guest room can be located in the south or north. •Bedrooms can be located in the east. •Services such as kitchen and toilets can be located in the west.
Main Building Components	Roofs	•Vaults and domes are climatically superior to flat roofs. •Use light colours for walls and roofs to reflect the heat of the sun. •Metal roofs cool rapidly at night. Daytime heat gain can be minimised by using sheeting with a reflective coating on its underside. •Shade the roof with suspended reed matting or timber boards or by vegetation above the roof. •Using an insulation layer on the outside of a concrete slab can increase the thermal time lag to eight hours. •Lightweight roofs have important effects on the thermal performance of buildings (even with extra-heavy walls). •The outer surface of the roof and the thermal resistivity of its materials are of primary importance. •Properly designed roof gardens help to reduce heat loads in a building.
	Walls	•The external envelope should have a high thermal mass. •The walls should be reflective and/or well insulated. •Use vertical wing walls to shade windows and walls from the low west-southwest and east-southeast sun. •Locate internal walls with respect to cross-ventilation. •Incorporate walls with cavities that act as air ducts for heat-exchange purposes. •Use wall materials with good insulation properties. •Light internal walls are preferable in rooms which are used by day such as the living room and kitchen. •The heat storage capacity and heat conduction property of walls are key to meeting desired thermal comfort conditions.
	Floors	•A suspended floor with a large well ventilated under-floor cavity will give a quicker response when temperatures drop slightly in the evening than a floor directly in contact with the ground.
	Doors	•For open plan dwellings privacy can be provided by designing doors made like shutters blocking the view but giving passage to airflow, by leaving the upper part of a room-height door open via hinges at the top.

	Shading devices	•The mashrabiya has five functions: (1) controlling the passage of light, (2) controlling the air flow, (3) reducing the temperature of the existing air, (4) increasing the humidity of the existing air, and (5) ensuring privacy.
	Finishing	•To reduce the effects of the sun on buildings the outside walls should be painted white or in light colours •The reflectivity of a facade with respect to insulation could be increased by painting it white or by utilising glazed brick-facings.
Building materials		•Choose roof and wall types with high insulating properties (U-values) •Adobe buildings are better suited for hot regions. •Insulation can improve indoor conditions provided thermal mass is not excessive. • Extreme thermal mass (typical of stone and mud) can have an important positive effect on the thermal performance of buildings.
	Wind catcher	• *Windcatcher*s can help in increasing the flow of air into houses. •The *malqaf* is more suitable to catch wind because it rises up high in the air. •The *malqaf* can be incorporated into modern buildings aesthetically.
	Sun space/	•The solarium employs a combination of direct gain and indirect gain system features.
	Fountain	•The fountain discharges water and mixes it with the surrounding air to increase humidity and to cool the air by evaporation.
	Solar panels	•Solar panels can be used for hot water and heating spaces.
	Balconies	•Balconies provide protection to walls and windows from the sun and the rain. •Rooms should have direct access to open balconies or verandas on one or two sides.

3.7 SUMMARY

The chapter presents the general concepts of climatic design. It reviews tools that can be used to pre-design climatic analysis and details the factors affecting climatic design that should be taken into consideration in the final guidelines. This section also provides the climatic design solutions in vernacular architecture as well as in contemporary architecture. It addresses the design strategies in warm-humid climates which could help in achieving the aim of this research of providing guidelines for architects to design with climate in hot regions in general and in Tripoli, Libya, specifically.

CHAPTER FOUR

CHAPTER ONE:	**INTRODUCTION**
CHAPTER TWO:	**SUSTAINABLE DEVELOPMENT**
CHAPTER THREE:	**CLIMATIC DESIGN**
CHAPTER FOUR:	**LIBYA- GENERAL BACKGROUND**
CHAPTER FIVE:	**RESEARCH METHODOLOGY**
CHAPTER SIX:	**ANALYSIS OF THE FINDINGS OF THE QUESTIONNAIRE, INTERVIEWS AND TEMPERATURE MEASUREMENTS**
CHAPTER SEVEN:	**THE FINAL CLIMATIC DESIGN GUIDELINES FOR HOUSING**
CHAPTER EIGHT:	**CONCLUSION AND RECOMMENDATIONS**

CHAPTER FOUR- LIBYA: GENERAL BACKGROUND

4.1 INTRODUCTION

To understand housing in any society requires the study of the history, culture and natural environment of that society in order to understand the elements which affect housing forms and outside spaces. Therefore, this chapter presents, in five sections, a study of urban limitation in Libya looking from geographical, historical, climatic and cultural aspects. The first section presents a general view of Libya, looking at its geographic, historical and climatic aspects. The second section discusses private housing in Libya generally. The third section reviews the cultural characteristics of Libyan communities and reflects on urban planning and housing. The fourth section examines the typical Libyan traditional courtyard house as well as the modern type of housing, in order to explore and understand the impacts which formulate its spatial configuration. The fifth section briefly presents a view of housing and climate followed by the conclusion of the chapter.

4.2 GENERAL VIEW OF LIBYA: LOCATION, GEOGRAPHY AND HISTORY

This section presents a general view of Libya. It discusses the Libyan geographical, historical and social contexts which give the study its credibility.

4.2.1 Location

Libya is located in the middle of North Africa. It is situated between 20 to 34° North and 10 to 25° East (El- Tantawi 2005) (Figure, 4. 1). It is the fourth largest country in Africa with total area of1.760, 000 square kilometres which is more than seven times the total area of Britain and Northern Ireland and one third of the area of the U.S.A. (Daza, 1982). The coastline on the Mediterranean Sea is 1955 kilometres. Libya is bordered by six neighbours. It shares a border to the east with Arab Republic of Egypt and Sudan; to the south Chad and Niger, and to the west, Tunisia and Algeria. The Mediterranean Sea is its northern border (Amer, 2007, Emhemed, 2005). Due to its location, throughout history it has been made a distribution centre between Europe and central Africa in one hand and between countries to the east and west of Libya (Daza, 1982).

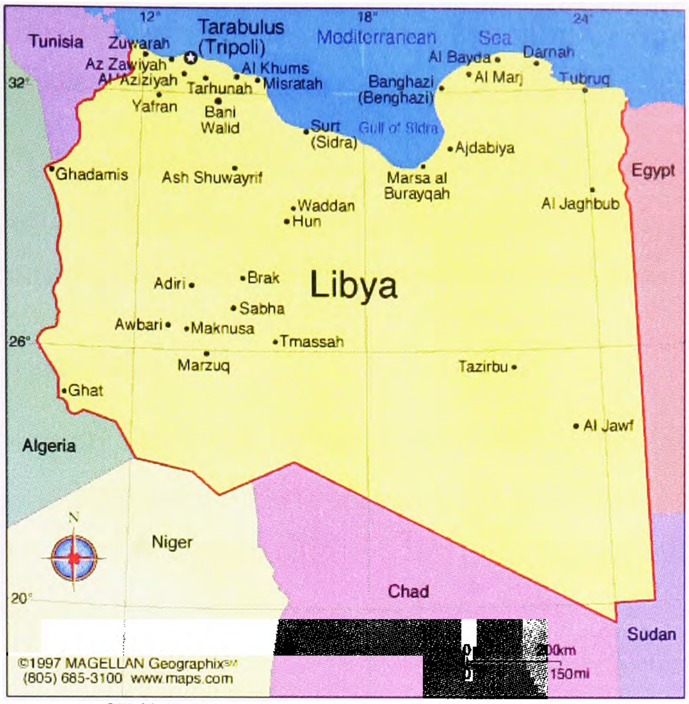


Figure 4.1: Location map of Libya. Source: Nfoplease.Com

4.2.2 Geographical Characteristics

To understand the development of urban and housing patterns it is important to start with the geography, history and civilisation of a place. Libya occupies a part of northern Africa between 20° to 34° N and 10° to 25° E (El-Tantawi, 2005 and Mukhtar, 1997). Libya is located geographically in the centre of the hot dry region in the north of Africa and the most serious challenges for development are the proportion of the country that is covered by desert and the scarcity of water (Grafa, 2006).

In Libya there are different methods of studying geography and planning. For example, Dioxides (1964) and Grafa (2006) divided Libya geographically and climatically into three regions which are: the coastal, mountainous and desert regions. While Habeb (1981) classified Libya into four geographical zones: the northern coastal plains, the northern mountains, the semi-desert zone and the desert zone (Emhemed, 2005). More than 95% of Libya is desert and is a part of the Sahara that has the most extensive area of severe aridity (El-Tantawi, 2005). These geographical conditions have influenced to a great extent Libya's physical structure, land use and the distribution of its population as most settlements are located along the coast in the north extending from the east to the west borders of the country (Amer, 2007). The population is concentrated on two centres: the first is in the northwest of the country (the Jifara Plain) where about 60% of all Libyans live, and includes Tripoli city (the capital of Libya) where more than one million people live, and the second centre is in north-eastern Libya (the Ben-Ghazi Plain). The main reasons for these concentrations are fertile soils and seasonable, moderate climatic conditions (El-Tantawi, 2005).

As previously stated, Libya generally is characterized by hot dry land features; consequently, useful lands for life and development in Libya are very limited. These geographical features of Libya should be considered as one of the key factors in climatic design.

4.2.3 Climate Characteristics

Climate in Libya is mainly caused by the interaction between the Mediterranean Sea and Sahara desert. Libya's latitude and longitude have placed it in a unique climatic zone where as many as five different types of climate can be noticed, but the main climatic influences in Libya are the Mediterranean Sea, Sahara desert and the mountain region.

Due to Köppen's climatic classification, Libya is located in a hot desert climate type (BWh) which covers a large percentage of the mid- and southern Libya where the mean temperature is above 18 °C all year. followed by a hot steppe climate type (BSh) in northern parts and Mediterranean zone (CSa) in north-eastern Libya on Jebal El-Akhdar (Figure.2.10) (El-Tantawi, 2005).

Dioxides (1964) confirmed that Libya geographically and climatically is divided into the same three regions; the plain coastal region; the mountainous region and; the desert and semi-desert (90% of Libya is desert). Said (1987) divided Libya into four climatic zones: the hot dry zone, the hot humid zone, the cold zone and the moderate (mild) zone. photius.com, (2005)stated that the dominant climatic influences in Libya are Mediterranean and Saharan.

This study gives further information on Dioxides three climatic regions (Figures 4.2, and 4.3) which are:

- The coastal region;
- The mountainous region and
- The desert and semi-desert.

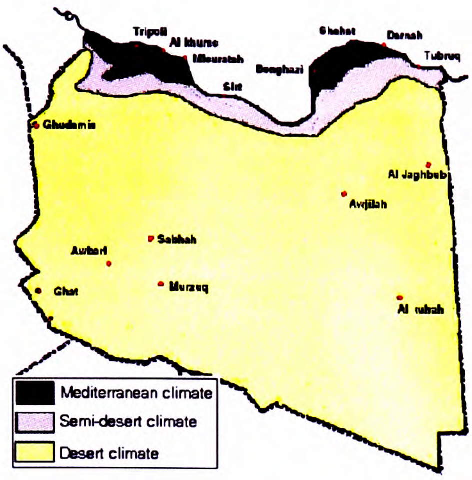


Figure 4. 2: The Libyan climatic regions.
Source: Amer (2007).

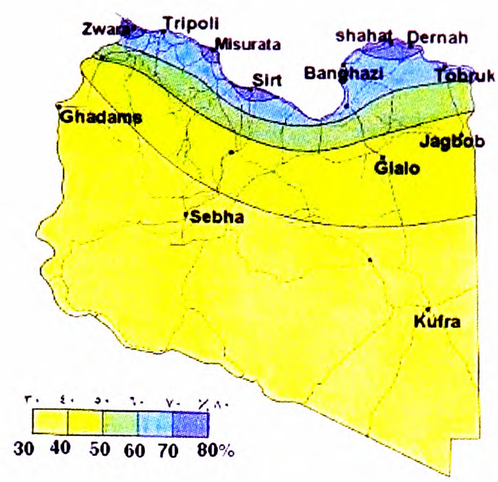


Figure 4. 3: The annual relative humidity.

4.2.3.1 The coastal region

Pidwirny (2006) clarified that, according to Köppen Climate Classification System this region located in moist mid-latitude climates with mild winters (C). Its extent is from 30 to 50° of latitude mainly on the eastern and western borders of most continents. Generally, this climate has warm and humid summers with mild winters.

El-Tantawi (2005) clarified that, costal area receive more efficient precipitation than that located in dry Sahara desert. And because the sun's mean angle is highest, on average at the equator and then becomes gradually lower pole-wards, mean temperatures gradually decrease with increasing latitude in Libya.

An average minimum temperature in the coldest month of the year (January) reaches of 7.6C° and an average maximum of 16.5 C°. The temperature the warmest month of the year (August) reaches an average minimum of 21.7C° and an average maximum of 30.8C°. Generally in this region, the temperature tends to be mild and tolerable in summer because of the Mediterranean Sea (Emhemed, 2005). The dominant winds in the coastal zone blow from the north and northwest in all seasons (Daze 1982). Emhemed, (2005) clarified that the southerly wind (*Ghibli*), which is very hot and dusty, does not affect this region because the mountain chains Aljabel Algarbe and Alakder protect it. Whereas, Amer, (2007) stated that this zone In July and August is affected for many days by wind from the south, the *Ghibli* which raises the temperatures in this region.

According to Emhemed (2005) the average humidity in this region is 58% to 65%, which in some years may increase in the summer (June to the end of August). Whereas, El-Tantawi (2005) stated that the mean annual relative humidity in the coastal region falls within 65-75%. The annual average rainfall in the plain coastal region reaches 300-400mm although it sometimes exceeds 650mm (El-Tantawi, 2005). Generally, rains occur from October to March and the maximum rainfall occurs during the months of December and January (Amer, 2007).

The average temperatures in Tripoli ranges from 30°C in summer to 8°C in winter and in the desert summer temperatures rise to over 50°C, but daytime winter temperatures range between 15 and 20°C, falling below zero at night (Arab.net 2002). According to Al-Fenadi (2007) El-Azizia city which is located 55 km south-east of Tripoli, recorded the hottest maximum shade temperature recorded on the face of the Earth (58°C) recorded on 13th September 1922. Generally, Mediterranean Sea plays an important role in modifying the climatic parameters in the coastal zone. It affects temperature and moisture conditions (El-Tantawi, 2005).

4.2.3.2 The desert region

The Libyan Desert is one of the harshest and most arid in the world, It is more extreme hot in the day and cold at night. Spring and autumn experience the *Ghibli,* (Pidwirny, 2006). The climate in the Libyan Desert and semi-desert region generally are characterised by very high annual temperatures with a large difference in temperature between day and night and between winter and summer (Amer, 2007). It is dry and hot in summer and mostly very arid since there is rarely rain in winter(Daza, 1982, Emhemed, 2005).

The north and north westerly winds are considered the most desirable winds for summer nights and their lower velocity also makes them less damaging during the winter months. The *Ghibli* and sand storms from the southeast are frequent during the summer (Amer, 2007).

The average humidity is 20% to 59%. The minimum average temperature in January is 2.1C° and the maximum average in August is 40.2C°. The winds in this region are southerly and in summer and spring, they are hot and dusty while in winter and autumn, the area experiences northerly winds(Emhemed, 2005).

4.2.3.3 The mountain region

The in the mountainous region is affected by the climate of the desert and semi-desert, particularly in summer. The summer temperature is mostly high because of the southerly wind (the *Ghibli*) which comes off the desert and brings with it dust as this wind does not encounter any natural obstacles (Emhemed, 2005). In this region the winter is generally cold, the temperature goes down to 0°C and snow appears on the tops of the mountains (Amer, 2007).

The average minimum temperature in January is 4.6C° and 32.5C° is the average maximum in August (Emhemed, 2005). The mountainous areas have the best summer climate, because the relative humidity is much lower than that in the coastal zone (Amer, 2007). In this region the average humidity is between 46% to 74% and the average rainfall in this region is 200mm to 400mm. In some years it reaches 600mm in Aljabel Alakder in the north-east of Libya (Emhemed, 2005).

Generally, the plain coastal and the mountainous regions are characterised by moderate temperatures because of their nearness to the sea; the desert climate is allied to that of the Mediterranean Sea.

4.2.4 Historical background

Libya has been subjected to varying degrees of foreign control (traveldocs.com, 2007). Over the centuries Phoenicians, Carthaginians, Greeks, Romans, Vandals, and Byzantines have ruled all or parts of Libya. The Greeks and Romans left impressive remains. Muslims led Libya from the 7th century AD and in these centuries most of the native people adopted Islam.

The Ottoman Turks dominated Libya from the 16th century until Italy invaded in 1911 and made Libya a colony. From 1943 to 1951 different parts of Libya were under the control of Britain, France or Italy. Libya was the first country to gain its independence through the United Nations in December 1951 and became the United Libyan Kingdom. In 1969 a military-led coup overthrew the royal government and established the new Libyan Arab Republic. Now, the official name of Libya is the Great Socialist People's Libyan Arab Jamahiriya[1]. For more details see Daza (1982), Emhemed (2005) and Amer (2007).

[1] Jamahiriya is the Arabic name which mean masses of people. Libya has been given this name since 1977.

4.2.5 Cultural characteristics

The need for behavioural control and for social connections is a very important limitation on the design of spaces (Emhemed, 2005). According to Aburounia (2007) about 97% of Libyans are Arab and of Barber origin (Amazigh) and the same amount of population are Sunni Muslims. The acceptance of Islamic ideas by the Libyan people has had a clear effect on culture and has affected its society. The essential attitude in designing Islamic urban patterns is to have a balance between the family's need for privacy and the need for a common bond with all society. The separation between men and women was adopted which led to changes in the organisation and details of different elements in the house and, in addition, how houses were grouped together to shape the urban structure.

Amer (2007) and El-Menghawi (2004) stated that the shaping of Libyan culture has been influenced by many outside cultures, which have come from both east and west. Emhemed (2005) confirmed this opinion and added that new houses built in recent times were designed to be similar to western houses and were far removed from Libyan cultural influences. As a result, Libyan people have modified these western houses.

Islamic principles and socio-cultural values in Libya play a very important role in controlling and directing the behaviour of people within internal and external spaces. Many authors such as Daza (1986), Shawesh (2000), El-Menghawi (2004), Emhemed (2005) and Amer (2007) have listed the main Libyan socio-culture factors as follows:

- Privacy in Libyan society is a priority consideration within housing spaces.
- The separations of age and sex and guests have long determined the roles played within the family.
- The extended family and elderly people have a special and high status in the society.
- The way of life of the Libyan people has many aspects that should be considered when designing external and internal spaces.
- The way of preparing meals in the kitchen, the need to have storage places and the way of serving food to guests and family members requires sufficient internal space.
- Safety and security are priorities in Libyan life.

Although all of these factors are well addressed in Libyan local architecture, most of them do not exist in contemporary houses. Emhmed (2005) explained that the effect of religion and social interaction on local architecture can be observed in two ways; Islamic religious teaching encourages privacy and modesty and courtyard houses fulfil this condition by providing an inward-looking house.

4.2.6 Housing and building laws in Libya

To design a dwelling unit, it is important to understand the building lows in this area, Emhmed (2005) clarified that the main components of planning and building legislation that affect housing projects in Libya are land use, streets' width, building height, site coverage and zoning regulations. He translated the Libyan planning and building Act 1969 into English, codes related to private housing building laws are presented as follows;

Modern legislation requires housing units to stand separate from one another across a specified minimum distance. Buildings should have the following dimensions:

- Yards and setback requirements; The Libyan Planning and Building Act 1969 illustrates the different distances of these setback requirements (front, side and rear), particularly in residential areas, according to the land-use and density of the area as determined in the master plan.
- Building height limits and number of storeys; maximum number of storeys, according to zoning type area.

The thickness of the external walls should not be less than 25 cm on the ground floor and 20 cm for the upper floors; and the thickness of the internal walls inside the flats should not be less than 20 cm

4.3 LIBYAN CONTEMPORARY DWELLINGS

After the discovery of oil in the 1960's, Libya, among many other developing countries, has witnessed rapid social and economical changes which have occurred at a variety of levels, such as in housing developments. Libyan housing policies have been changed to reflect the economic changes (Azzouz, 2000). The increase in the cities' population has caused a rapid increase in the demand for housing, which in turn has worsened the already existed shortage. Grafa (2006) found that the housing shortage in Libya increased sharply during the 1980s and 1990s. Bukamur (1985) argued that, after independence, the housing situation remained inadequate in quality and quantity. He clarified that, in the aim of providing adequate, hygienic houses with facilities and services suited to modern life and at the same time conforming to the financial capabilities of individuals and families, Libyan housing passed through several stages and phases of development and programmes until it reached its present position. Two main sectors participated in the housing development process are: the public sector, and the private sector. Under the title of contemporary housing, the next part will clarify these sectors in more details.

The demand for housing has been explained by El-Menghawi (2004) as being caused by two main factors which are: firstly, migration from rural areas and neighbouring countries, and secondly, the need to accommodate newly married people. Consequently, the demand for more of the public sector models has increased. She claimed that multi-storey buildings have failed to satisfy social and functional needs and many people prefer to live in one-family houses rather than multi-storey buildings. Accordingly, the public have well received the single-family house solution for the advantages it offers which are: a good level of architectural solutions allowing the integration of functional relationships within the social conditions of the dwelling; allowing direct access to vehicles and services for every house, and providing a special open space for each group of inhabitants.

Many authors such as El-Fortia (1989), Emhemed (2005) and Amer (2007) argued that there are socio-economic problems associated with these new living environments; in addition to the fact that the spatial configuration of the flats have internal spaces that are unable to sustain the traditional patterns of family life and to meet the demands of daily living. They raised many problems that have appeared in these projects, such as a lack of privacy, noise, a lack of children's play areas and that the fact that provision of adequate space is rarely accounted for, nor are the cultural and social backgrounds of the residents. El-Menghawi (2004) thought that the westernisation process has provoked change in these societies and that the cities' appearance has begun to show a western face in many aspects of urban life.

Mukhtar (1997) clarified that three major kinds of housing exist in contemporary architecture: public, popular and private sectors. The public sector is the smallest sector and builds houses used by a mixture of lower and lower-middle income families. The popular construction activities meet the needs of the poorest households, while the private sector supplies the middle and upper income groups. He specified that urban housing in Tripoli city is provided by only two categories, the public and private sectors. Government provides the public housing sector and the private sector comprises mainly private owners (houses produced for individual use) and housing co-operatives (Figure 4.4).

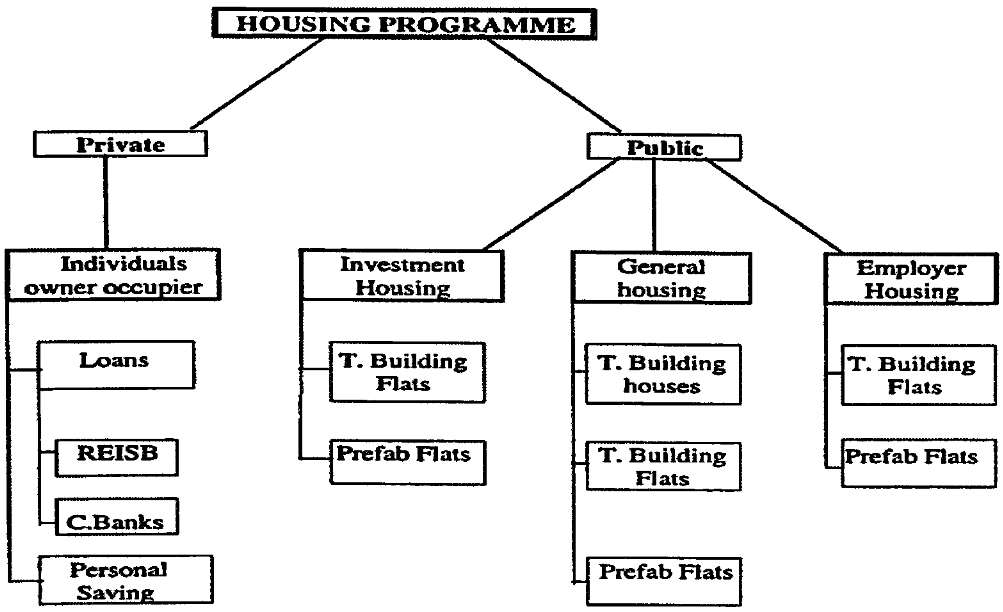


Figure 4.4: Housing programme in Tripoli. Source: Mukhtar (1997)

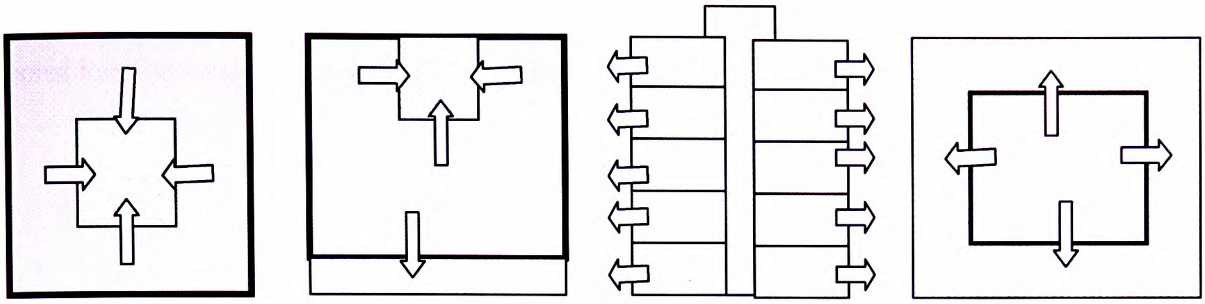
Daza (1982) clarified that because of the rapid social and economic changes in Libya, new houses and their occupants' way of life have changed according to the current types and quality of urban houses. These types vary depending on location, the socio-economic status of the owner and the building regulations and materials available. But, in general, the basic elements which are prerequisites for a home for a Libyan family throughout the country are:

- A private area exclusively for the family;
- A visitors area;
- Functional flexibility where some of the living space can be used according to changing circumstances.

El-Menghawi (2004) also classified the contemporary dwelling models into two main categories: the first one is government housing or public housing; the second category is private housing or self-built housing.

Almansuri et al., (2010 A) classified the housing types in Tripoli into four major types: courtyard houses, as models of vernacular private houses; row houses as an improvement on the private courtyard house; flats as a model of international style public housing and villas as a model of contemporary private housing (Figure 4.5).

More details about the private types of housing can be seen in the case studies (section 6.4).



1 Plan 2 Plan 3 section 4 Plan

Figures' key: Buildings Garden or courtyards

Figure 4.5: The development of house design in Tripoli from the courtyard house to the villa type.

To provide a clear picture of public housing projects and private sectors, the next section will summarize the main concepts of these kinds of contemporary housing.

4.3.1 Public sector housing (government housing)

El-Menghawi (2004) classified the typical modern public high-rise flats into two main groups: small (low-rise) apartment blocks consisting of 2-4 flats, normally two on every storey, and high-rise buildings consisting of a number of flats varying from 6-30 flats, on every floor 3-4 flats (Figures 4.6).

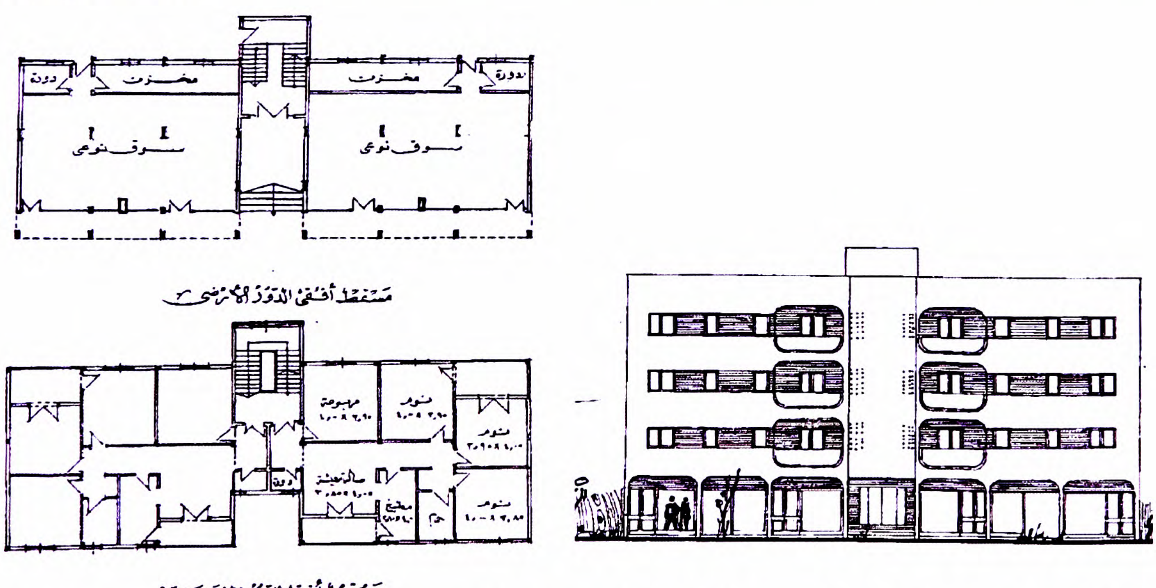


Figure 4. 6: Low-rise public Housing. The ground floor in a public sector apartment block used as a multi-purpose area Source: El-Menghawi (2004)

Emhmed (2005) clarified that high-rise flats (Figures 4.7) are built with new building materials imported from outside the country and their structures are being constantly eroded.

He believed that these types of building have failed to respond to climatic and environmental considerations and they have neglected local available materials' resources.

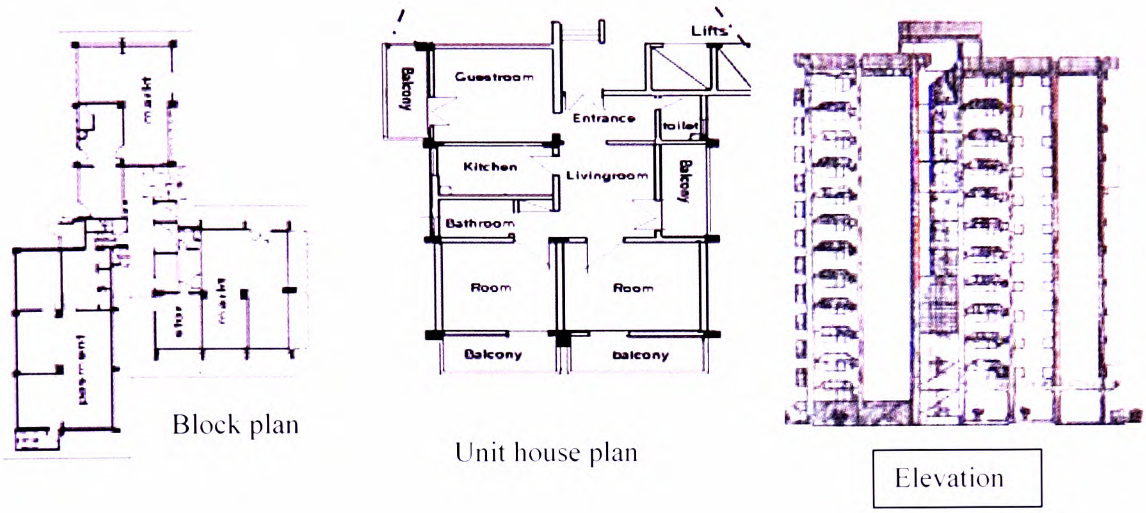


Figure 4.7: High-rise building. Source: After Amer (2007)

El-Menghawi (2004) stated that other types of public sector housing which are designed as single-family houses are mostly semi-detached dwellings of one storey or of two storeys, where two single family houses are arranged vertically with separate entrances as shown in Figures 4.8. This type shares similarities with the privately built dwellings in terms of autonomy in the use of the external open spaces.

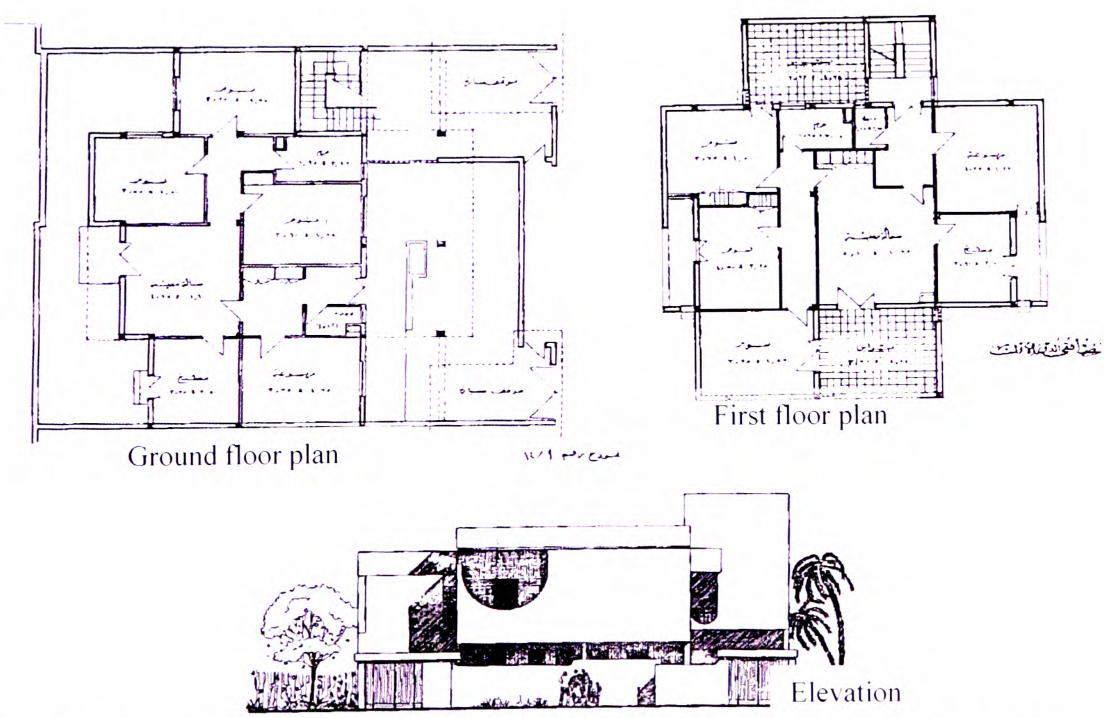


Figure 4. 8: An example of two single-family houses arranged vertically with separate entrances to provide more privacy Source: El-Menghawi (2004)

4.3.2 The private type

Amer (2005) described this type of contemporary residence as the western house with different patterns. El-Menghawi (2004) described these types of houses as middle classes housing. Libyan people are highly impressed by Western patterns. The design form and the façade's elements may express clearly its modernity by trying to be similar to the Western villa type, and meanwhile it is, by contrast, occupied within by traditional parameters. These houses are characterised by the absence of a courtyard, and instead are surrounded by gardens with high fences.

Spaces within this type are generally classified into (1) common spaces which include guest spaces with a private lavatory and (2) private spaces which consist of a family living room, kitchen, bedrooms and bathrooms (Figure 4.9). In the case of duplex villas the private spaces are placed on the upper floor. However, in the one storey villas the common spaces are situated in the front of the building and the private ones are behind. The space arrangement within the villa type of housing may be briefly described in general as follows: the entrance; the reception area; the living room; dining room; Bedrooms, the kitchen and Toilets.

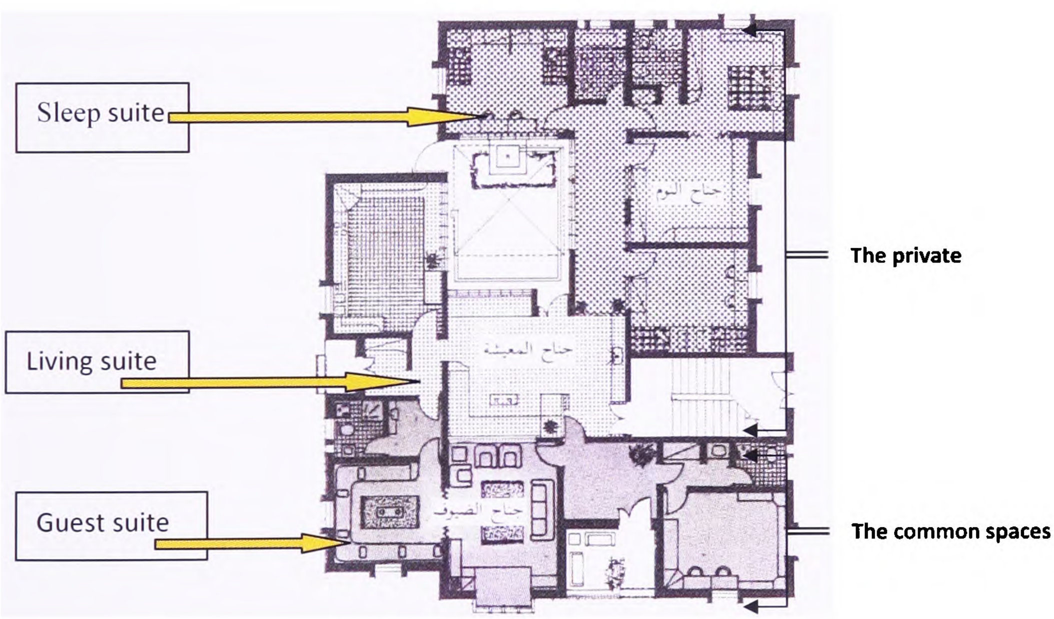


Figure 4. 9: The main zones in the private dwelling.
Source: After El-Menghawi (2004)

A new wave in housing started some years ago. Small private companies designed and built different kinds of houses (villas or flats) and sold them to people. These small projects helped to provide more suitable houses with more comfortable spaces and areas. However, these companies did not consider climate as is clear from (Figures 4.10 and 4.11) where the designer used patios just to provide light and ventilation to toilets, and rooms were located in all elevations which means that they did avoid the western elevation. Also, no shading devices were used. In addition to this, they used thin walls without thermal insulation. Thus, it can be seen that these kinds of building did not take climate into consideration. This opinion was confirmed by Emhemed (2005).

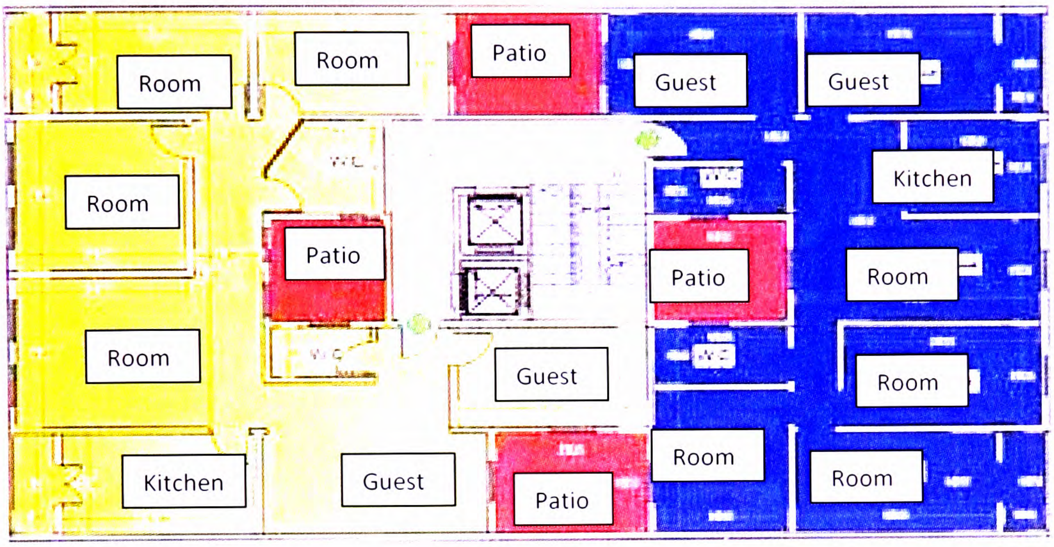


Figure 4.10: Typical floor plan for private flats. Source: After (Almanara.org)

Figure 4. 11: Front elevation of three apartments. Source:.Almanara.org

It can be said that Libyan modern public housing has neglected traditional principles and has failed to take into account climatic and cultural values and people's needs.

This part of the study gave background information on the private building types available in Libyan contemporary dwellings. The next section presents examples of Libyan traditional housings.

4.4 LIBYAN TRADITIONAL DWELLINGS

Emhemed (2005) state that, the courtyard houses are evident throughout all the regions of Libya with nearly the same configuration of spaces and differ only in building materials and techniques. This section presents examples of vernacular houses from the three Libyan geographical regions (Ghadames from desert region, Garyan from mountain region and Tripoli from coastal region).

4.4.1 Ghadames as an example of desert region

The vernacular urban and architectural patterns in housing settlements in Ghadames provide useful hints for designing more sustainable environments. In this context, the compact city, covered streets and covered courtyard, provide the elements most important to climatic comfort efficacy in a hot arid climatic region (Almansuri et al., 2008). The coming sections aims to present the main vernacular features that can be used in future hot regions houses.

4.4.1.1 Ghadames- Introduction and Location

As shown in (Figure 4.12), Ghadames is a town located in a Saharan oasis at the point where the borders of three Arab countries meet: Algeria, Tunisia and Libya.

It is located about 620 km southwest of Tripoli in the desert region, its geographical co-ordinates are: 30°08' latitude north and 9°30' longitude east (Chojnacki, 2003).

Ghadames is recognized for its beautiful and creative architecture, designed to fight the harsh desert climate. The present old town is probably 800 years old; it is often called "the jewel of Sahara", and was in 1999 added to the UNESCO World Heritage List, as one of five places in Libya (Kjeilen, 1996).

Figure 4.12: The location of Ghadames. worldsurface.com/images/maps/Libya

4.4.1.2 The Climate

The climate in the Libyan desert and in the semi-desert region generally is dry and hot in summer. In winter it is mostly very arid since there is rarely any rain. In reviewing the literature, the researchers noticed that there is no consistent data. Emhemed (2005) stated that, the average humidity is 20% to 59%. The minimum average temperature in January is 2.1C°

and the maximum average in August is 40.2C°. The winds in this region are southerly in the summer and spring and they are hot and dusty, while in winter and autumn, the area experiences northerly winds. Ahmed (1985) confirmed these facts and illustrated the monthly and hourly periods of climate as shown in (Figure 4.13).

Chojnacki (2003) noted that temperatures of over 50.0°C have been recorded in this region. Ghadames rises about 340 - 370 m above sea level. The relative humidity of the air ranges from 72% in winter to 17% in summer.

The average monthly climate indicators in Ghadames based on 8 years of historical weather readings cited by climate-zone.com are shown in Table 4.1. As can be seen in Figure 4.13 and Table 4.1, the maximum average temperature during 1985 - 2007 has increased from two to three degrees in most months.

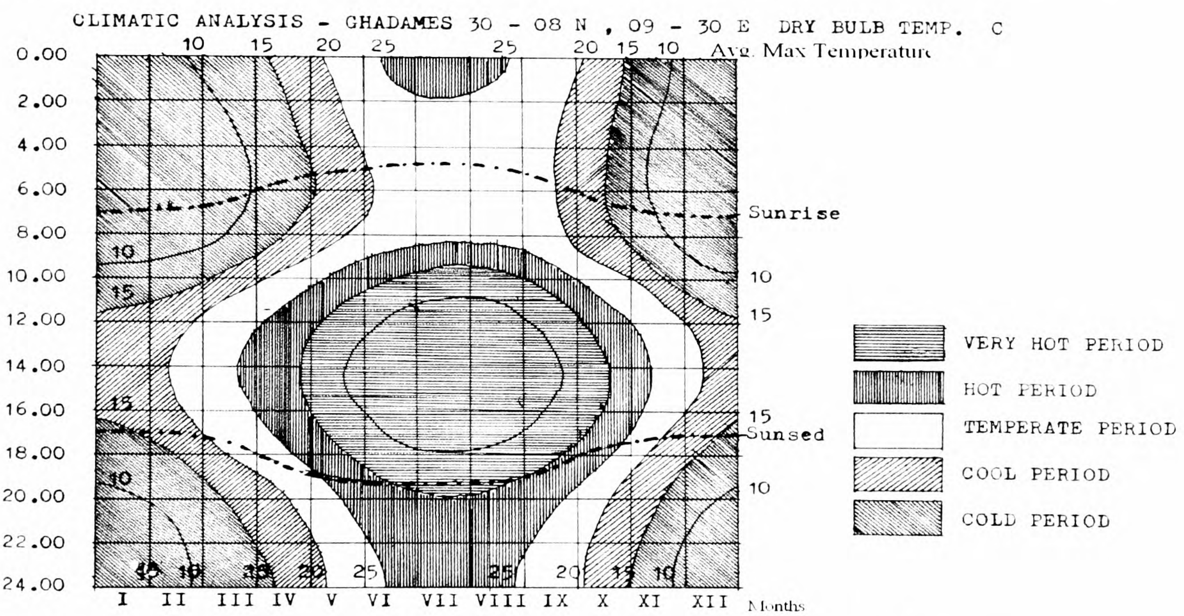


Figure 4.13: Shows the hourly climatic analysis during a year in Ghadames.
Source: Ahmed (1985)

Table 4. 1: displays the average monthly climate indicators in Ghadames.
Source: Climate-Zone.Com

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Avg. Temperature	11	13	18	22	28	32	33	33	31	23	17	12
Avg. Max Temperature	17	20	25	28	35	39	41	40	37	30	24	18
Avg. Min Temperature	5	7	11	15	21	23	25	26	24	17	11	6
Avg. Rain Days	0	0	0	0	0	0	0	0	0	0	0	0
Avg. Snow Days	0	0	0	0	0	0	0	0	0	0	0	0

4.4.1.3 The Characteristics of the city form

The architecture of the old city in Ghadames (Figure 4.14) is well adapted to desert life. It includes an almost unique system of covered streets with formally arranged squares, to bring together the compact form and reduce exposure to the sun and to provide complete privacy of family life and suitable conditions for social interactivity (Chojnacki, 2003; Azzouz, 2000).

In order to create a comfortable internal microclimate, traditional architecture in Ghadames responds to the harsh desert climate through protection, modification & adaptation. Protection from extreme solar radiation, high temperatures and dusty winds, (by modifying and adapting to these harsh conditions), is undertaken through sensitive and conscious solutions, through construction technologies and well-studied planning and design by using suitable building materials with certain thermal properties that correspond to the ambient environment (Al-Zubaidi, 2002).

El-Fortia (1989) described the building composition of Ghadames as being firmly grouped together and constructed vertically rather than spreading out horizontally. He explained that a tight cluster of houses creates its own cooling system by keeping the streets free from direct sunlight and maintaining the temperature at relatively modest levels, even on the hottest summer days. The small windows located in the narrow gaps between houses help to draw in cool air through the openings and through the house entrances which, in turn, cause a movement of cool air into the streets, providing in this way an almost ideal ventilation system.

The main principles shaping the old part of the town and the nature of the traditional housing construction within it are:

- Compact urban fabric (Figure 4.15),
- Covered streets (Figure 4.16),
- Narrow passageways,
- Exclusively designed houses,
- Building materials and construction.

These principles help to minimize the thermal load on the building envelope and provide comfortable conditions even in the summer time. The streets are also built in a way which makes it possible to maintain a favourable microclimate, functioning together with the buildings as a single, compact structure to keep the temperature and the humidity of air at a satisfactory level (Figure 4.17). In addition to reduced exposure to the sun, it provides full privacy for family life and suitable conditions for social life.

The normal streets are used by men (Figure 4.18) whereas the roofs are used by women for general circulation. Because of that the height of roofs for the entire city remains the same and reaches 10m. According to Al-Zubaidi, (2002) the design of the streets was adapted as one of the most important planning solutions in desert cities because the streets, ventilated and lit from frequent small openings every 15m makes different pressure zones. The air movement is from high-pressure zones to low pressure zones, where the hot air is replaced with cooler and humid air in the shaded passageways.

Figure 4.14: An over view of Ghadames old city.

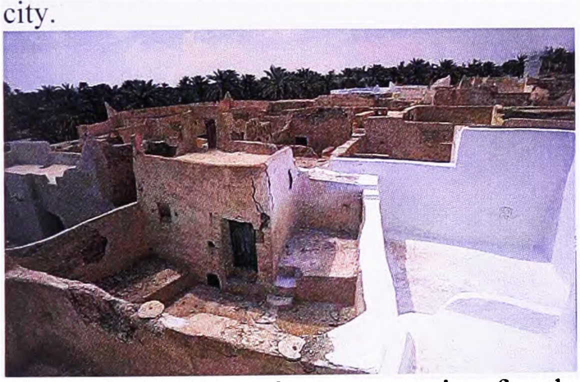


Figure 4. 16: Top view perspective for the city of Ghadame.

Figure 4. 17: Covered streets

Figure 4.18: Meeting spaces.

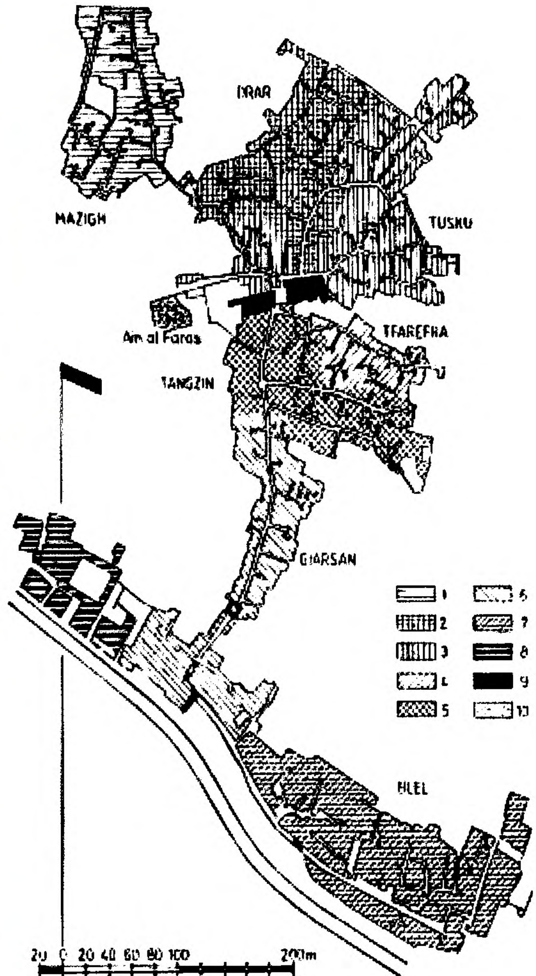


Figure 4. 15: Ghadames - the old town.
Source: Chojnacki, (2003)

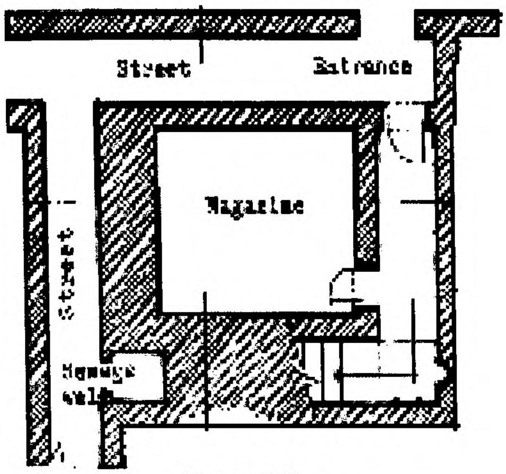
Figures (4.14 to 4.17)
source (Almansuri, 2000)

4.4.1.4 Type of traditional housing

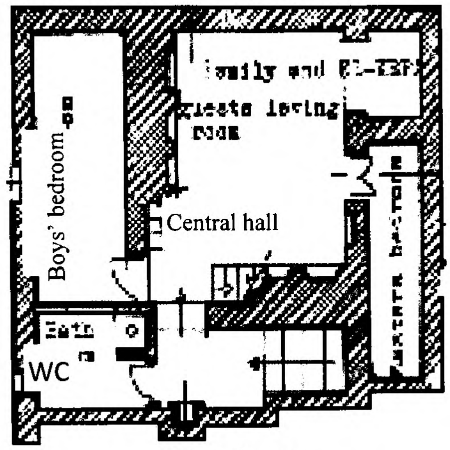
The houses in Ghadames are attached on two or three sides. They comprise a number of spaces extending on three levels. Men use the first floor and women live on the top floor where they could meet each other or call across the roofs in complete privacy from the men, also they could use the roads located at ground level when they needed to. Figure 4.19 illustrates the design concept of one of the old city houses which includes four levels. The ground level consists of the main entrance, lobby, storage area (which receives ventilation from the entrance door), a small space for sewerage located under the toilet (opened only from the outside towards the green areas) and stairs leading to the toilet which is located between the first and second floor.

The first floor includes the main central hall known as the '*Sadr el-beit*' used as a living and guest area and leads to other bedrooms and storage areas on different levels. This hall is often characterised by artistic masterwork with brass pots, plaited fabrics, and mirrors to reflect the light (Figure 4.20). The hall is more than 4m high (Figure 4.22) and includes a skylight centred in the ceiling with a maximum area of 1m square to supply light and ventilation (Figure 4.21). The open roof/terrace is used to prepare meals and also to sleep on during summer nights.

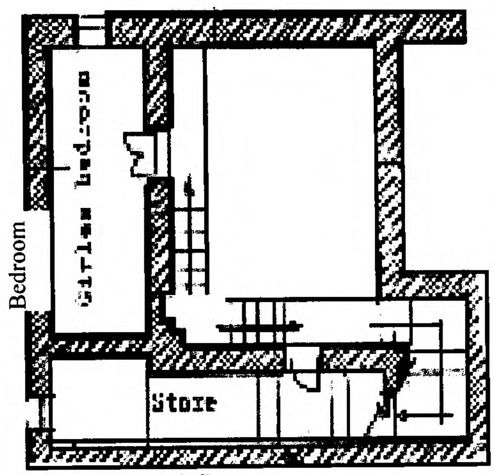
The upper level of the house mostly forms an open terrace. It includes high walls to provide privacy and to help in circulating the air. This area is kept for women's use for two reasons: firstly, because all the dwellings' roofs are connected and women can move freely from one house to another through these connections and, secondly, the kitchen is located on the upper floor (Daza, 1982).



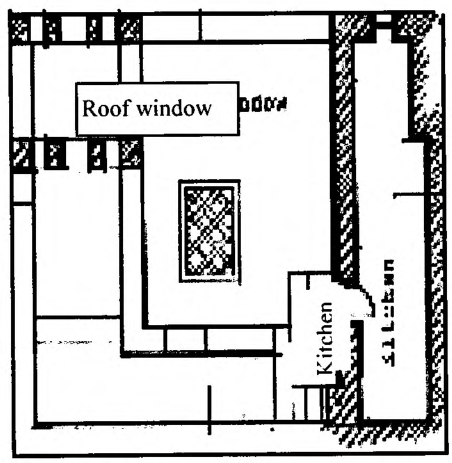
Ground floor



First floor



Second floor



Roof floor

Figure 4. 19: Plans of a typical house in Ghadames. Source: Ahmed (1985)

Figure 4. 20: Shows the interior space of a Ghadames house.

Figure 4. 21: Shows the roof opening of a Ghadames house.
Source: Almansuri, (2000)

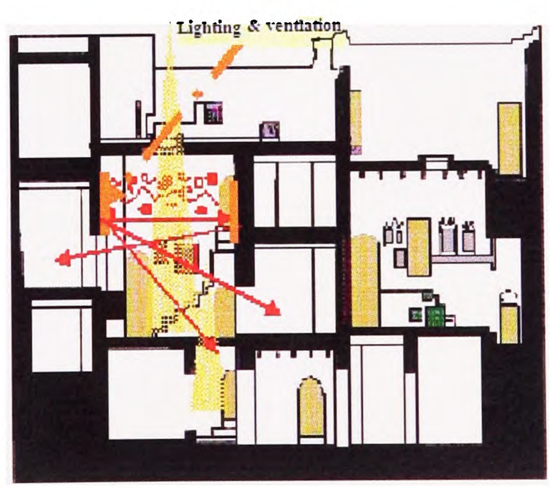


Figure 4.22: Longitudinal section in Ghadames's houses shows the different levels and the concept of lighting and ventilation.

4.4.1.5 Building materials and construction system

The primary elements in the construction of these dwellings are locally available materials. The building elements of the walls and roofs have sufficient thermal resistance. They consist of heavy thick walls of mud, stone and hay that were mixed, shaped into blocks and seasoned over a period of a year (Azzouz, 2000).

According to Daza (1982), the main material for such walls were 'sun dried bricks' which were made out of earthy clay mixed with water, formed in a rectangular wooden frame and then dried in the sun. Corresponding to the wall thickness, the sizes of the bricks measure 0.60 x 0.40m on the ground floor, 0.50 x 0.40m on the first floor and 0.40 x 0.40m on the top floor (Al-Zubaidi, 2002). Walls, arches and vaults were built using the clay as a mortar to connect the courses of bricks together. Stone was used as a foundation and sometimes used in the parapet wall (Figure 4.23). They used palm trees as the beams for the roofing (Figure 4.24) and to make doors and shelves (Figure 4.25). Branches of palm trees were used as a flooring surface which was then covered with palm tree leaves; they were also used as a base for roofing substances (such as clay mixed with sand and small pieces of stone), a surface was then plastered and finished with limestone white wash (Figure 4.26).

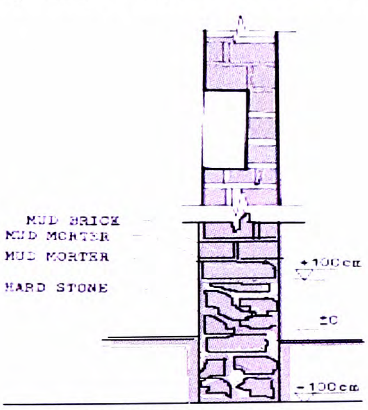
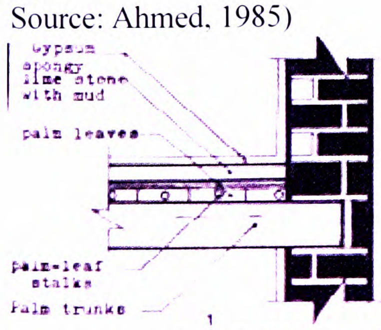


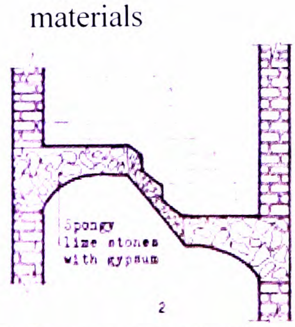
Figure 4.23: Wall and foundation. Source: Ahmed, 1985)

Figure 4. 24: The roof materials

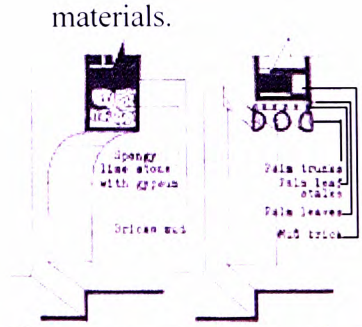
Figure 4. 25: Door materials.



the construction building and how it was constructed



Staircases construction



The two methods of the lintels construction.

Figures 4.26Figure 4. 26: Shows the building materials and method of construction. Source: Ahmed, (1985)

Figures (4.24, 4.25) source: Almansuri, (2000)

4.4.1.6 Thermal performance of traditional building

To achieve optimum comfort and energy savings, the building envelope should integrate the design of the building form and the materials as a total system and it is important how they operate heat transference through the building and how they modify the internal climate of the building in reaction to the external climate. In Ghadames, the effects of the variation in outside temperature and the extreme solar radiation are the most patent climatic conditions that affect the interior of a building (Al-Zubaidi, 2002). Ahmed (1985) found that the thermal temperatures inside the old houses in summer and in winter (as shown in Figure 4.27) were always temperate.

An article on an investigation into thermal comfort in the summer season in Ghadames by Ealiwa et al. found from the results of a survey that the occupants have an overall impression of higher standards of thermal comfort in old buildings than in new buildings (Ealiwa et al., 2001).

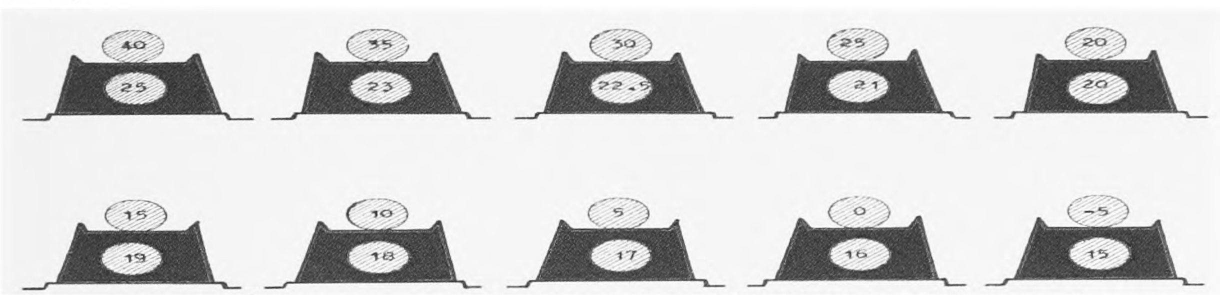


Figure 4. 27: The difference in temperature inside and outside Ghadames old houses. Source: Ahmed, (1985)

Almansuri et al., (2008) concluded that the architecture of the old city of Ghadames is well adapted to desert life (as shown in Figure 4.28) and succeed in providing a sustainable environment according to its characteristics which are identified as follows:

- Achieving comfortable living spaces in a cruel climatic region.
- Producing strong social bonds and thus representing a clear expression of the socio-cultural requirements.
- Providing protection from the heat and the sun for those out in the street and improving the circulation of air into houses by covering and winding some streets which allows the wind to circulate down the streets.
- Using local materials.
- The design of the housing reflects the modesty that is expected between males and females through their complete separation.

- The layout provides visual privacy from outside and allows female members of the household to be in contact with the outside through the roof tops.

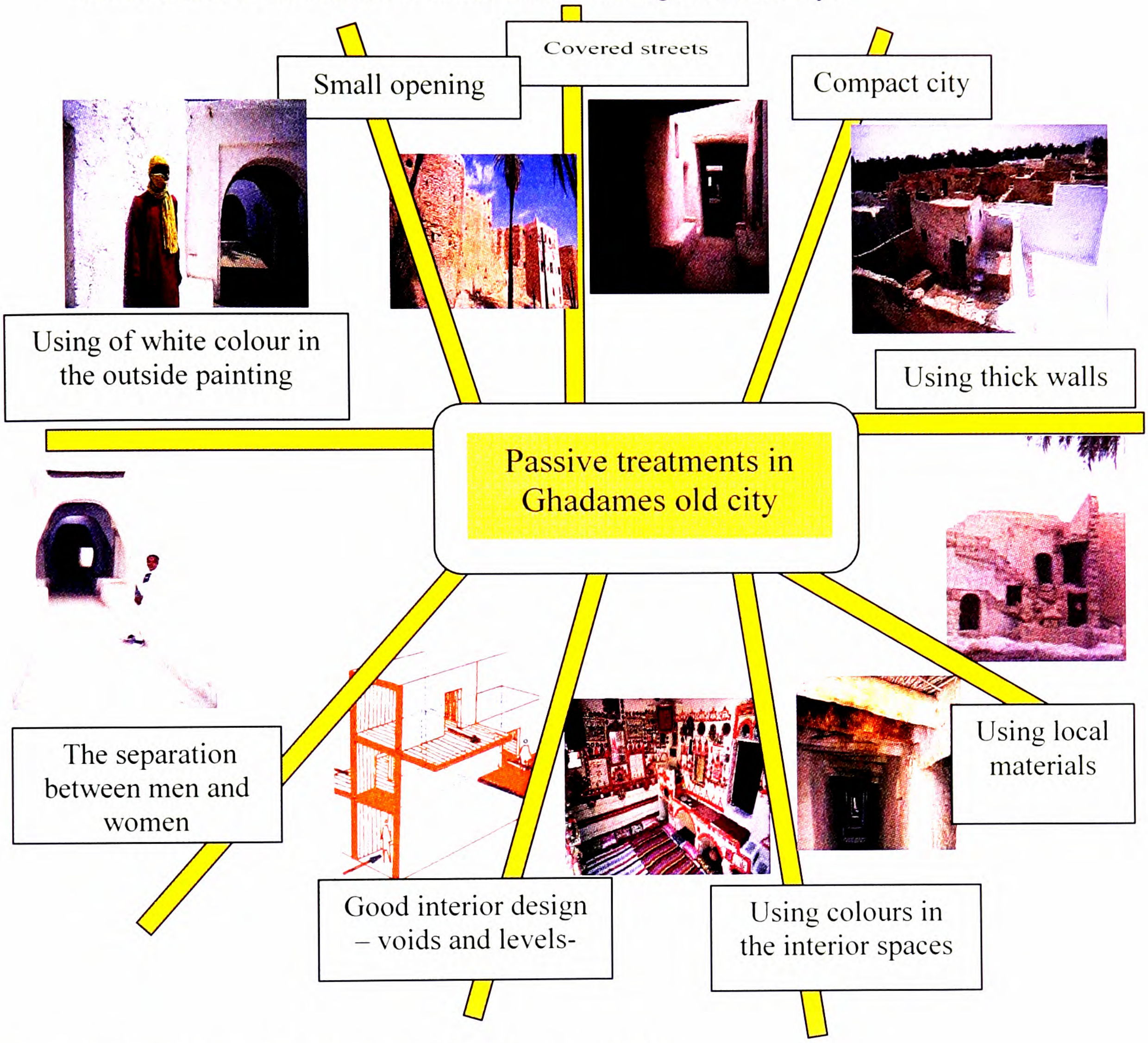


Figure 4. 28: The passive solutions in Ghadames old city.
Source: Almansuri et al., (2008)

4.4.2 Gharyan : an example of vernacular housing in the mountainous region

Libya consists of two mountainous areas, one of them being the Mountains of Algabl Alakhder and, the other, the Mountains of Nafousa (Al-Jabal Al-Gharbi) which are located in the north western region of Libya which extends from the south of Tunis to the southern region on the frontier with Tripoli. The underground houses are located in the western mountains. Gharyan is the biggest city in Nafousa Mountains. Buildings in this region usually underground.

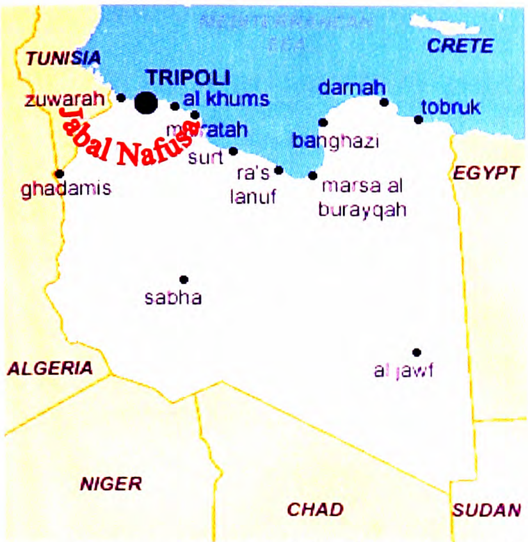
These building structures can be considered as one of the passive energy strategies that have been used in many places (including Arab countries) for a long time.

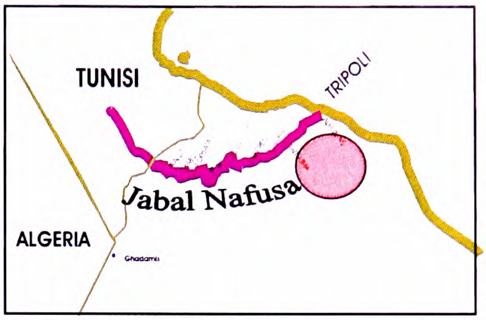
Al-Zubaidi (2002) stated that the typology of these buildings are recognized as environmentally friendly technology that can be developed and used as a basic design strategy for sustainable architecture in the future.

4.4.2.1 Gharyan- Location and climate

According to Madi (2005), Jabal Nafousa lies within the province of Gharyan and this area lies between the longitude of 8 -50° to the east (0-14° to the east) and at a latitude of 23° - 50° to the north (30° -32° to the north). Gharyan is about 94 km from Tripoli. Golany (1980) stated that Gharyan is located within a stony area in the western mountains (Nafousa Mountains) (Figure 4.29). The main geological component in the region is hard limestone, which can be excavated and carved. The nature of the topography in Gharyan means that it is strong enough to hold up ceilings and walls but also that it is easy to excavate.

According to Madi (2005), the Mountains of Nafousa represents a transitory region (as concerns temperature levels and the rate of rainfall) between the coastal region and the desert region. The average maximum summer temperature is 13°C and may reach 42°C and in the winter the temperatures reaches below 0°C in some regions. The relative humidity varies from 35% to 80% and can be 100% in the winter. Al-Zubaidi (2002) stated that climate in Gharyan is similar to the Mediterranean climate in that, generally, it is temperate and cold in winter and hot in summer. She provided annual specifications with the mean annual temperature being about 12-14°C, and the maximum temperature in July and August reaching 33°C, which drops in January to 5°C.





The Jabal Nafusa region- Gharyan
Source : Madi (2005)

Figure 4. 29: Location of the Mountain of Nafusa

4.4.2.2 The characteristics of the city form in the mountainous region

In the mountainous region (Jabal Nafousa) two types of housing can be seen, these being those built completely underground and those located above the ground level (Amer, 2007). Most of the troglodyte dwellings ('damos' in Arabic) are located underground (Figure 4.30), and these dwellings consist of holes excavated in the rocky projections. Madi (2005) stated that, due to the shortage of building materials in this region, the traditional dwellings of Gharyan were dug into the ground as troglodytes. The entire house with low ceiling heights is made by excavating the ground, only the entrance that comes above the ground is actually constructed. Sometimes these caves and courtyards are hidden from view and the ground plan of the houses varies depending upon the soils of the district.

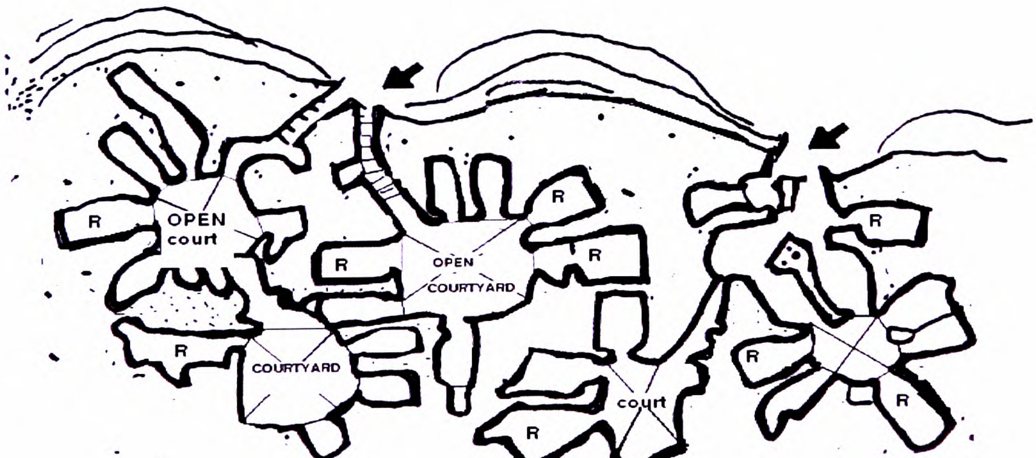


Figure 4.30: The compact grouping of underground houses.
Source: Amer (2007).

4.4.2.3 Type of traditional housing

Madi (2005) and Baccoush (2006) classified the houses according to their location. They classified them into two types: the underground houses and the above ground houses (houses built of stone and gypsum mortar).

Albakosh and Emhemed (1998) stated that there are three types of buildings in the Libyan mountains. The first type are not for living in and are suspended houses which are used for defence reasons or for food storage. The second and third types are used for living and these are the excavated houses and semi-excavated houses. Shaiboub (1979) and Madi (2005) added another type - the mixed type and they described this type as a combination of styles, half house and half cave. They clarified that caves and houses have existed in the past and that their relative importance depends on the economic conditions.

A. The Troglodyte type of house (underground houses)

Amer (2007) categorised these houses into three types:

- First type (Aboskefa): this is completely underground without any elevation.
- Second type (Al-Feseal): this is partially underground with some elevation

Third type (Al-Mgara): is a "hanging" house i.e., it is a cave-like excavation into a vertical cliff face.

A1. The first type (Aboskefa):

Aboskefa or Elsakifa (as Madi (2005) called it) types of dwellings are completely underground (Figure 4.31). Baccoush stated that Aboskefa consists of three main parts: Alskefa, the courtyard and Aldawames. The Alskefa is the connected space between the entrance and the courtyard; it usually takes a curved shape for privacy reasons and to divert winds. The width does not exceed 3.5m and the height does not exceed 2.5m (Figure 4.32). The **Courtyard** is circular or rectangular in shape and is surrounded by a number of rooms. It covers 50% of the total house area; its dimensions are 6-8m wide, 8-10m long and 8-10m in diameter across its circular shape (Figures 4.33 and 4.34) (Baccoush, 2006).

The courtyard is used to provide natural light and ventilation and is a place where daily activities take place. In the courtyard, a small tank in the ground is filled with salt and organic materials that are used to absorb the rainwater (Shaibub, 1979; Daza, 1982; Bukamar, 1985 and Amer, 2007).

Aldawames are underground spaces open to the courtyard which are used for family life. They have irregular rectangular shapes. The depth and width of these rooms are 6m x 3m and their height is 2.5m-3m. Usually the floor is lower than the courtyard's floor by some 30 to 60cm (Figure 4.35) (Baccoush, 2006 and Amer, 2007). The construction of underground houses has been classified by Amer (2007) into three stages: digging the courtyard; constructing the entrance; excavating the rooms.

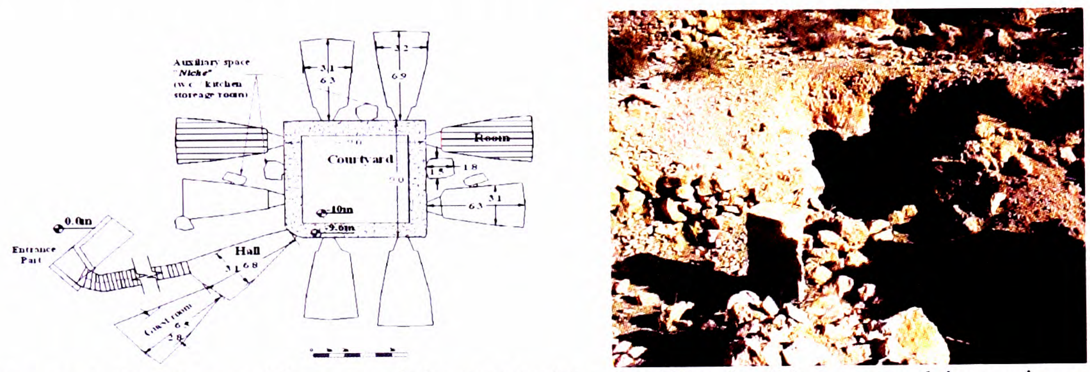


Figure 4. 31: General layout of the troglodyte dwelling in Gharyan and its main entrance. Source: Elwefati et al., (2009) Photo source: The researcher

Figure 4.32: The entrance (Alsakefa).

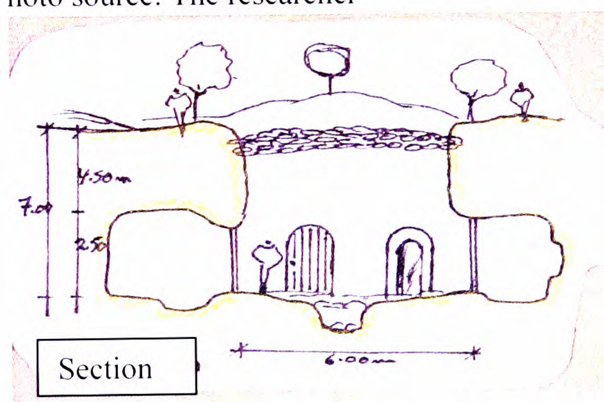


Figure 4. 33: The dimensions of the troglodyte houses.
Source: After Albakosh and Emhemed (1998)

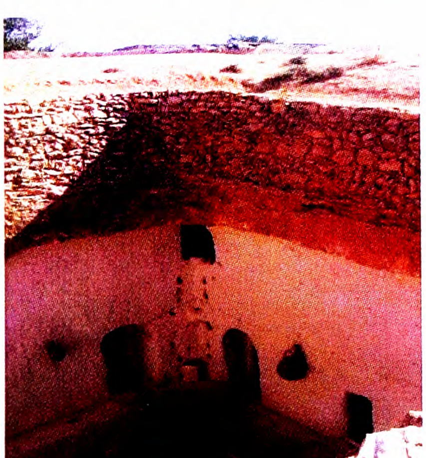


Figure 4.34: The courtyard

Figure 4.35: The family room (Aldawames).

A2. The second type (Al-Faseal):

An Alfaseal house is considered as an improved type upon the Alsakefa type of dwelling. It is located in the foothills of the mountains on a steep slope with a rock layer that is used as a roof to a depth of 2 to 4 m. Houses have some elevation above the ground and comprise a courtyard, almost rectangular in shape, and a number of rooms (Aldawames) that are less in number than those in the Alsakefa type. They were dug into the rock on three sides, the fourth side being built from stone. Aldawames in this type were bigger because of the large rock roof (Figure 4.36). This type of dwelling combined underground techniques and stone and gypsum mortar techniques (Baccoush, 2006 and Amer, 2007)

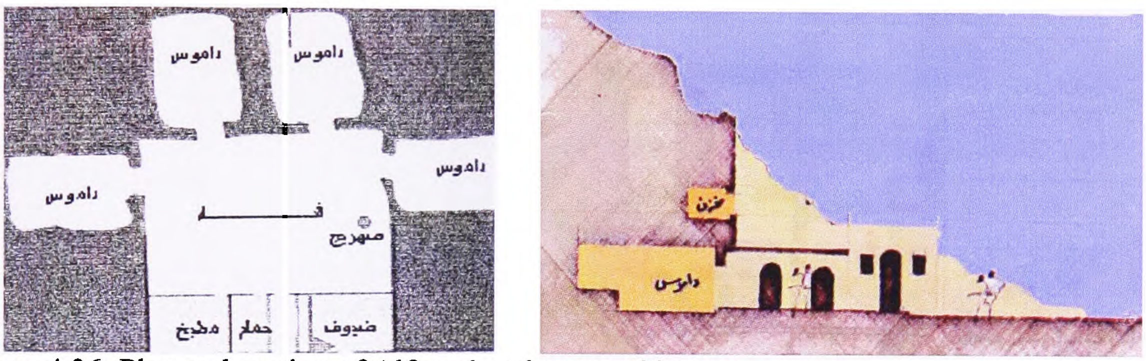


Figure 4.36: Plan and section of Alfaseal underground houses.
Source: After Albakosh and Emhemed (1998)

A3. The third type: suspended house (El-mkhara)

This type is located on the sides of valleys and is known as a suspended house. The houses rise above ground level by about 3m or more because they were used defensively. The problem with these houses is their location: there is no fixed staircase and entry is through a moveable staircase, made from natural plants. They include many rooms with some open holes which were used for observation. They also contain openings in the ceiling used for ventilation (Figures 4.37 and 4.38).

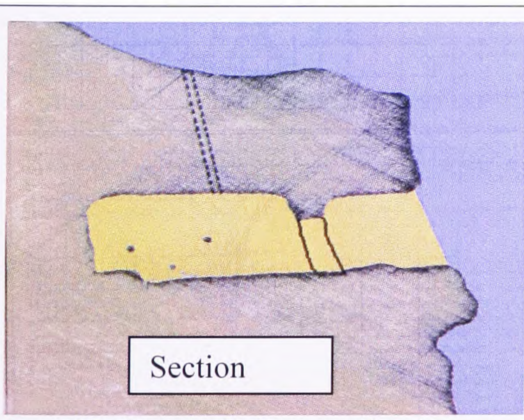


Figure 4.37: Suspended excavation house.
Source: After Albakosh and Emhemed (1998)

Figure 4.38: Suspended excavation, which was used for food storage.
Source: Hamed (2009)

B. The above ground houses

Amer (2007) classified this type of housing form into flat roofed courtyard houses and vault roofed houses. The form of these types of houses are similar to the courtyard houses in the coastal area, However, the shape of the courtyard and the rooms are different, where the corners are curves rather than being right-angled (Figure 4.39) (El-Fortia, 1989 and Amer, 2007).

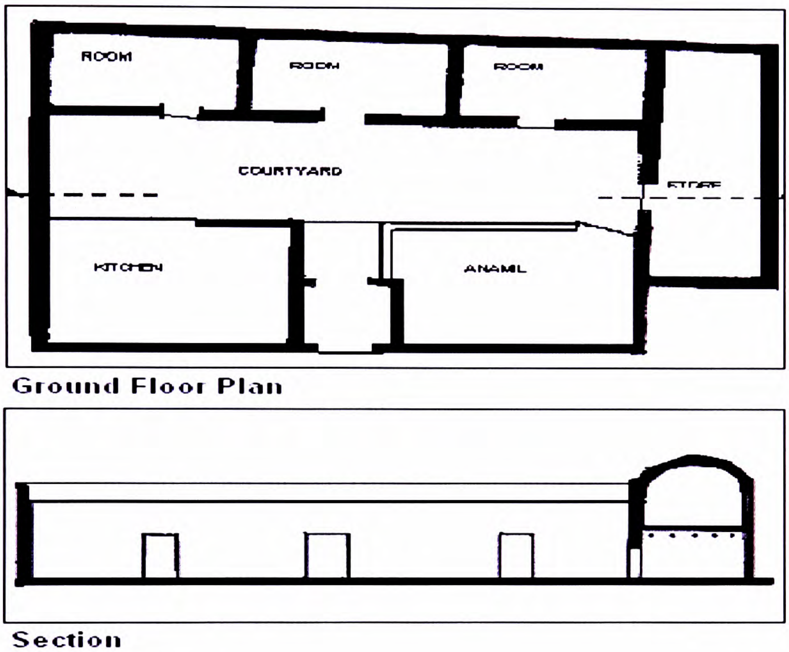


Figure 4. 39: Vault roofed house. Source: Amer (2007)

C. mixed types, half house half cave (Cliff-dwellings)

This kind of housing is built on the steeply inclined ground. It includes two parts, one part is underground, which is the main courtyard, and the other part is the room above the level of the ground and on the same level of the courtyard (Figures 4.40, 4.41 and 4.42). Madi (2005) divided the construction process into several steps: digging the yard in the lower part of the location and constructing the fourth side of the yard: digging the main rooms underground (of rectangular shape and dimensions varying from 3 to 7 m, with a width of 1.5 to 2.3m, and a ceiling of palm branches). These main rooms have windows less than 1.4m above ground level with a height of 50 cmand a width of 40 cm. Windows and doors are distributed in the inner wall towards the direction of the yard except for the reception room, which has its entrance outside the house.

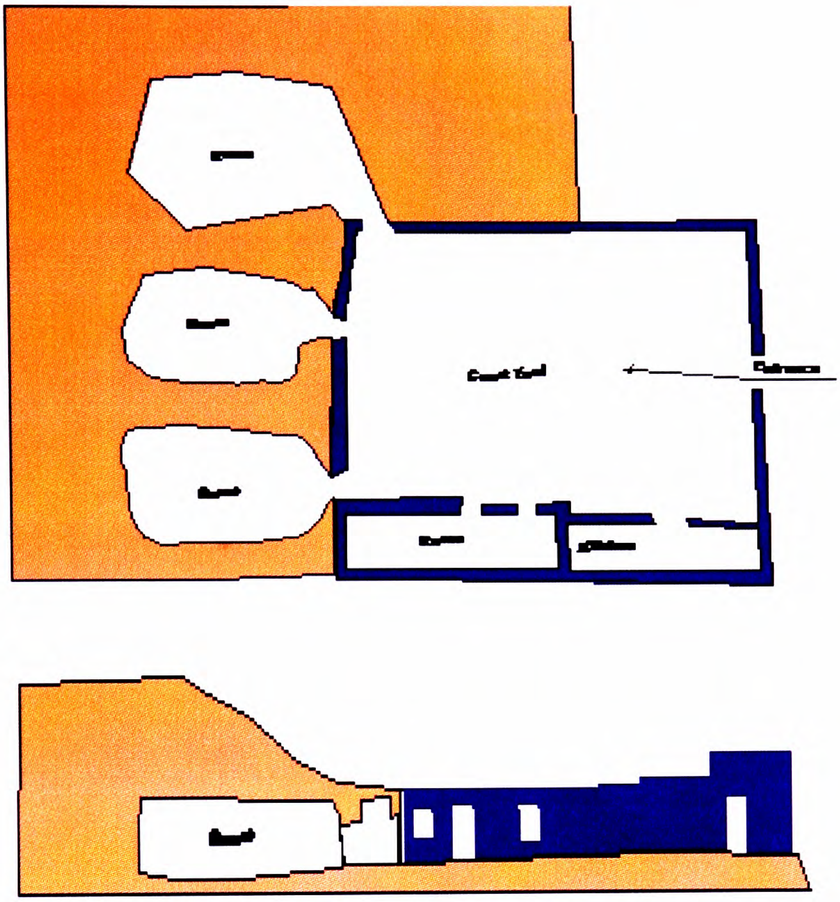


Figure 4. 40: Plan and section of a Cliff-dwelling. Source: Madi (2005)

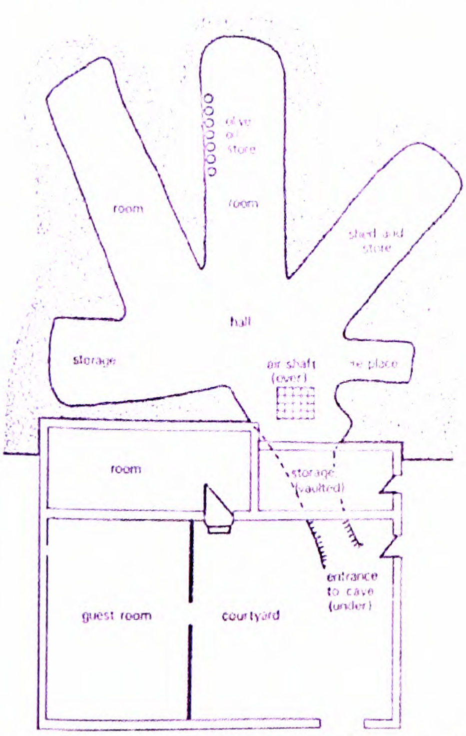


Figure 4. 42: Elevation of the mixed type.

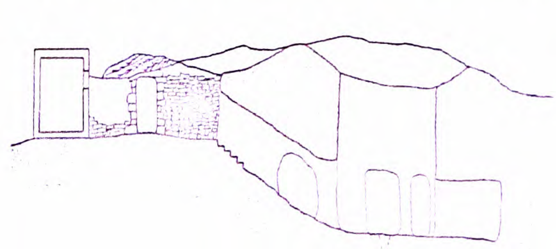


Figure 4.41: Plan and section of the mixed type of dwelling.

Source: Shaiboub (1979)

4.4.2.4 Building materials and construction system

The material used in the construction of this type of dwelling is rough local stone, lime and clay mortar. The essential materials for the construction of the foundations and the walls are stones and a moulded mix of gypsum and lime stone. The thickness of walls at the base reaches 1.5 m and then gets thinner as the height increases. Walls are built in different stages. It starts by building the wall to a height of 1 m and filling it with small gravel in order to achieve the cohesion between the components of the wall. Small gravel and the mix of gypsum and lime stone are used to fill the space between walls.

Inclined walls support the other walls from the outside, with the use of arches and bows to reinforce the support and to hoist the ceiling (Figures 4.43). Wood is used for the lintel of the doors. In order to improve the texture of the surfaces, the inner walls are treated by a mix of gypsum and lime stone and in order to achieve the white colour (or for the decoration of the inner surfaces) gypsum and salt is used (Figure 4.44).

The flat roof is formed from palm–tree trunks and olive branches which are placed across the small rectangular rooms, and then covered with a mixture of straw, clay and gravel (Figure 4.45). The stairs are made from stones (Shaiboub, 1979; Daza, 1982 and Madi 2005)

Figure 4.43Figure 4. 43: Inclined walls supported the other walls from outside.
Source: Madi (2005)

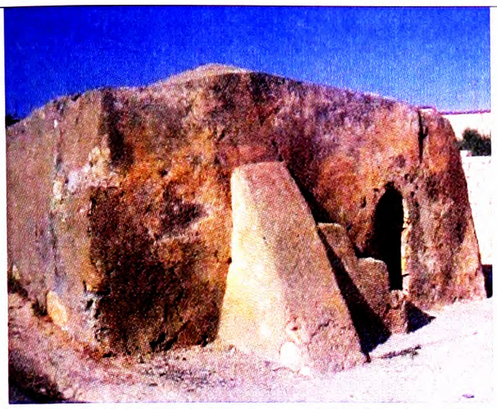


Figure 4. 44: Using a moulded mix of gypsum and lime stone to improve the external texture.

Figure 4. 45: Using palm–tree trunks and olive branches in flat roof.

4.4.2.5 Thermal performance of traditional buildings in the mountainous region

Many studies have been undertaken to measure the temperature in the hottest and the coldest times in the mountainous region old buildings. Temperatures remained constant in the summer at about 27° C and in the winter at about 18° C. The success of using excavated houses is a direct result of the constant temperature of soil at a specific depth (about five meters). During the year the sun's rays could not reach the rooms. Also this depth protected the covered areas in the cold winter (Figure 4.46) (Albakosh and Emhemed,1998).

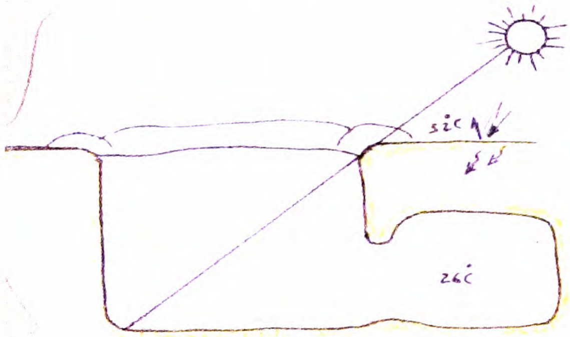


Figure 4. 46: the differences between indoor and outdoor temperature.
Source: Albakosh and Emhemed (1998).

Emhemed,(1997) compared the internal temperature measured inside a new contemporary house, taking the measurements in the courtyard of Al-Faseal house and inside the underground of Al-Faseal house for one year focusing particularly on measuring the temperature inside within the warmest week (9 to 15 August 1996) and also in the week of 6 to 13 January 1997 (Table 4.2 and Figure 4.47).

The results showed that there was a difference in the interior temperature in the underground house of not more than 1°c which means that the temperature is constantly 27°C and the humidity was between 35 to 45% which means it is located in the comfort zone. In the coldest week, the internal temperature in the Al-Feseal house ranged between 16.5-18°C and humidity ranged between 31-100%. This confirms that these houses are comfortable most the time, and that the internal temperature remains constant even the exterior weather changes.

Table 4. 2: Average internal temperature in a modern house, in a courtyard of Al-Faseal house and in a room of Al-Faseal house. Source: After Emhemed (1997)

Location/ months	Modern house	In the courtyard	Al-Faseal house
January	10.5	15	21.5
February	11.5	15.5	22
March	14.5	16	22
April	17	20	24
May	25	25	27
June	28	30	27
July	30	30	27
August	32	35	27
September	26.5	25.5	25
October	25.5	27.5	24
November	18.8	20	22.5
December	13.5	15	21.5

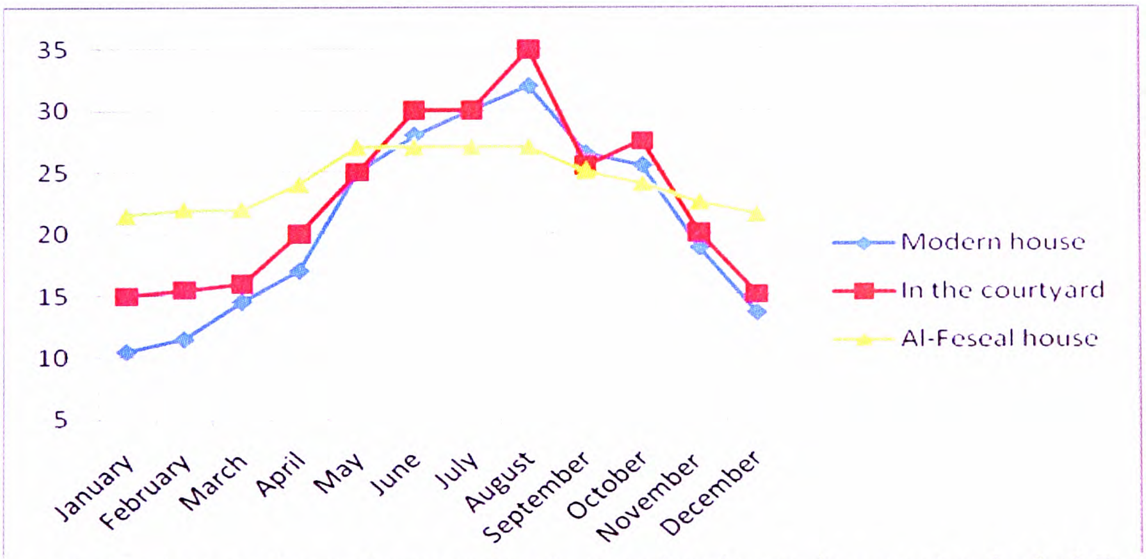


Figure 4. 47: Average internal temperature in a modern house, in a courtyard of Al-Faseal house and in a room of Al-Faseal house. Source: After Emhemed.(1997)

A recent survey undertaken by Elwefati et al., (2009) to investigate the bio-climatic characteristics of traditional and contemporary houses confirmed the above results and showed also that the majority of indoor temperature readings in the summer months for a traditional house that is completely underground are more or less constant, and within the range for human comfort. This is because the house is isolated to a great extent from the external environment, is made of natural local materials and was planned properly.

In contrast, the indoor readings for the contemporary house followed the diurnal fluctuations closely and at times the indoor temperature became higher than that outside (Figure 4.48). This is an indication of the thermally inferior properties of contemporary buildings, which render them uncomfortable during the summer.

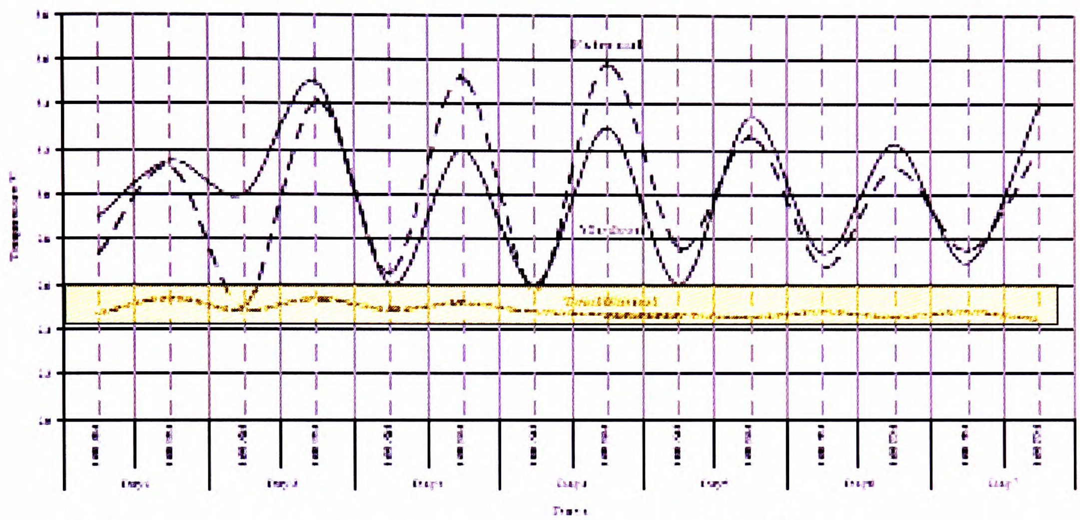


Figure 4.48: Temperature data for Gharyan during one week in July.
Source: After Elwefati et al., (2009)

Winter data also shows the same trends within the traditional and contemporary houses as that recorded during the summer. Temperatures in the traditional house are stable and within the comfort zone during the day. During night time they drop slightly below the comfort level. However, the traditional house is warmer than the contemporary one, which is uncomfortably cold all day long (Figure 4.49).

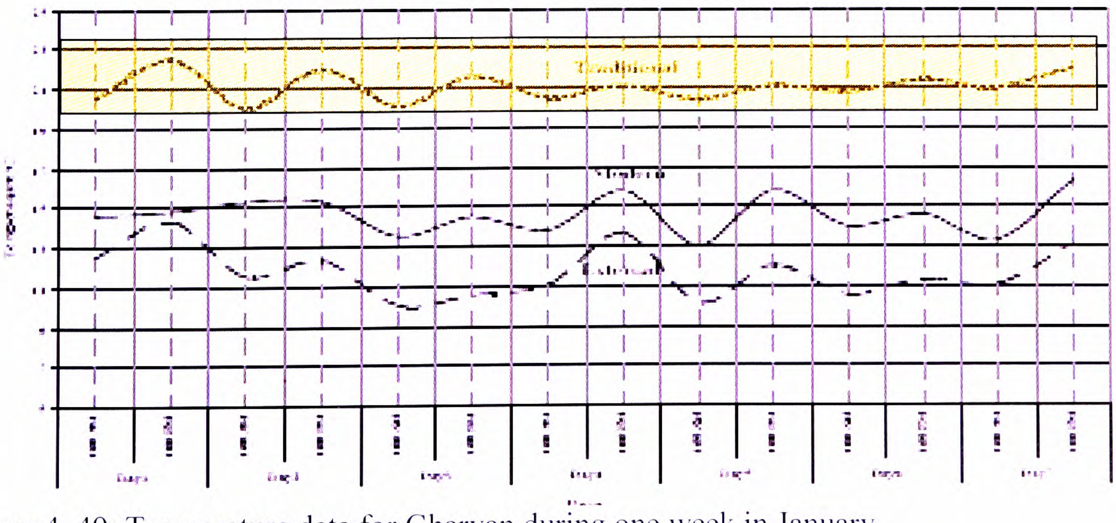


Figure 4. 49: Temperature data for Gharyan during one week in January.
Source: Elwefati et al., (2009)

Elwefati et al., (2009) summarised the reasons for thermal discomfort in contemporary houses. These were: the inappropriate thermal properties of modern reinforced concrete structures, incompatible design of the urban fabric and individual buildings, inappropriateness of the houses within the local environment and complete dependence on imported construction materials.

It can be concluded that underground houses provide a more comfortable indoor environment on both hot and cold days. The main advantages and disadvantages of traditional mountain houses as presented by Emhemed,(1997), Amer (2007) and Elwefati et al. (2009) are summarized in (Table 4.3).

Table 4.3Table 4. 3: The advantages and disadvantages of underground houses.

Advantages	**Disadvantages**
• Simplicity of house design. • Cheap to build and do not require much material. • As a result of the stability of temperature underground, they are warm in winter and cool in summer. • They are very useful in hot and cold dry regions. • The offers good sound resistance. • They reduce energy consumption used by 50-80%. • They do not need more energy in storing goods, such as refrigeration. • Heat gain and loss are minimal. • Provide more open spaces and preserves land. and • Protection against earthquakes and war;	• Lacking in sanitary systems and utilities. • Sand storms may cause problems. • Needs artificial light on some cold dark days. • Needs fans to circulate the air. • There is a long distance between dwellings which isolates the family from their neighbours. • Can be unsafe for people and animals, especially at night, who might fall into unprotected courtyards. • Not safe in cases of fire. • Difficult to maintain because of sanitary problems. • Does not fulfil current needs. • Not fashionable. • Have a lack of privacy.

From the climatic point of view, the information presented in Table 4.3 shows that the advantages of traditional houses are greater than their disadvantages. Accordingly, the findings of this part of study support the belief that the bioclimatic qualities of traditional dwellings make them better than contemporary ones from the point of view of thermal comfort, energy efficiency and economy; all qualities which are desirable for a sustainable built environment.

4.4.3 Tripoli as a case study location and as an example of coastal region

As clarified in the introduction chapter, the purpose of choosing Tripoli as the location for the case studies can be summarized as follows: the geographical and climatic characteristics of Tripoli are similar to those in of the Mediterranean region, the cultural conditions are typical of those in most Moslem and Arab countries; it is the capital of Libya, where about 40% of the total Libyan population resides, and its old city is still in a good condition and provides good examples of vernacular architecture.

4.4.3.1 Tripoli: Location, geography and climate

Tripoli is located in the northwestern region of Libya along the Mediterranean coast as shown in (Figure 4.50). Geographically, it is situated to the north of the Equator, at longitude 32.56 degrees, and at latitude 13.15 degrees east of Greenwich (Amer, 2007). The climate in the Mediterranean and semi Mediterranean Sea (coastal region) is characterised as hot and humid in the summer season and warm and rainy in the winter season (Shawesh, 2000).

Figure 4.50: Tripoli's location in Libya.

The climate of Tripoli is relatively pleasant most of the year except in July and August when temperatures can reach as high as 40°C with high levels of humidity. The prevailing winds in the coastal strip are from the north and become less and less dominant as the distance from the sea increases. The wind speed in Tripoli can reach 30-35 knots in winter (El-Fortia, 1989). Amer (2007) added that this area in July and August is affected for many days by the south wind *(Ghibli)* which raises the temperature in this region. The annual average rainfall in the plain coastal region reaches 300-400mm though it sometimes exceeds 650 mm or falls to less than 200mm in the driest years (Emhemed, 2005). The average winter temperature is 15°C with cold nights and rainy days (Elwefati et al., 2009). The average humidity in this region is 58% to 65%, which in some years may increase in the summer from June to the end of August (Emhemed, 2005). According to Al-Fenadi (2007) and Bukamur (1985) El-Azizia city, which is located 55 km southeast of Tripoli, recorded the hottest maximum shade temperature recorded on the face of the earth (58°C); this was recorded on 13th September 1922. Contrastingly, Amer (2007) stated that the coastal regions are characterised by cold, wet winters, and hot, dry summers. However, as can be seen in Table 4.4 the minimum average temperature in Tripoli during a 11 year period from 1995 to 2005 ranged between 6.9°C and 24.9°C and the average humidity recorded for the same period of time (as can be seen in Table 4.5) ranged between 65%-68%. Table 4.6 presents the maximum and minimum temperatures for one year between 08/2009 – 07/2010. The readings show that the average minimum temperatures ranged between 8.9°C-22.9°C and the average maximum temperatures ranged between 18°C–34°C. This shows that Tripoli is located in a hot humid region (Figure 4.51). This is also confirmed by the outcome from psychrometric chart and bioclimatic charts that are presented in the next section. More detailed climatic data provided for Tripoli has been adapted from the Weather Tool which can be found in (appendix 5).

Table 4. 4: The average lowest temperatures in Tripoli during the eleven years 1995-2005. Source: National Centre for Meteorology - Tripoli station

Years	Jan	Feb.	March	April	May	Jun	July	Aug.	Sep.	Oct.	Nov.	Dec.
1995	7.2	10.5	12.2	13.1	17.7	22.1	23.5	25.3	24	18.2	14	11.8
1996	11.4	10	12.5	14.8	18.2	20.8	23.4	25.3	24	17.5	14.5	12.2
1997	10.8	10.2	11.2	13.8	18.1	24.8	24.8	25.2	22.7	19.7	14.7	10.9
1998	9.6	10.7	10.9	15.8	18.1	22.5	23.2	24.2	23.4	20.3	13.2	10.5
1999	10.9	8.7	12.7	14.8	19.9	24.2	23.8	26.5	24.6	21.7	15.9	10.8
2000	7.8	9.6	12.2	16.1	20.3	21	23.5	23.4	23.4	19.4	15.2	12.1
2001	10.5	10.2	14.5	14.7	19.9	20.7	22.9	24	24.4	21.1	16.5	11.1
2002	8.5	10.9	14.5	15.5	19.2	20.8	25.4	25.5	23.5	18.6	15.3	10.8
2003	10.5	9.3	11	15.3	18.9	22.7	26.4	25.5	24.4	22.8	16.7	11.3
2004	9.8	11.8	13.2	15.7	18	21.5	23.4	25.5	22.1	21.1	15	9.8
2005	7.9	6.2	11.4	12.6	16	19.4	22.8	23.3	22.8	18.9	13.4	9.3
Average	9.6	9.8	12.4	14.8	18.6	21.9	23.9	24.9	23.6	19.9	15	11

Table 4.5Table 4. 5: The average humidity in Tripoli during eleven years. Source: National Centre for Meteorology - Tripoli station

Years	Jan	Feb.	March	April	May	Jun	July	Aug.	Sep.	Oct.	Nov.	Dec.
1995	71	74	66	70	95	65	74	64	70	78	71	74
1996	70	67	70	66	66	71	60	61	69	68	67	59
1997	72	72	73	66	63	60	69	74	75	77	63	59
1998	66	69	65	61	64	52	64	66	66	69	68	68
1999	71	71	69	69	63	59	65	60	63	61	62	59
2000	68	65	63	58	61	64	60	68	62	63	65	66
2001	55	59	57	64	60	69	61	66	66	64	66	69
2002	73	69	63	61	59	59	68	65	63	53	62	68
2003	63	64	71	66	62	68	62	65	67	61	63	65
2004	64	64	67	63	61	60	63	61	64	64	71	71
2005	77	73	74	71	70	70	69	72	71	78	75	83
Average	68	68	67	65	66	63.4	65	65.6	67	67	66.6	67.4

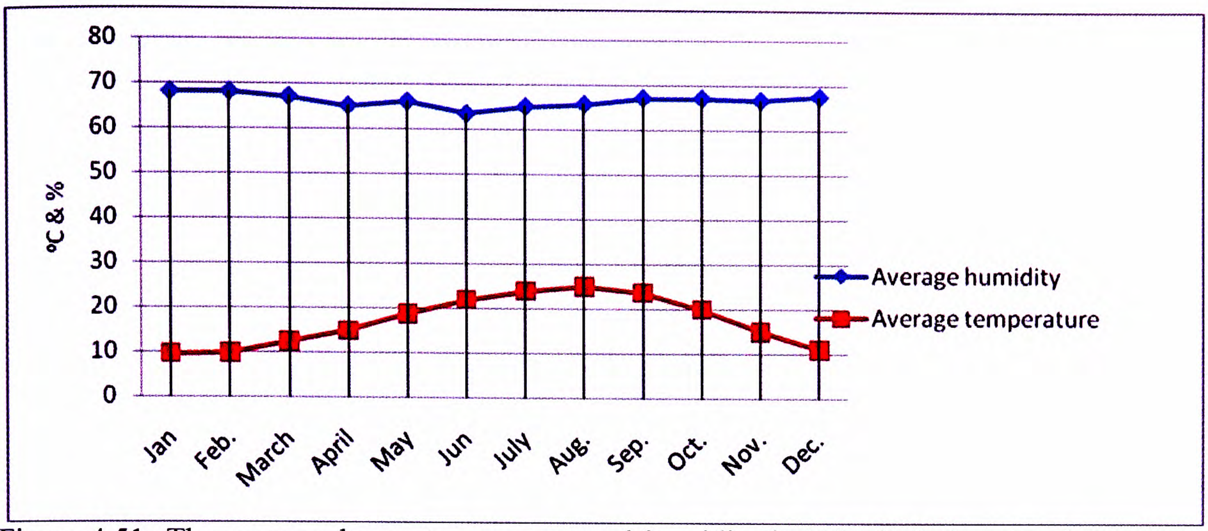


Figure 4.51: The average lower temperature and humidity in Tripoli during the eleven years (1995-2005).

Table 4.6Table 4. 6: The maximum and minimum temperature during one year (08/2009 – 07/2010).

Dates	08/08	09/08	10/08	11/08	12/08	01/09	02/09	03/09	04/09	05/09	06/09	07/09
Max. Average Temperature	33.7	32.2	29.2	23.5	18.0	18.3	18.2	21.6	24.9	28.6	32.0	34.0
Min. Average Temperature.	22.2	22.9	19.2	13.5	09.2	10.2	8.9	10.8	13.1	16.7	20.4	22.8

4.4.3.2 Climatic data and design strategies for Tripoli climate

In this part, detailed climatic data alongside design strategies for the Tripoli climate as suggested by the Weather Tools software provided by Marsh and Square One (2005) and other references will be discussed as follows:

The psychrometric chart presented in (Figure 4.52) shows that four months of the yeas the weather is located in the hot humid zone (June to September), two months are located in the warm humid zone (May and October), another three months located in the moderate zone are (March, April and November) and the last three months (December to February) are located in the cold zone. Three months are located in the comfort zone; May, April and November. The bioclimatic chart (Figure 4.53) provided by Bukamur (1985) shows similarity with most of climatic classifications of Tripoli. However, the month of November is located under the comfort zone in the cold area. Six months which are located outside the comfort zone, in the warm and hot humid areas, need ventilation or air-conditioning to achieve internal comfort.

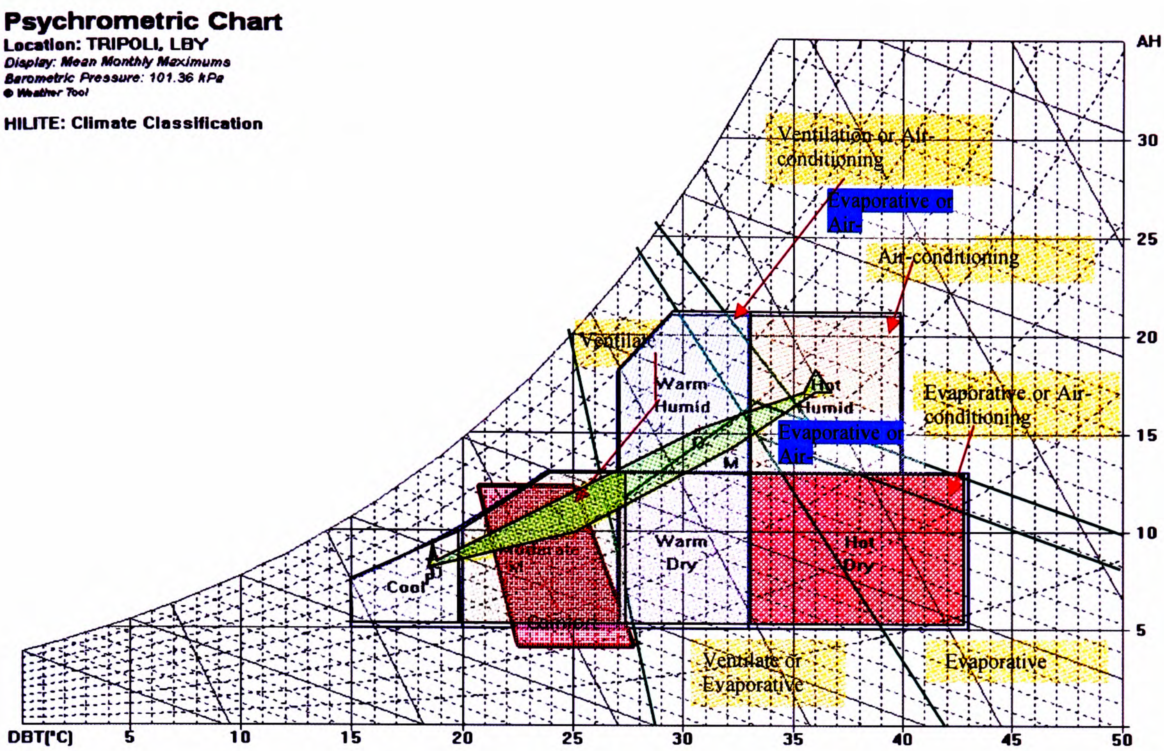


Figure 4. 52: Climatic classifications for Tripoli in the psychrometric chart.
Source: After Marsh and Square One (2005)

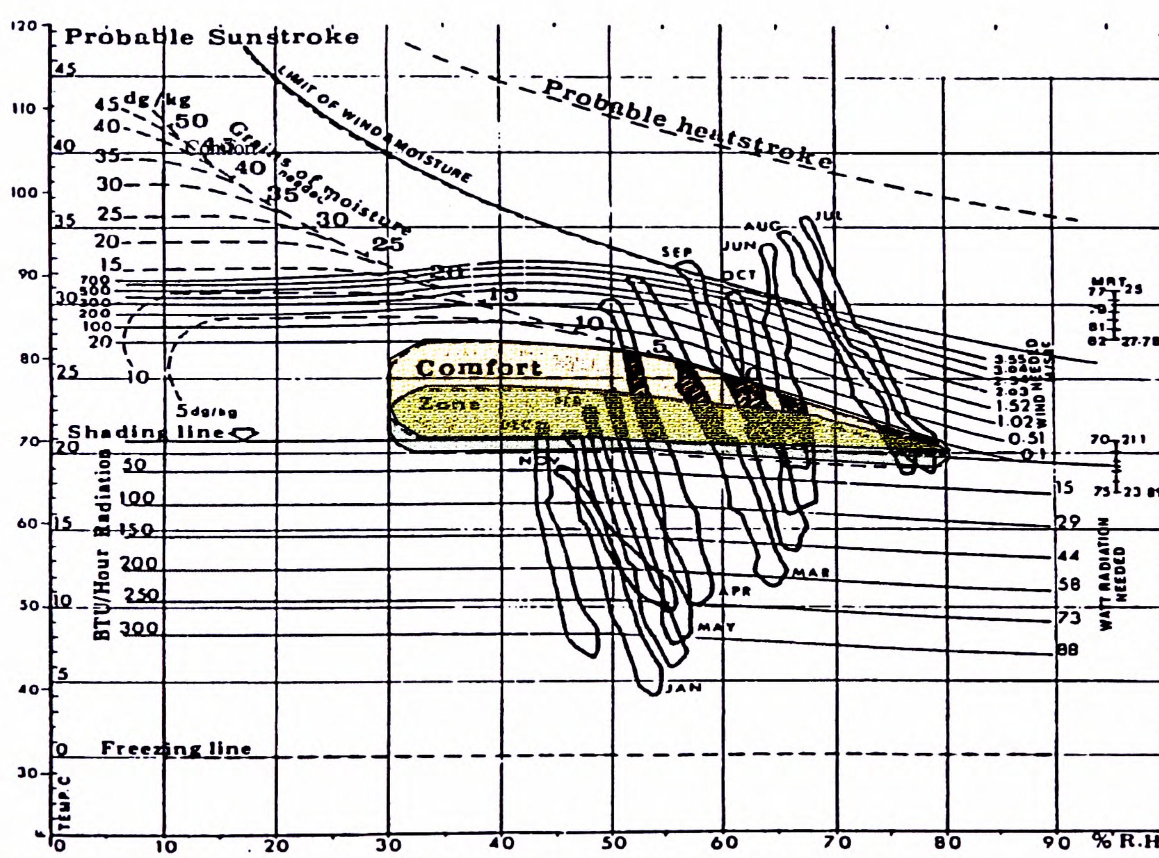


Figure 4. 53: The climatic classifications for Tripoli in the bioclimatic chart.
Source: After Bukamur (1985)

The passive design techniques selected for the Tripoli climate as presented in (Figure 4.54) shows that natural ventilation could play a great role in providing internal thermal comfort without using air conditioning. About six months of the year require active cooling systems to provide the desired comfort; however, this can be reduced by using passive design techniques such as orienatation, shading devices and vegetation. Bukamur (1985) provided some passive solutions, as presented in (Figure 4.55). He suggested using mixed types of shading devices in the north elevation (although it can be argued that the north elevations do not need any kind of shading device because there is direct sunrise on that elevation) and, as he showed in (Figure 4.56) a desirable wind can help to moderate the internal environment.

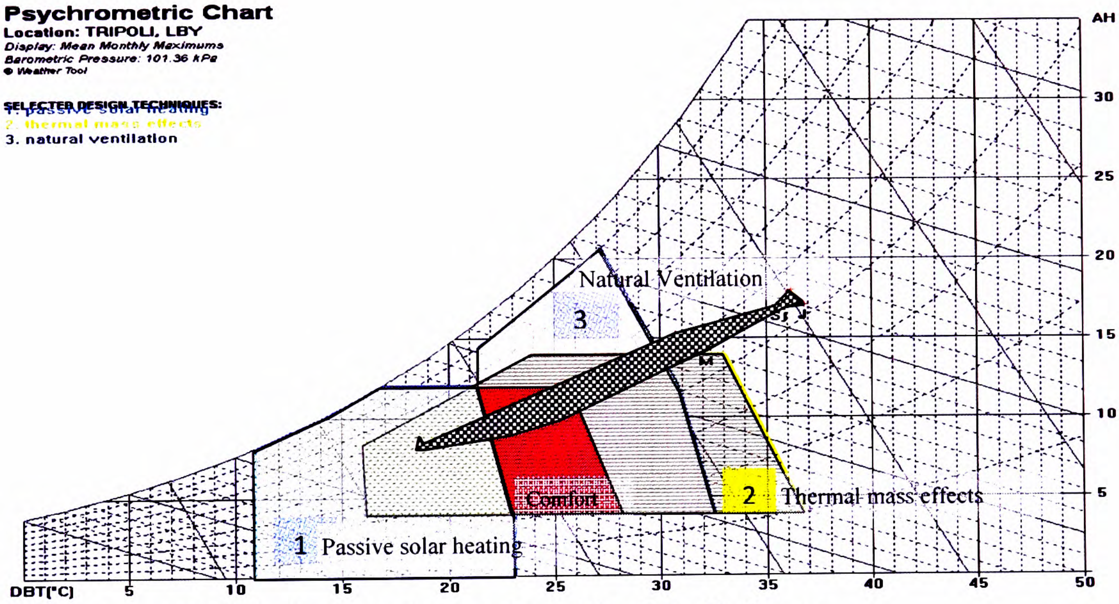


Figure 4.54: The passive design techniques selected for Tripoli climate.
Source: After Marsh and Square One (2005)

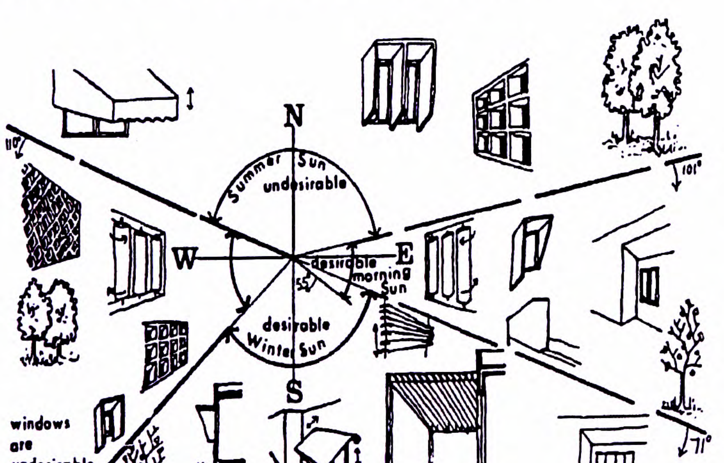


Figure 4. 55: Passive external solutions for Tripoli climates.

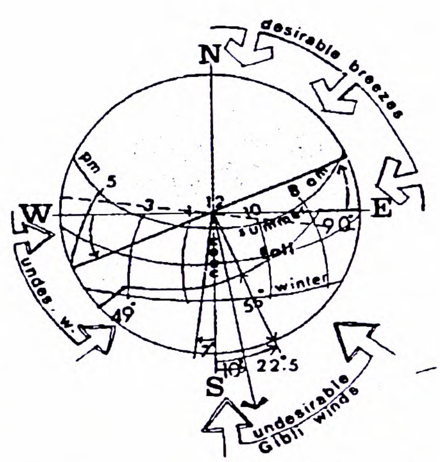


Figure 4. 56: Orientation according to desired winds.
Source: Bukamur (1985)

The optimum orientation for Tripoli, as suggested by Marsh and Square One (2005), is that the long elevation should face north and south with a small incline (15.5 ° to 17.5°) to face east south (Figure 4.57). This suggestion confirms the strategies offered by the literature.

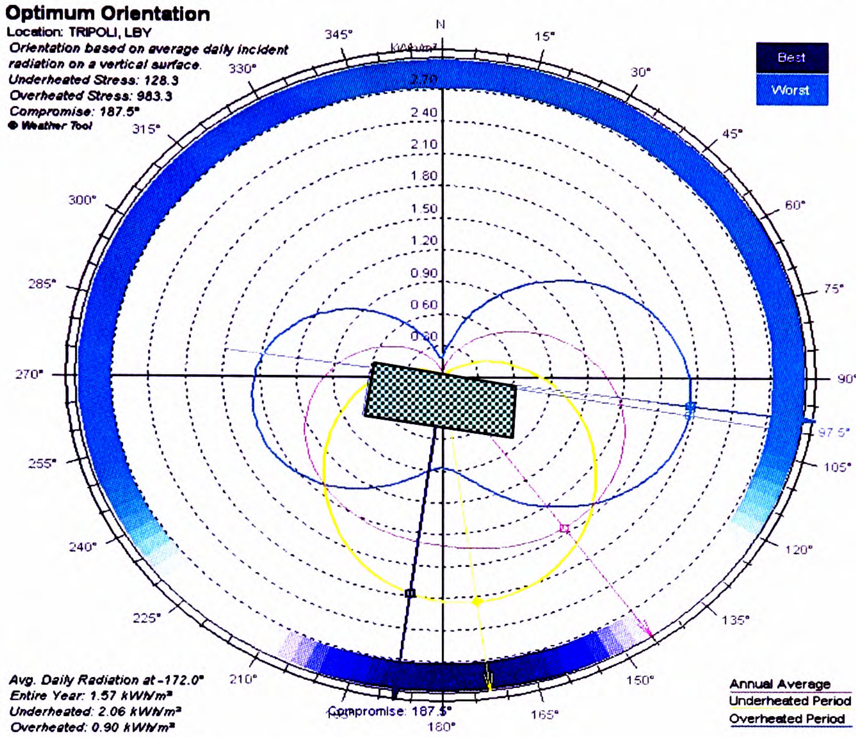


Figure 4. 57: Optimum orientation for building in Tripoli.
Source: After Marsh and Square One (2005).

4.4.3.3 Traditional houses in Tripoli

Two types of inward looking houses were found in the traditional city: the one storey house and the two storey house. These houses were characterised by a courtyard by which rooms were connected. The coming sections will explain the courtyard type in more detail.

4.4.3.4 The characteristics of the old city form

Daza (1982) stated that Tripoli's old city reflects a strong and clear picture with simplicity of means in every area and where the geometrical combination of the buildings are simple and clear. Azzouz (2000) added that consideration of climate, customs and traditions were major factors in shaping the city (Figure 4.58) and Shawesh (2000) believed that the location of the old city and its relation to the sea were the keys to its long life and determined its character.

The old city is compact in its pattern where houses are surrounded by three neighbouring houses to decrease the area of walls exposed to heat (Figure 4.59). Its scheme follows no superimposed grid system; it gives an obvious example of organic growth. The streets are usually narrow, twisted, with surprise changes and slight curves. The width of the streets or alleys is only 2 to 3 metres.

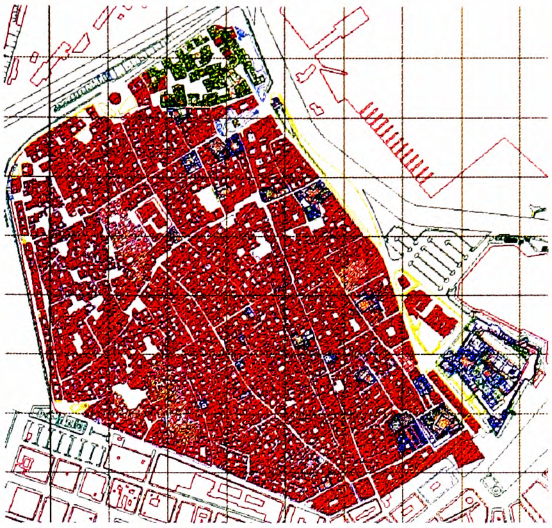


Figure 4. 58: Map of old city, Tripoli.
source : the institute of development and maintenance the old city

Most streets include flying buttresses (arches) between the opposite walls of the houses and street elevations. The function of these arches is not only to brace and support the houses but they also help to provide more shade and they break the street length (Figure 4.60). There is another feature which plays the same role as that of the flying buttresses and these are the projection of rooms (Figure 4.61). The system of streets is hierarchical in its design and planning is according to function and width. These features in the streets help in providing shaded areas, good ventilation and a cool atmosphere. They also provide a suitable place for people's daily life.

Another significant feature in the formation of the old city is the open spaces where the city has become a place of courtyards. Shawesh (2000) clarified the importance of the open spaces in the neighbourhood: it is not only their location, physical form and boundary but also how they determine and influence the people's behaviour and way of life. Their function depends on the other parts of the city and on human status and requirements. The same author classified the open spaces in the old city into four types according to the size, location and use (in terms of degree of privacy): private spaces (house courtyards), semi-private open spaces, semi-public spaces and public spaces.

The principles shaping the old city have helped to minimise the thermal load on the building envelope and to provide comfortable conditions even in the summer time.

Figure 4. 59: The compact city.
source; Mirathlibya.Blogspot.Com

Figure 4. 60: The flying buttresses.

Figure 4. 61: An example of a projection room.

4.4.3.5 Tripoli courtyard house

Most Tripoli courtyard houses are attached on two or three sides. The majority of the houses consist of two storeys usually built around a regular courtyard. Single storey houses also exist. Courtyard houses consist of a number of narrow, rectangular rooms, bathrooms, kitchen, and one or two guest rooms, all oriented towards the open courtyard as shown in (Figure 4.62). The average area of these houses is around 300 square meters and the courtyard ranges in size from 70 to 100 square meters. The shape of courtyard may be rectangular or square (Amer, 2007). The dimensions of the courtyard vary; it can range in size from 3 x 4m to 8 x 10m (Emhmed, 2005). They are usually in proportion to the height of the building in order to provide enough shade for most of the summer's days.

The environment within the courtyard is also regulated for different functions at different times of the day and of the year. The houses are inward looking towards the courtyard. Rooms depend on the courtyard for almost all their light and for air circulation, sometimes in conjunction with small high-level slit-like openings in the extended wall. On the second floor the windows are generally large and obscured by *Mushrabiyeh* to maintain privacy and let to light and airflow into the house. Shawesh (2000) clarified that great attention was paid to the interior space of the house rather than to the exterior facade. The richest details of decoration can be found, for example, in the main bedroom which can be very well furnished and decorated.

The main traditional house components were summarised by Shawesh (2000) as follows:

1- Main entrance - situated in such a way that men or strangers cannot see into the interior spaces.

2- Guest room - located close to the main door. It is usually square in shape and its windows open on the outside (not into the internal courtyard).

3- Salah- mainly used by family members or relatives and women for daily activities.

4- Internal courtyard- usually rectangular or square in shape, to which all rooms open

5- Bedrooms - these rooms are separated from the main entrance and their size varies between 2.5-3m x 5-6m.

6- Kitchen - which is usually located in the south facade of the courtyard. Its windows are situated at a high level.

7- Toilet - also with a window located at a high level.

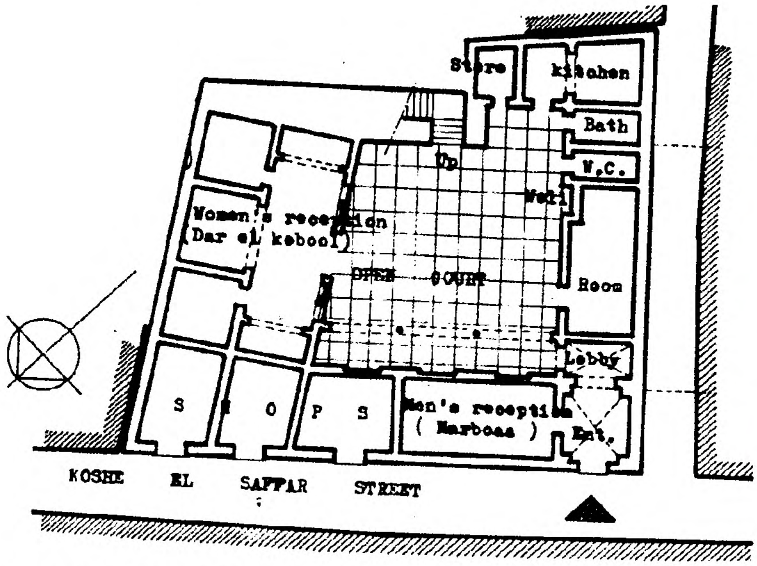
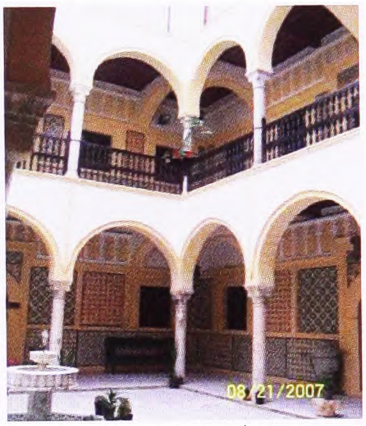


Figure 4. 62: traditional two story courtyard house



Typical courtyard house.

Source; Almansuri (2000)

To reduce the effects of heat and glare on the home and its occupants, the courtyard might have trees, water pools and/or wells and awnings. Rooms are further protected from the rays of the sun by the building of a loggia along one or more sides of the courtyard (Figure 4.62). The courtyard is usually entered from one corner through a veranda. The upper floor has a similar veranda with arches surrounding the courtyard to provide access into the rooms on the first floor. The interior layout of the house was essentially designed to maintain the privacy of the female members of the family from the view of male visitors.

4.4.3.6 Social function of the courtyard

The effect of religion and social interaction on local architecture can be observed in two ways. Islamic religious teaching encourages privacy and modesty, and courtyard houses help to fulfil this condition by providing an inward-looking house. In addition to climatic functions of the courtyard serves many other functions, as summarised by Amer (2007) as follows:

1- Providing ventilation & air movement to cool rooms.
2- Providing natural light and shaded areas.

3- Providing privacy.
4- Providing a quiet place which offers good protection against the passage of heat and street noise.
5- Providing a space for the family to gather after sunset. It is also used as an area for activities during weddings and when meeting friends.
6- Providing an ideal safe area for babies and children to play in where their mother can easily watch them.

4.4.3.7 Construction methods and building materials

Traditional house design in Libya depended on the natural resources available locally for building material. All the construction materials such as limestone, sand, stone, mud and sun dried brick were locally available and used in the walls (more than 70cm thickness). In the roof plants were used such as palm-tree trunks (used as beams with maximum length of 2.4m), pine timber joists, palm tree stems and fine concrete earth or mud were also used (Figures 4.63 and 4.64). These types of building materials restricted the height, width and shape of the housing. These constraints also gave traditional houses in Tripoli a sense of consistency in their scale, height, width and external shape (Almansuri, 2000).

El-Fortia (1989) stated that the walls and roofs in the traditional buildings were made of very thick material and that the roof was covered by a mortar layer, followed by a layer of mud; both were constructed from local materials that offered a high degree of resistance to the heat such as limestone, The other way to respond to heat was by painting the roof and external surfaces in white which reflects solar radiation.

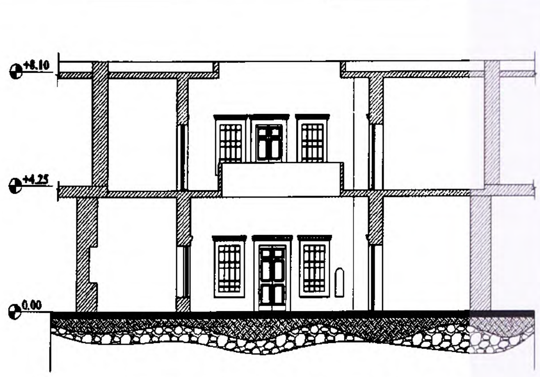


Figure 4. 63: Section of a traditional house in Tripoli.
Source: Elwefati et al., (2009)

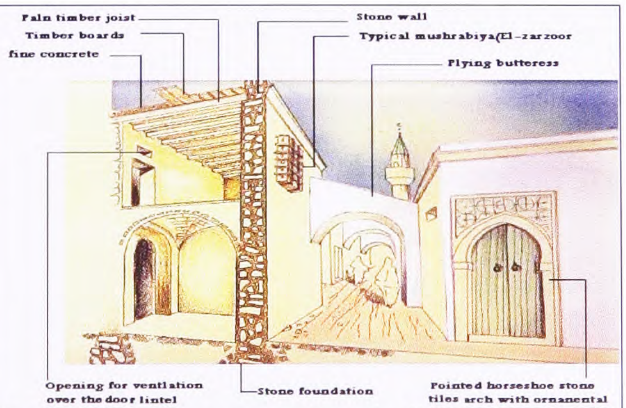


Figure 4. 64: A cross-section of alley and building materials in traditional city of Tripoli.
Source: Amer (2007)

4.4.3.8 Thermal performance of traditional courtyard houses

To achieve optimum comfort and energy savings and to modify the internal climate of the building in reaction to the external climate, the building envelope should integrate the design of building form and materials as a total system in order that heat transference can travel through it. In a Tripoli courtyard house high temperatures and extreme solar radiation as well as high humidity on some days in summer time and the extreme cold and rainfall, all create the climatic conditions that affect its interior design. The results of this study show that the open courtyard house recorded the lowest indoor temperature in the summer times and the highest indoor temperature in winter times. As can be seen in (Figure 4.65), case study number 2 (the open courtyard house) offers a better indoor environment than the other case studies (for more details, see chapter 6).

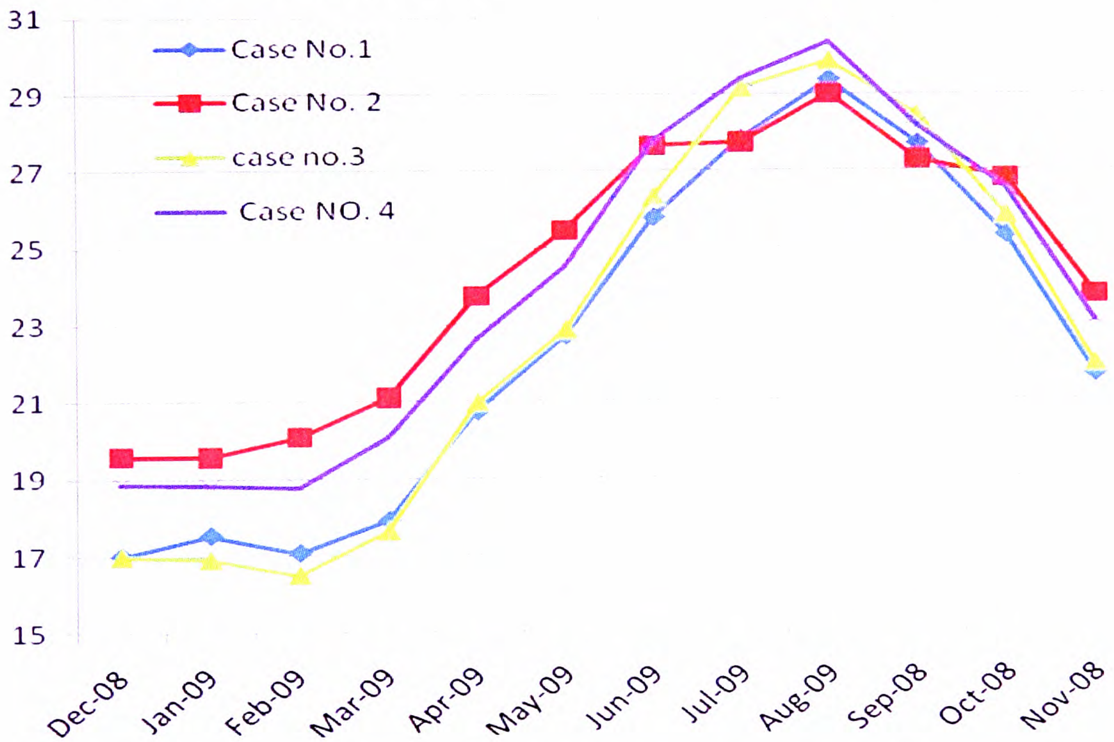


Figure 4. 65: Indoor temperature measured in 4 different case studies in Tripoli.

4.4.3.9 Discussion on the development of the courtyard

Despite the huge belief that the courtyard is the ideal solution in hot climate regions, some authors have argued that the success of the courtyard depends on integration with other factors. For instance, The Center for Desert Architecture and Urban Planning (CDAUP) (2008) stated that the success of courtyards in creating a good microclimate depends on their detailed design, requiring careful attention to a range of factors including geometry, finished materials, and the use of vegetation. To achieve a suitable and satisfactory courtyard building Muhaisen et al. (2005) stated that special arrangements should be made at the design stage. This includes the internal envelope's finishing and materials as well as the proportions of the physical parameters of the courtyard form. And finally Edward et al., (2006, 231,22) argued that climate is not the underlying reason for the building of courtyard houses and gave an example of Milan and Aleppo where they share this same building type but not the same climate. However, they stated that "*The courtyard is after all a tradition which over the past century has come under three great threats - war, earthquake and globalization - yet remains vibrant and relevant*".

From the above discussion and from the results of the field study and the opinion of the residents, it was discovered that many reasons raised were given for covering the courtyard and they are as follows:

- The position of the courtyard in the middle of the house is not always appropriate; it is difficult in both summer and winter time to move from one room to other.
- It adds extra room with a large area.
- It is difficult to use air conditioning in a courtyard house.
- Many people want to emulate the modern type of housing and see their own houses as old fashioned.
- People associate the courtyard house with poverty, slum areas, a lack of facilities, outmoded style and inadequacy of services

By observing some covered courtyard houses in Tripoli, it could be seen that some problems accrued as a result of covering the courtyard. These are as follows:

- Lack of lighting and air movement.
- Increase in the percentage of humidity.
- Increase in the percentage of temperature.
- No connection to the outdoors
- Loss the aesthetic and climatic features (trees and fountain)

From the above discussion, and in order to understand the advantages of courtyard houses and contemporary houses (to take advantage of these considerations in future housing) these advantages are summarized in Table 4.7.

Table 4. 7: Advantages of the courtyard and current houses.

Advantages of the courtyard	Advantages of current houses
• It provides air movement & ventilation. • It provides natural light and shaded areas. • It provides the privacy, particularly from the streets, neighbours and visitors when compared with contemporary housing. • It is a quiet place, which offers good protection against the passage of heat and street noise. • It is a space for the family to gather after sunset. It is also used as area for activities such as during a wedding or meeting friends. • It allows children greater safety in terms of their playing area, where their mother can easily watch them.	• They offer different spaces for varied functions such as Arabic and western salons. • The superior quality of the finishing. • The good arrangement of the interior space. • More privacy is offered in terms of separation between brothers and sisters. • There is greater potential for future extension and adoption than in traditional housing. • They are more structurally stable.

In terms of future housing design, Amer (2007) and Almansuri et al. (2009A+B) identified that new housing design should consider the following:

- Combining the advantages of traditional and contemporary designs.
- Taking the courtyard concept as an essential element in design (using appropriate building materials, proportions that can provide adequate shading, an appropriate position, providing a movable cover to avoid excessive summer heat and winter rain. A solarium house can also be a good solution and a courtyard can be used as a solarium when using moveable covered windows).
- Flexibility and harmony suitable for modern furniture.
- Avoid large windows and small balconies which are not generally used in most houses because of social-cultural and climatic reasons. Where balconies are used for shading should be provide, and for privacy reason, a large part of them can be covered by musharbiya.
- Use local building materials with modern technology and new insulation materials.
- The design should be suitable for its geographic location and reflect the local identity and social-culture aspects.
- Use light colours which reflect the sun's rays.
- Avoid high rise buildings.
- The contribution of users in the design process is important to fill the gap between designers and users.
- Pay attention to economic factors and the cost of materials.

4.4.3.10 Lessons can be learned

The results from previous Libyan vernacular housing examples show that people have, for many centuries, adapted their buildings to a harsh climate. All the solutions offered by vernacular houses have been very successful in their regions. However, because of changes in life style, improvement in building materials and development of building technology, these solutions (as they were) cannot meet current human needs, but lessons can still be learned from vernacular architecture. These solutions can be improved to meet today's needs, as shown in (Table 4.8) which provides lessons from desert region and (Table 4.9) which shows lessons from coastal region. (Table 4.10) summarises the performance of buildings against the bioclimatic needs in the three regions.

Table 4. 8: Design strategies in hot arid regions (desert).
Source: Almansuri et al., (2008)

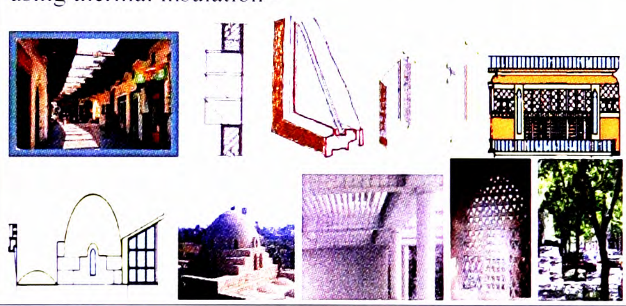
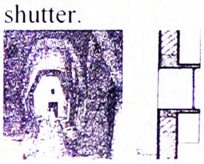
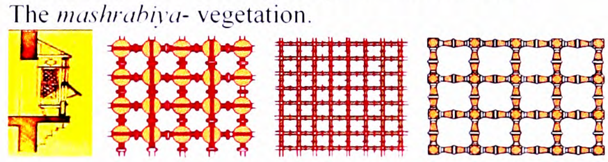
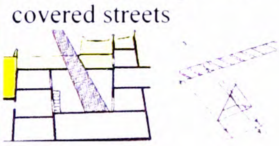
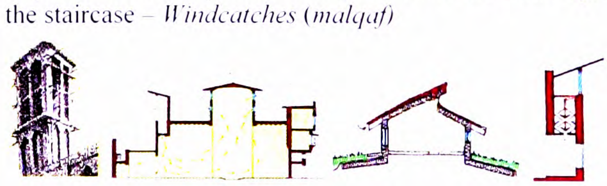
The problems	Traditional solutions	Proposed solutions
protection from the heat and sun-	Compact city – covered streets- small openings- bright colours- Thick walls- local materials 	Shading devices and vegetation to shade streets- appropriate proportion between buildings heights and streets width- bright colours, double glazing, small openings, Sun-breaker, arching the roofs, shading the roofs, improving the local materials and using thermal insulation - 
protection from dust	Compact city – wood shutter. 	wood shutter on small openings -ventilation blind The *mashrabiya*- vegetation. 
ventilation	Roof opening- the staircase- small openings in the covered streets 	Improve the roof opening -The position of the small openings- the staircase – *Windcatches* (*malqaf*) 
Lighting	Roof opening- small opening – the staircase – using mirrors and metal – bright colours	Improve the roof opening -the position of the small openings – bright colours- using mirrors and metal 
Humidity		Use the fountain inside the buildings and in the open spaces.

Table 4. 9: The advantages and disadvantages of the courtyard house and lessons learned in hot humid regions (coastal)

	Advantages	Disadvantages	Proposed solutions- Lessons learned
Urban planning	The closely compacted houses serve as barriers to sun and sand and act as spheres of family privacy. Projecting rooms over narrow streets and flying buttresses support houses and create shadow on the walls. A single façade facing the narrow streets, minimised exposure to direct heat.	The narrow streets are not suitable for the use of cars. Lack of most basic amenities and facilities.	Shape, minimum interaction between the exterior and interior and use courtyards to provide air and light. Use the projecting rooms, shading devices and vegetation to provide more shaded areas.
Position	Central courtyard provides light and air to all other spaces.	Difficulties in circulation in the summer and winter time.	Use the courtyard as an internal garden and use new materials and technology to cover and open the central courtyard when needed.
Size	Ideal proportion in size to the height could provide a shaded area all the time.	If the size is too big or too small, it will not work as a thermal modifier.	Use the appropriate size of courtyard and shading devices & small openings
Climatic factors	Provide light and air. Temperature control, natural ventilation reduces potential control of daytime interior temperature. The height of ceiling is usually up to 4m with a small opening in the top to help circulate the air.	In the winter season rain can enter a courtyard. In the summer season glare can be a problem.	Possibility to cover the courtyard when needed. Small windows, add wind towers which works by providing a shaft of air. Shading devices such as *Mushrabiyeh,* arcades, and projecting roofs provide shaded outdoor living spaces, & ensure air ventilation.
Social factors	The fundamental characteristics of the courtyard houses are in line with the family's tradition of being isolated from the public and its need for a private family life.	Noise from the courtyard reduces the comfort inside the rooms.	Noise insulation, change the position of the courtyard Use *Mushrabiyeh.*
Building materials	Heavy materials delay the transmission of daytime heat depending on the thickness of the walls. The high heat storage capacity of thick walls reduces the impact of radiation.	The exposure of exterior walls to radiation.	Improve local materials, use thermal insulation, reflected surfaces & double-glazed windows. Use *Mushrabiyeh.*
Landscape	Greenery and water enhance the microclimate created by the courtyard and create a healthier and more enjoyable environment.	The shortage of water sources.	Use plants & fountains to create a shaded area and pleasant place.

Table 4.10: Buildings' responses to the bioclimatic needs in the three regions.
Source: Elwefati et al., (2009)

Bioclimatic Characteristics		Tripoli (coastal area)	Ghadames (desert area)	Ghariyan (mountainous area)
Urban Design	a) To prevent penetration of solar radiation and provide shade	• Clustered houses • Narrow streets • Flying buttresses	• Clustered houses • Narrow streets • Covered Streets	• Dug into the ground
	b) To provide ventilation and cooling	• Winding streets to circulate wind	• Winding alleys	• Dug into the ground
	c) To prevent hot winds and sand from the desert		• Planting trees around the city	
Architectural Design	a) To regulate the air movement comfort of the house	• The open courtyard (Fig 8)	• Only door to the main room opens into the street • Small openings in the roof	• Small door openings into courtyard
	b) To keep indoor environment constant			• The underground dwellings, known as "Troglodytes"
Building Materials	a) Wall construction	• Lime stone	• Mud brick	• Sand stone
	b) Roof construction	• Timber and lime stone	• Palm branches and rubble stones	• Olive branches and rubble stones

It can be gathered from the data garnered from the theories; the opinion of the professionals and some of the householders who were still living in the courtyard houses in Tripoli; as well as from the temperature measurements in the selected case studies, that the courtyard house is important as an ideal climatic solution in the hot regions. However, these courtyards will probably not work unless some other factors as shown in Figure 4.66 exist, such as the following;

1- The position of the courtyard in the centre of the house should be changed to avoid having to cross them all the time. New technology can be used to provide the possibility of covering the courtyard and opening it when necessary.

2-The walls surrounding the courtyard should have a good thermal resistance and a long thermal time lag.

3-The courtyard should include trees and a fountain to provide shaded areas and evaporation.

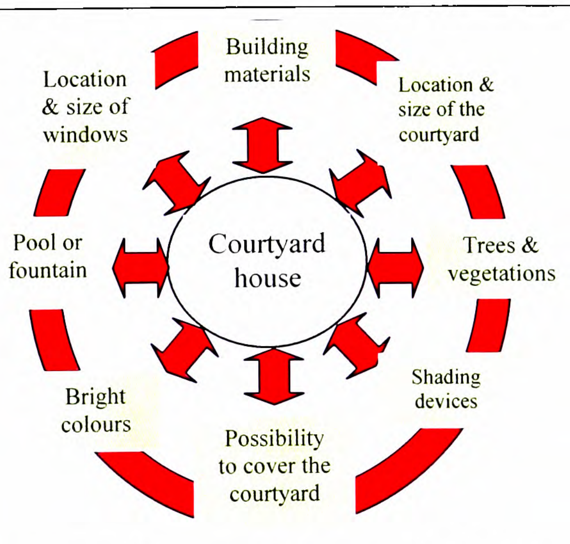


Figure 4.66Figure 4. 66: Factors affecting the performance of the courtyard.
Source: After Almansuri et al., (2009 A)

Building material is one of the important factors that should be taken into consideration in future housing and more specific studies are needed to specify the better type of building material that can be used for a specific place. Table 4.11 classifies the building materials used in vernacular and contemporary houses in three different locations.

Table 4.11: Building material used in traditional and contemporary houses.
Source: Elwefati et al., (2009)

	Region	Main building material	Binding material	Plastering material	Additional materials
Walls	Tripoli *Traditional*	Lime stone	Lime Cement mortar	Lime Mortar cement	Steel bar between spans
	Gharyan *Traditional*	Sand stone Rubble stone	Mud Cement mortar	(Gypsum Cement) mortar	-
	Ghadames *Traditional*	Mud brick Volcanic rocks	Mud Cement mortar	Lime Gypsum	Lintel wood for fenestration
	Libya *Contemporary*	Masonry units	Cement mortar	Cement mortar	Reinforced beams for lintel
Roof	Tripoli *Traditional*	Lime stone Timber	Lime Cement mortar	Lime Mortar cement	Steel bar between spans
	Gharyan *Traditional*	Rubble stone Olive branches	Mud Cement mortar	(Gypsum Cement) mortar	-
	Ghadames *Traditional*	Rubble stone palm branches	Mud Cement mortar	Lime Gypsum	-
	Libya *Contemporary*	Hollow clay pots precast tie beams	Cement mortar	Cement mortar	Pre-cast tie beams

4.5 SUMMARY

This chapter investigated and reviewed Libya's background from geographical, historical, climatic and cultural perspectives. The review intended to clarify how these aspects affected housing. In addition, it explored contemporary public and private housing and also explored vernacular housing in three different locations (desert, mountain and coastal) with a greater focus on Tripoli as a case study and on its courtyard houses. By exploring and comparing their respective features, it was hoped to learn lessons that can help in developing future housing in Libya.

This chapter clarified that Tripoli is located in a hot humid region and more attention should be given towards passive solutions such as good orientation, ventilation, shading devices and vegetation; all these can help in regulating internal thermal comfort. Some of these solutions are presented in addition to the solutions provided by vernacular houses. This chapter also states the reasons given for covering the courtyard and the problems that accrue as a result of covering the courtyard and has suggested some ideas for re-using the courtyard in new architecture. The chapter shows that a traditional courtyard house is an advanced structure that offers successful social and climatic solutions. Climatically, the open-air interior courtyard performs an important function as a modifier of climate in hot arid areas. During the daytime it allows for outdoor activities to be carried out protected from the wind and the sun; at night it serves as an air well that provides a cool breeze. The thick and nearly solid external walls surrounding the spaces around the courtyard also have a dual function, to withstand severe elements like hot sandy winds on the one hand, and to minimise the penetration of the sun's direct rays to the living spaces on the other.

Therefore, it can be assumed that the courtyard is mainly a result of physical and behavioural factors. Through an analysis of Tripoli's traditional dwellings one can clearly observe that the design and use of the courtyard do reflect a compound interaction between diverse environmental and cultural aspects.

From a climatic point of view, the courtyard offers necessary shade to the rooms in summer since it is usually surrounded by arcades, while in the winter it offers a warm place. The courtyard protects the families from the harsh climate, as well as offering daylight and natural ventilation to the surrounding spaces. Accordingly, the courtyard house remains an appropriate built form and it could still fulfil the requirements of a contemporary lifestyle if redefined and considered in the light of technological and socio-economic changes.

CHAPTER FIVE

CHAPTER ONE:	INTRODUCTION
CHAPTER TWO:	SUSTAINABLE DEVELOPMENT
CHAPTER THREE:	CLIMATIC DESIGN
CHAPTER FOUR:	LIBYA- GENERAL BACKGROUND
CHAPTER FIVE:	RESEARCH METHODOLOGY
CHAPTER SIX:	ANALYSIS OF THE FINDINGS OF THE QUESTIONNAIRE, INTERVIEWS AND TEMPERATURE MEASUREMENTS
CHAPTER SEVEN:	THE FINAL CLIMATIC DESIGN GUIDELINES FOR HOUSING
CHAPTER EIGHT:	CONCLUSION AND RECOMMENDATIONS

CHAPTER FIVE: RESEARCH METHODOLOGY

5.1 INTRODUCTION

This chapter explains the approach to the research questions. It identifies the research methodology as a major step in the research process as it is very important to be able to identify and develop the appropriate research methodology for the research questions. This will allow integration of methods, experience, tools, producing and dealing out in answering the research questions to achieve an accurate expression of knowledge based results and conclusions. Chandler (2004) defined methodology as a key element in any thesis. It refers to the choice and use of particular strategies and tools for data gathering and analysis. The methods of research provide data which in its raw form is normally unstructured but tends more often to be substantially detailed allowing its richness of content and scope to be rigorously examined.

Fisher (2004) views methodology as a study of methods and raises the questions about the researchers need to know and how suitable their claims to knowledge might be. According to Berry (1983) research methodology is not just about data collection and the rules for evidence, it is more about the nature of explanation and the means by which explanations are produced. However, there is no one universally accepted scientific methodology, but rather a combination of methodological paradigms is used to form the methodology of the research undertaken. In such a way, every methodology is unique and applicable only for its intended purpose. Therefore, considering the above issues, it becomes clear that the methodology used for the research needs to be sympathetic to the issues being investigated.

Kagioglou et al (1998) proposed a 'nested' research methodology which integrated into three main themes; research philosophy; research approach and research techniques. Sexton (2007) summarised nested methodology as shown in (Figure 5.1).

Research philosophy:

- Ontology – What knowledge is?

Assumptions that we make about the nature of reality

- Epistemology - How we know it?

General set of assumptions about how we obtain and accept knowledge about the world

• Axiology – What values go into it?

Assumptions about the nature of values and the foundation of value judgments.

Research approaches:

• How the knower goes about the task of knowing

• Dominant theory generation and testing methods

Research techniques:

Individual techniques for data collection and analysis.

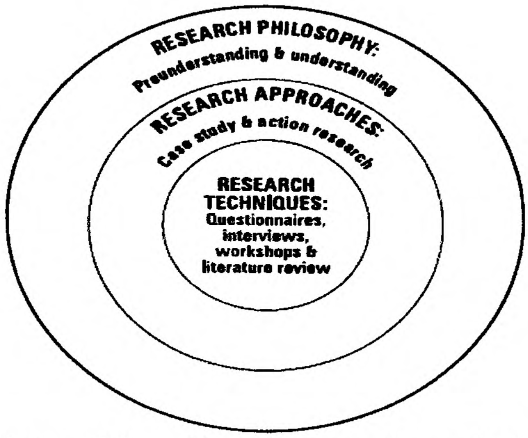


Figure 5.1: Nested research methodology. Source : Aouad (1999)

Saunders et al., (2003) improved the model of Kagioglou et al., (1998) and identified a further two layers within the process of research as shown in (Figure 5.2) They stated that research process like an 'onion' with five layers. The external layer is research philosophy, after that the research approach, the third layer is research strategy then time horizons and finally data collection. This model proposed an approach that flows from research philosophy to research approach and then to research techniques (Saunders et al., 2003).

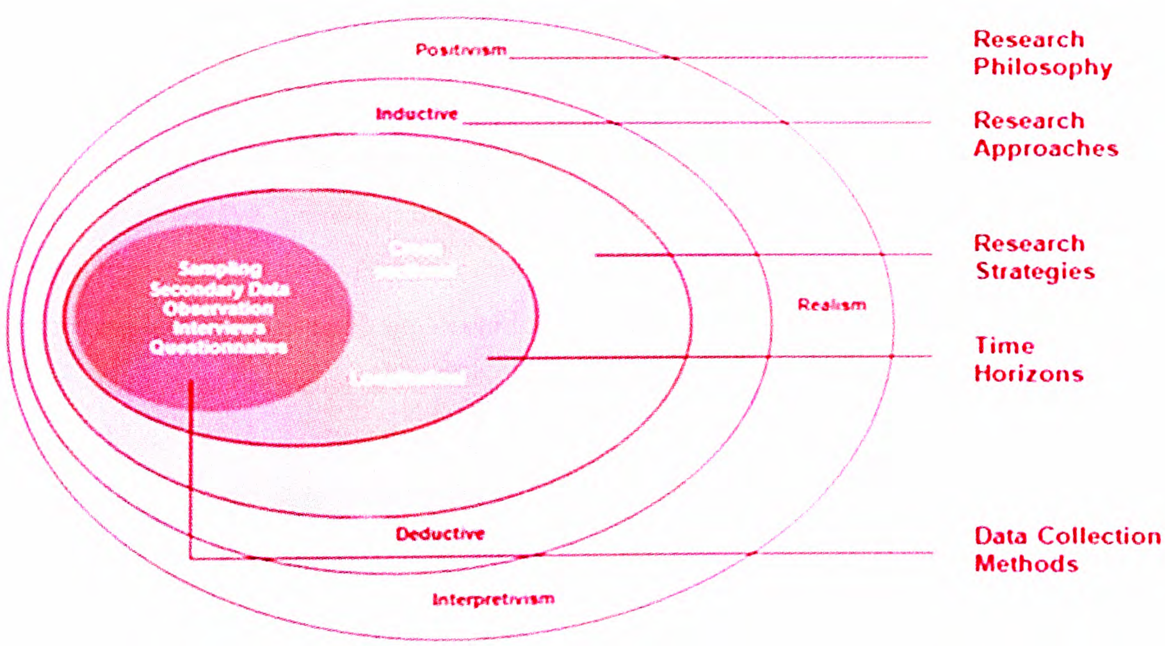


Figure 5.2: Research process 'Onion'. Source: Saunders et al., (2003)

Saunders et al., (2007) improved the research onion to include an extra layer which is research choices that includes mono-methods, mixed-methods and multi-methods.

Easterby-Smith, et al., (2002) pointed out some definitions of common usage terms in the research field; ontology, epistemology, methodology, and methods as illustrated in (Table 5.1).

Table 5.1: Ontology, Epistemology, Methodology, and Methods.
Source: Easterby-Smith et al., (2002)

Ontology	Assumptions that are made about the nature of reality
Epistemology	General set of assumptions about the best ways of inquiring into the nature of the world.
Methodology	Combination of techniques used to enquire into a specific situation
Methods	individual techniques for data collection, analysis, etc

This research examines the influences of climate in designing housing in Tripoli- Libya and aims to provide guidelines for architects to design more climatic housing in hot regions. In order to understand the quality of buildings and meet the physical and environmental needs, a research methodology needs to describe the overall approach used to generate new knowledge, based on research philosophies to enable this knowledge generation. The next section will clarify the research philosophy adopted in this research.

5.2 RESEARCH PHILOSOPHY

Research philosophy can help to classify the type of evidence required, how to gather it and how to understand it in order to find an answer to the basic problem under investigation. Easterby-Smith et al, (2002) clarified that reference to research philosophies will enable the researcher to resolve the research questions by identifying, adapting or even creating research designs that projects beyond one's own experience and that knowledge and the failure to understand and think through philosophical issues can have a negative effect on the quality of the research outcome. They give three reasons explaining why it is important to understand philosophical issues in organisation research. First, such understanding helps to clarify research designs which include what kind of evidence is required and how it is to be gathered and interpreted and also how this will provide answers to the basic questions being investigated in the research. Second, knowledge of philosophy helps the researcher to recognise which designs will work and which will not.

It should indicate the limitations of specific approaches. Third, it helps the researcher to identify, and even create, designs that may be outside the past experience of the researcher.

According to Baker (2001) there are basically two contrasting extremes in research philosophies known as positivism and interpretivism. However Saunders et al, (2003) expands the categorisation of philosophies by identifying another dimension of philosophy, named realism which falls within the two extremes.

The positivist approach focuses on developing and testing hypotheses and generalising research findings from data, whereas the interpretivism approach aims to develop a deeper understanding of ambiguous and multidimensional concepts through exploratory techniques (Easterby-Smith, 1991). Philosophers of science and methodologists have been engaged in a long-standing epistemological debate about how best to conduct research. This debate has centred on the relative value of two fundamentally different and competing schools of thought or inquiry paradigms (Amaratunga et al., 2002). Easterby-Smith et al., (1991) defined the main two approaches, positivism and phenomenology, as follows;

- Logical positivism uses quantitative and experimental methods to test hypothetical-deductive generalisations.
- Phenomenological (Interpretive) Science inquiry uses qualitative and naturalistic approaches to inductively and holistically understand experience in context specific settings. This approach tries to understand and explain a phenomenon, rather than search for external causes or fundamental laws.

The same authors summarised the main differences between the positivism and the phenomenological viewpoints in (Table 5.2).

Table 5. 2: The two schools of science. Easterby-Smith (1991)

Approach	Concepts	Methods
Positivism	Social structure Social facts	Quantitative Hypothesis testing
Interpretive science (phenomenological)	Social construction Meanings	Qualitative Hypothesis generation

Sexton (2007) clarified the relation between the approaches and location of some common methods in (Figure 5.3).

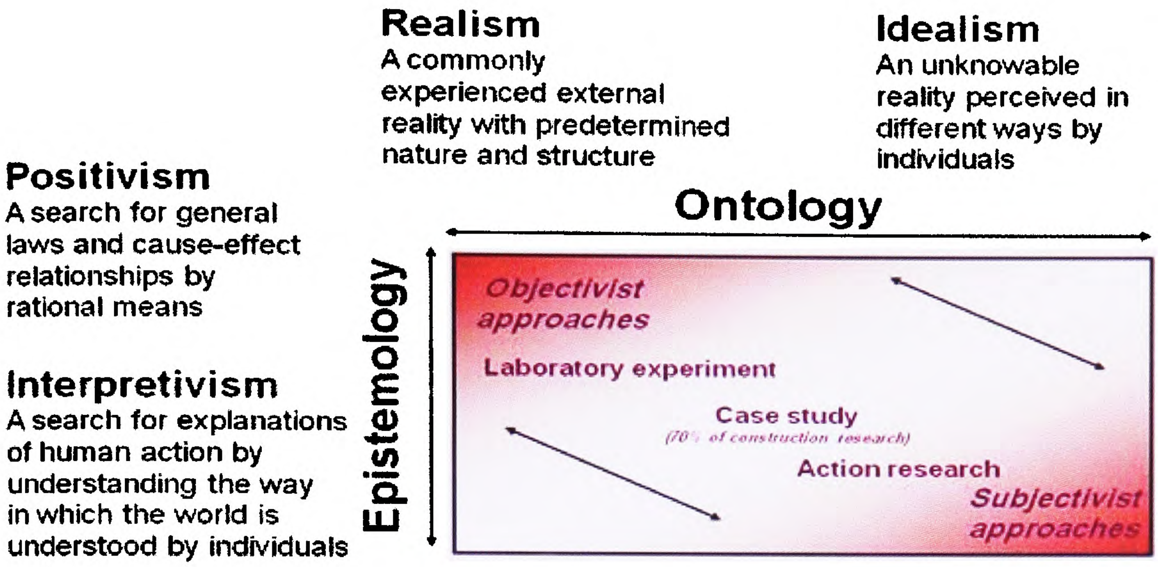


Figure 5. 3: Research philosophy and its relationship with some common methods.
Source: Sexton (2007)

To sum up, each of these philosophies relies on different concepts and methods for conducting research. It is therefore necessary to start through philosophies which can help to find out the most appropriate method to conduct the research at the very early stages. The positivist approach tends to employ more deductive quantitative methods such as experiments and surveys, whereas the Interpretivism approach tends towards the more qualitative methods such as observation, in-depth interviews and group discussions.

Both Positivist and Interpretive approaches have their advantages and disadvantages as long as that the researchers must be prepared to take advantage of every situation surrounding the research process. The selection of one paradigm or the other or even both may be determined by the nature of the problem. The interpretive paradigm has been adopted to meet the requirements of this research, however, to reduce the biases inherent in the case study strategy (see page 189), the positivist paradigm was used to support the main paradigm where appropriate.

The main reason for using both paradigms is that the subject is supported by an extensive theoretical background, focusing on the level of peoples' satisfaction and housing preferences together with the measurement of thermal comfort inside houses. The Interpretive paradigm was chosen for this study to understand the householders' satisfaction with both traditional and contemporary housing in terms of the internal microclimate. Also, to explore the opinions of design and construction professionals in terms of climatic design of modern housing for Tripoli society.

The Positivist paradigm was chosen to explore reasons underlying the covering of courtyards by residents where theories and professionals confirmed that the courtyard house is the best climatic solution in hot regions. It has been used to investigate the internal thermal comfort in traditional and contemporary housing in Tripoli by sampling the temperature inside four selected houses from two areas " the old city area and the contemporary city area". The research approach adapted in this research is explained in the next section

5.3 RESEARCH APPROACH

Saunders et al., (2003, 2007) stated that research approach strategies can be divided into deductive and inductive approaches. The deductive approach is used to search for causal relationships between variables through deducing a hypothesis, and that generalisation of the theory will not be expected as the inductive approach would be particularly concerned with the context of the research. In more detailed analysis Sutrisna (2008) summaries deductive and inductive research approaches as follows;

In the deductive approach:

- Start by analysing the literature to provide the context for the research;
- Identifying gaps between existing theories or evidence;
- Formulating a hypothesis;
- Data collection followed by the analysis resulting in the findings.

In the inductive approach:

- Inductive research open to any possible results;
- The literature review is not recommended in the early phases in certain methodologies, such as the grounded theory methodology, as it may influence the stance of the researcher;
- Develop explanations and theories from the observations of the empirical world;

In order to achieve specific research objectives, a combination of research approaches may be more effective (Figure 5.4), Saunders (2003) states that combining the two approaches is possible as it will enable the researcher to collect benefits from both.

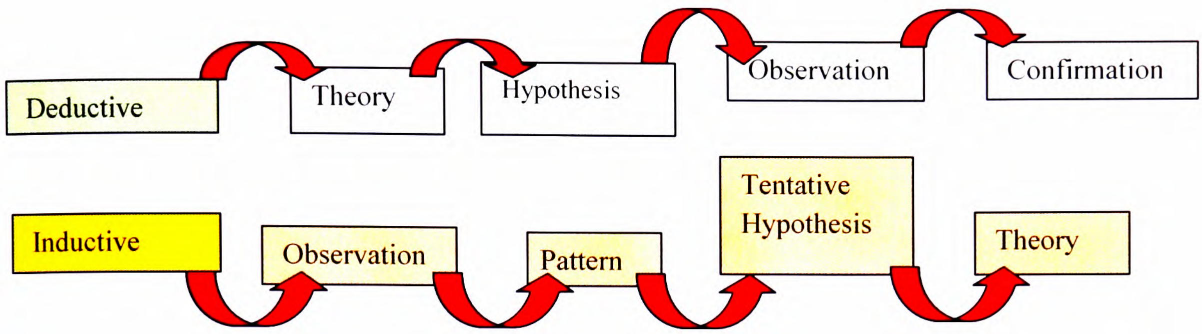


Figure 5. 4: The different between the deductive and inductive approaches.
Source: Almansuri et al., (2009 B)

A combined research approach (inductive and deductive) was selected for this research. In this research, a theoretical framework was first confirmed from the existing literature which was then investigated in the case studies. Although this area is particularly well theorised, there is scope to improve theoretical framework of climatic design.

5.4 RESEARCH STRATEGY

Research strategy is used to structure the research, to show how all of the major parts of the research project work together to try to address the central research questions. Naoum (2007, 37) states, "*research strategy can be defined as a way in which research objectives can be questioned*". In the same reference the author identifies that the choice of strategy should be dependent on the research topic.

'*Deciding on which type of research to follow, depends on the purpose of the study and the type and availability of the information which is required*' (Naoum, 2007; 37). Robson (2002) defined a research strategy as an empirical examination of a particular contemporary phenomenon within the real life context using multiple sources of evidence. Jankowicz (2000) identified the research strategies as the research methods and suggested four methods (archival method, the case-study, the survey and the field experiment).

5.4. 1 Case study

Yin (2009) stated that case study is one of five methods of research, these different types being experiment, survey, archival analysis, history, and case study. The use of a case study approach has become extremely widespread in social science research. However, as in all approaches case study has strengths and weaknesses.

In more detail, Yin (2003, 2009) explained that case studies were used because the authors simply wanted to cover contextual conditions, believing that they might be highly relevant to the phenomenon of study. In addition to exploring the variables within the research aim and to answer study questions, multiple cases will provide large analytical benefits.

Yin (1994) clarified that case study is the preferred strategy when "what", "how" or "why" questions are being posed and when the focus is on a contemporary phenomenon within a real life context. In this regard, the research investigated how to practice climatic design in modern housing in hot climates in a way that reinterprets the best features of traditional and contemporary approaches and provides a housing architecture relevant to the environmental problems that are anticipated in the next century. Also the research aimed to clarify why we need climatic design and what are the underlying principals. Finally it answers the question 'what can we learn from traditional housing solutions that can deliver good performance for a modern society?'

Jankowicz (2000; 220) cited four stages of work that can be done in the case study as follows:

1- Determining the present situation;
2- Gathering information about the background to the present situation;
3- Gathering more specific data to test alternative hypotheses about the important factors in the present situation;
4- Presenting recommendations for action and evaluating the outcomes of these recommendations after they have been implemented.

Case studies can be single or multiple-case designs, where a multiple design must follow a replication rather than sampling logic. When no other cases are available for replication, the researcher is limited to single-case designs (Tellis, 1997).

Yin (2003) confirmed and stated that case study research could be based on single or multiple case studies. Employing a multiple or single case study approach depends on the kind of case study to be carried out.

Yin (1993) listed several examples along with the appropriate research design in each case of exploratory, explanatory, and descriptive case studies. Yin (1994) and Naoum (2007) classified case studies into three types for research purposes:

- Exploratory case studies: the theoretical approach to the problem. Sometimes considered as a prelude to social research.
- Analytical case studies: may be used for doing causal investigations.
- Descriptive case studies: require a descriptive theory to be developed before starting the project.

Therefore, the nature of this research makes the multiple case study approach the most appropriate to permit an in depth investigation of the potential causes and effects that have made Libyan vernacular houses well adapted to climate and also analyses the causes that have prevented Libyan contemporary house construction from adopting passive design technology. This was achieved by understanding householders and professionals' opinion and by observing and sampling temperatures in four selected houses. Multiple sources of data collection were employed, to provide extra input for the direction of the overall data analysis.

5.5 RESEARCH METHODS

One of the major classification systems concerned with research methods is through quantitative and qualitative research. These two systems are methods for developing the research in a way which best suits the individual research question; consequently a fair and perfect representation can be recognized. Naoum (2007) illustrates the research strategy methods as shown in (Figure 5.5).

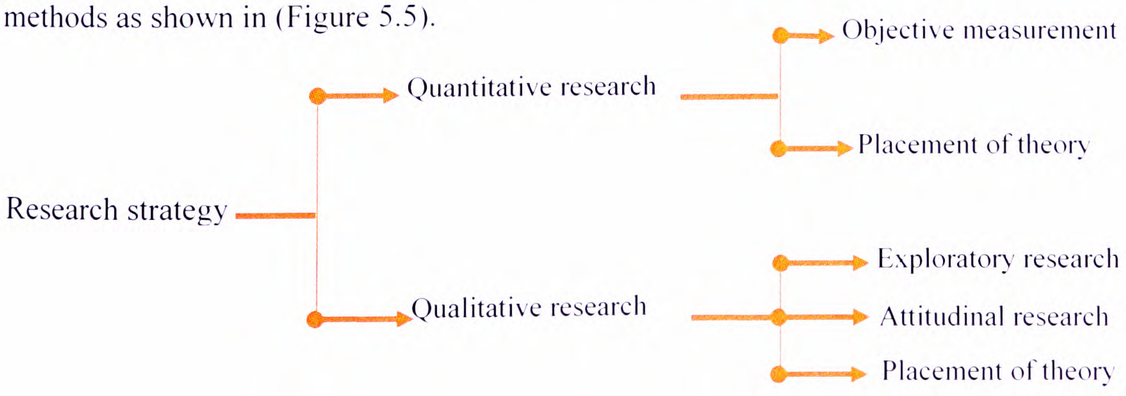


Figure 5. 5: Research strategy methods. Source: After Naoum (2007, 38)

These research methods have been subject to argument in the past as they are both used extensively within the industry and present different perspectives to viewing research and its development (Fellows and Liu, 1997). Hall and Hall (1996:45) explained that the advantages of using different research strategies and methods can solve the problems related to one strategy by the strengths of another, for instance, "qualitative studies can be used to set the scene for a quantitative survey, or to explore in more depth issues thrown up by such a survey. Combined methods which give each type of study equal weight are rarer".

This thesis uses both quantitative and qualitative research as literary and statistical data which can be researched and analysed to draw conclusions. To fulfil the aims and objectives of this research, the research is mainly qualitative with temperature measurements in buildings being quantitative. Prior to undertaking the research, it is important to understand the difference between quantitative and qualitative research.

5.5.1. Qualitative research

Naoum (2007) defined qualitative research as subjective in nature, concentrating upon experiences and opinion rather than actual enumerative evidence. All research is undertaken using two categories of research- 'exploratory' or 'attitudinal'. This helps to build upon situations where there is limited knowledge available; interviewing and generating personal opinion. By Naoum (2007; 41) in his explanation of qualitative research of an exploratory nature, "*expect the research questions to develop and change during the study….often in qualitative studies the questions are under frequent review and reformulation*".

The role of the researcher is vital in qualitative research where the background of the researcher, gender, point of view and so on, can all contribute, however, it does not mean that the personal elements can randomly affect the findings, but it does promote the view (Groat and Wang, 2002).

Qualitative research has the ability to seek and gain substantial insights and to be able to understand peoples' perceptions of the World whether as individuals or as part of groups (Naoum, 1998). In comparison to quantitative research where scientific technique are used to obtain measurements, qualitative research concentrates more towards the beliefs, understanding, opinions and views of people who are investigated. Qualitative research is subjective and the information provided is often descriptive or attitudinal. Qualitative research will be required for the case studies as well as working with the review of previous theories, interviews and questionnaires.

5.5.2. Quantitative research

The main aim of the quantitative approach seeks to collect accurate data. This type of approach to research usually adopts a scientific method in which initial study of the theory and the literature yields analysis to be measured through specific aims and objectives with a hypothesis to be tested. Some of the implications of this type of approach are the requirement to separate and provide independence of the observer from the subject topic and to initiate formulations for consequent testing and validation.

Quantitative research deals with tangible and reliable evidence and is used when facts and accurate evidence is required. It is based upon an objective nature and can be defined as , " *an inquiry into a social or human problem, based upon testing a hypothesis or a theory composed of variables, measured with numbers, and analysed with statistical procedures, in order to determine whether the hypothesis or the theory holds true*" (Naoum, 2007; 37).

The scientific approach, analysing a problem using a statistical method, would be appropriate for this type of research. All outcomes can be numerated allowing future comparison, using statistical procedures to form valid conclusions.

Naoum (2007) clarified when the selection of quantitative research is needed as the following:

- Need to find facts about an idea, a question or an attribute.
- Need to gather factual evidence and in order to test a theory or hypotheses needs to study the relationship between the facts.

5.5.3. The mixed approach

One major feature of qualitative data is that they focus on naturally occurring, ordinary events in natural settings, therefore it gives a real life view. It is useful when researchers need to discover or explore a new area, or to supplement, validate, explain, illuminate, or reinterpret quantitative data collected from the same setting (Amaratunga et al., 2002). Jankowicz (2000) confirmed this and stated that there is no simple decision rule which allows choosing one method for set of circumstances, and another for another. As it can be infer red from discussion, many different factors influence the choice. Using more than one method or technique, known as triangulation, can be by achieved using archival review, questionnaire, interviews or observation.

Hussey and Hussey (1997) mentioned that using both qualitative and quantitative methods for collecting data has many advantages; a questionnaire survey providing quantitative data accompanied by in-depth interviews to provide qualitative insights. Also Amaratunga et al., (2002:23) confirmed this and stated, *"There is a strong suggestion within the research community that research, both quantitative and qualitative, is best thought of as complementary and should therefore be mixed in research of any kinds".* (Figure5.6), illustrates the triangulation of qualitative data.

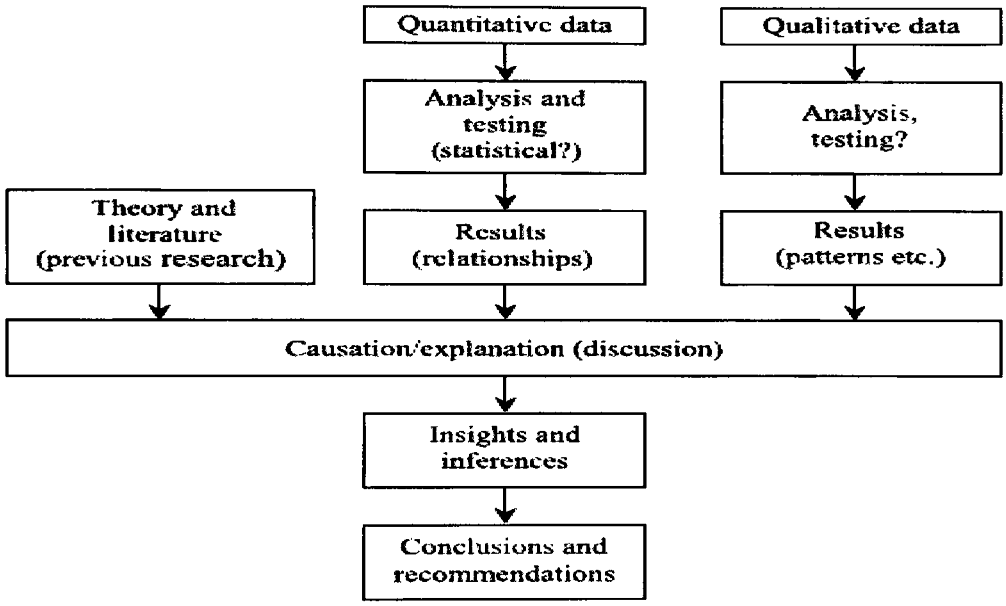


Figure 5. 6: Triangulation of qualitative data. Source: Amaratunga et al., (2002:24)

From the above clarification, it is clear that the two approaches are largely complementary and cannot be easily separated. The weaknesses of such quantitative methods lie mainly in their failure to ascertain deeper underlying meanings and explanation of the phenomenon, even when reliable and valid.

From the above discussion, the researcher has chosen both qualitative and quantitative research as the main approach for this study. This enables the researcher to dive into the real life of context; to explore the included features and factors which seems to be more appropriate in the research. The qualitative method is powerful for giving insights, findings, and recommendations. The quantitative approach is used when there is a need for using numbers and percentages in the data analysis. The quantitative approach is very powerful for gaining insights, results and in drawing conclusions. However, the use of the quantitative approach in this research was to simplify and analyse data which were provided by the measurements undertaken in the case studies that were determine using special instruments to measure the indoor temperature of local and contemporary selected houses in Tripoli (more details can be found in section 6.5). The research design adapted will be summarised in the following section.

5.6 RESEARCH DESIGN:

The aim of the research design is to satisfy the research aim and objectives and to define the methods, approaches, techniques and strategies through which the empirical research was conducted and investigated in order to answer the research questions defined in chapter one. Trochim, (2006) stated that research design provides the glue that holds the research project together. Yin (1994) defined the research design as the researcher's guidance in the process of collecting, analysing and interpreting observation. He identified five components of research design that are important for case studies:

- A study's questions;
- Its propositions, if any;
- Its unit(s) of analysis;
- The logic linking the data to the propositions; and
- The criteria for interpreting the findings.

It can be assumed that the research design must clarify the nature of how the questions will be answered, and how the researcher intends to deal with them. In addition, research design provides the plan and structure, which give the expected results an explanation. (Figure 5.7) illustrates the research design adopted in this research.

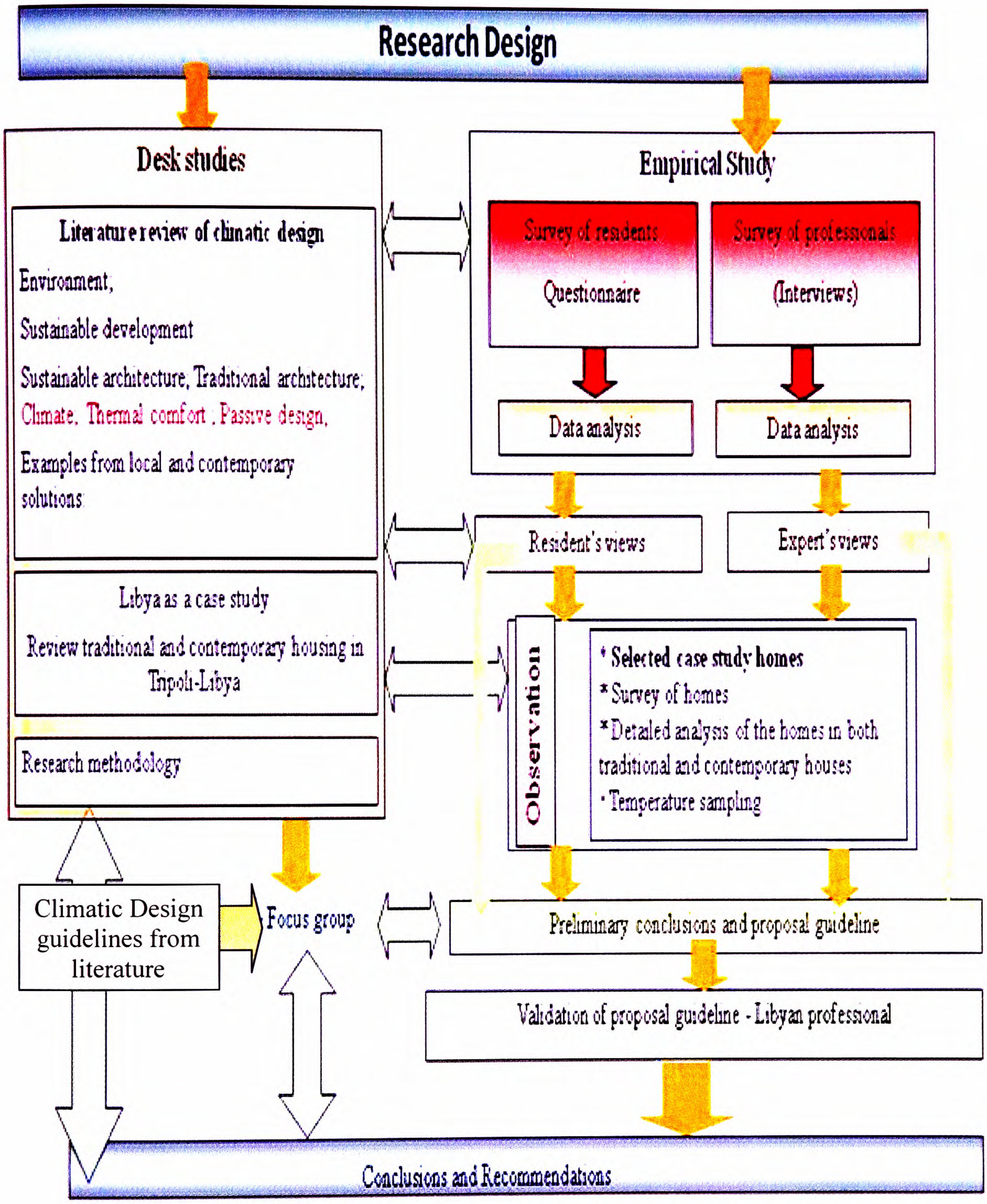


Figure 5.7: The research Design.

The next section will discuss the research techniques used in this research, mainly the methods of data collection and data analysis techniques used.

5.7 DATA COLLECTION

Data collection refers to the method that is used to collect the information required. There are two main methods of data collection that consist of 'fieldwork' research and 'desk' research; each of the two can be conducted using different sub methods. Nauom (2007) clarified that there are many ways to collect found within two headings. First, fieldwork research (primary data collection) such as a survey or case study approach; second is the desk study (secondary data collection) such as statistical or descriptive formats.

There is no single source of evidence that has a complete advantage over all the others, however, interviewing is found to be the most widely used data collection technique in a qualitative approach for its high level of flexibility and its capability of producing data of a great depth (Yin, 1994). Also triangulation can generate in-depth research findings, and wider perspectives about the research phenomena. In addition, using multiple data collection methods is particularly recommended in terms of the validity of the research findings (Robson, 2002; Yin, 1994). The case studies that adopt triangulation methods are rated more highly than those that rely on single sources of data. Moreover, multiple data collection sources can produce a more complex, holistic and contextual portrait of the phenomenon under study, and the corroboratory evidence is also likely to make the findings and the conclusions of the study more convincing and accurate, thereby increasing the validity of the study (Yin, 1994).

5.7.1 Primary and secondary data collection

The literature review not only serves as an introduction to the work but also for the provision for essential background information. Naoum, (2007) described the literature review as secondary data that can be either descriptive or statistical and which is obtained from other sources. He defined the approaches to data collection as shown in Figure 5.8.

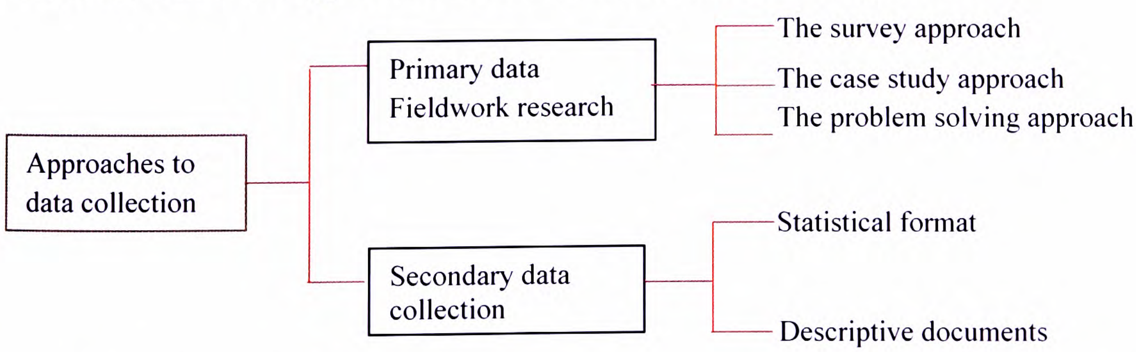


Figure 5.8: Approach to data collection. Source: author after Naoum (2007)

Yin (2003) stated that, although the research data collection will be mainly interviews and documents such as journals, it is important to ensure that biased views are not allowed to control the direction of the results and conclusions.

Fieldwork research uses primary methods of data collection achieved through surveys, interviews and questionnaires; it gathers new research and supporting evidence based upon the aims and objectives identified. Fieldwork as cited in Naoum (2007) is often considered to have three practical approaches: the survey, the case study and the problem solving approach. This can be conducted using the following:

1- Survey approach- gathering data from a large sample in a limited time frame, considering the descriptive or analytical results perspective.
2- Case studies- look in-depth at a current situation involving individuals, groups and organizations, focusing specifically on one area. This method can be descriptive, or analytical and attacks the problem theoretically which can be supported by diagrams.
3- Problem solving approach- the current situation is reviewed, a problem identified, a solution derived and appropriate changes implemented. All changes can then be evaluated in the future to measure their overall impact.

Fisher (2004, 53) listed the most frequent used research methods as:

- Questionnaires
- Interviews
- Panels, including focus groups
- Observation, including participant observation
- Documents and Databases.

Groat and Wang (2002:192) outlined the data collection tactics that can be used in qualitative research as presented in (Table 5.3).

Table 5. 3: The variety of data sources for qualitative research.
Source: Groat and Wang (2002:192)

Tactics	Interactive	Non-interactive
Interviews	In-dept interviews Key informants interviews Career histories	
Focus groups	Discussions guided to test in small groups Participants help construct the right questions	
Surveys	Multiple sorting Projective surveys (games)	
Observation	Participant observation	Nonparticipant observation stream of behaviour; Chronicles; and Field notes
Artefacts and buildings Archival documents		Art factual interpretation Archival interpretation

To sum up, fieldwork research is often referred to as primary data and data that are acquired first hand through survey, interviews and questionnaires. The desktop study is often referred to as secondary data that is obtained from sources such as text books, journals…etc. No single data collection method has a complete advantage over the other data collection methods, in fact they are often complementary. Therefore, a good case study should use multiple sources of evidence to achieve broader and often higher quality research findings. As the desktop study is a form of secondary data collection, the literature research study helps to understand the requirements, benefits and problems of climatic design. The desktop study consists of a careful review of textbooks, specialist journals, newspaper publications and electronic sources. To fulfil the aims of the study the use of secondary data also provides useful comparisons to the primary data gathered for the study.

5.8 THE PRIMARY DATA PROCEDURE

In order to achieve specific research objectives, a combination of research methods may be more effective. This research depends on using triangulation data collection (Figure 5.9) which helps contribute additional knowledge to the research and in that way different methods complement each other. Each of the different methods (questionnaire, semi-structured interviews and focus group, as well as direct observation, sampling and the collection of supporting documentation) will help capture a more complete, holistic and contextual portrayal of the cases and reveal the varied dimensions of the best way to conduct passive design in our future housing. Moreover, methodological triangulation can be employed in both quantitative validation and qualitative inquiry studies.

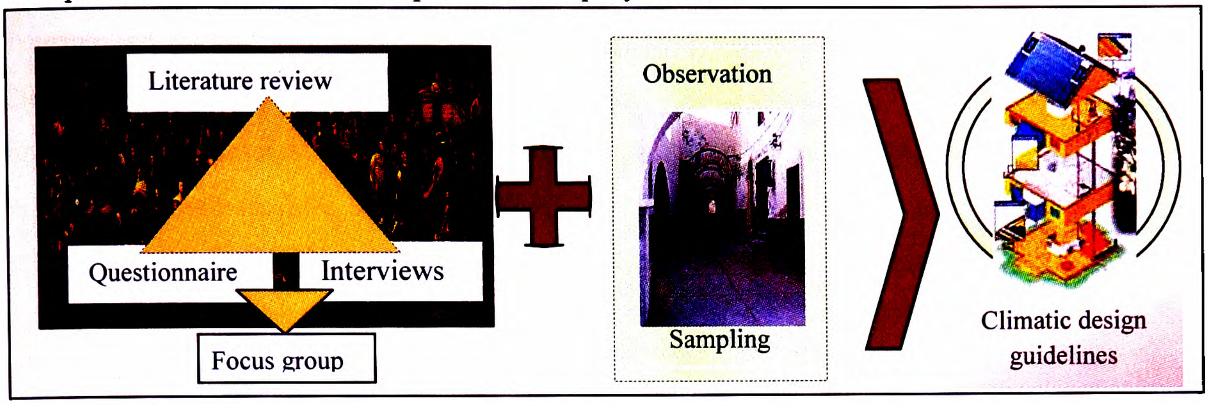


Figure 5.9: Data collection 'triangulation'. Source: Almansuri et al., (2009 B)

To achieve research objectives, an explanation of each method with more detailed data collection used in this research are clarified in the following sections.

5.8.1 Questionnaires

The use of questionnaires is one of the data collection methods widely used and commonly associated with the quantitative research approach technique. Many researchers use this type of research technique as it provides flexibility and a wide range of results which can be adapted to almost any area of research. Naoum (1998) clarified that, the essential element of a successful questionnaire is the format of the questionnaire. The questions should be very carefully worded without faults such as ambiguity, vagueness, technical expressions, difficult questions and so forth. Considerations that must be made when assessing the appropriateness of either open or closed questions are;

1. The objective of the questionnaire;
2. The respondent's level of information about the topic in question;
3. The extent to which the topic has been thought through by the respondent;
4. The ease with which respondents can communicate the content of the answer or the extent to which respondents are motivated to communicate on the topic (Naoum, 1998; 71).

The difference between pre-coded and open questionnaires has been described by Fisher (2004) as: pre-coded have lots of tick boxes for respondents to fill in, but open questionnaires have a few open questions and plenty of space for people to make their responses in their own words.

Fellows and Liu (1997) described the aim behind sampling is to provide a practical means of enabling data collection and processing components of research to be carried out whilst ensuring the sample provides a good representation of the whole population. Jankowicz (2000) explained that there are two ways that can help to draw up a sample; non-probability sampling (Accidental sampling, Purposive sampling and Quota sampling) and probability sampling (Simple random sampling, Stratified random sampling and cluster sampling). He stated that to make judgments about a specific topic, the purposive sampling which involves choosing people whose views are relevant to an issue will be useful. Similarly, Naoum (1998) suggests adopting a selective sampling approach which is generally regarded as the most suitable for undertaking interviews.

The aim of this study is to provide guidelines for architects in their use of climatic design strategies in their building projects because residents know their housing situation better than anyone else. A survey of residents was undertaken to understand their attitude towards traditional and contemporary housing in terms of their degree of satisfaction about the house design, its comfort, layout concepts, function, building materials, suitability and problems.

A selective sampling approach, 'Purposive sampling', was used in selecting respondents from the contemporary house case study area, householders were selected who lived once in a traditional house and were currently living in a contemporary house. In the vernacular area where the majority of occupants are not Libyan, the respondents selected are Libyan.

5.8.1.1 Questionnaire design

To collect the needed data that covers the key issues of the research, the questionnaire and interview questions (see appendix 1) were carefully prepared using the research aim, objectives and the relevant literature as guidance for generating the questions.

Moser and Kalton, (1979) stated that, it is important to ask people about things that they understand and are appropriate for research, accordingly, a pilot study is the surveyor's main and most useful tool.

To enhance the validity of the questions, a pilot questionnaire was designed and distributed to a number of contacts within the University of Salford including, the supervisory team, a number of academic staff in the built and human environment department and a selection of researchers who have extensive experiences in survey designs. The comments obtained from the reviewers were very helpful in improving the overall design of the questionnaire. Due to the pilot study the following modifications were made: to consider the confusions and misunderstanding regarding the wording of some questions; reduce the number of questions and improve the design form and structure of some questions. Respondents participated in the survey in order to gather their opinions on the overall design of the questionnaire, and on the clarity and relevance of the questions posed in relation to the study being investigated. Some issues were further reported such as issues related to sustainability where the respondents advised the author to simplify, ease and reduce the number of questions also adding extra clarification. Therefore, this advice was taken into consideration in the final questionnaire form to validate its content. (Figure 5.10) clarifies the survey process.

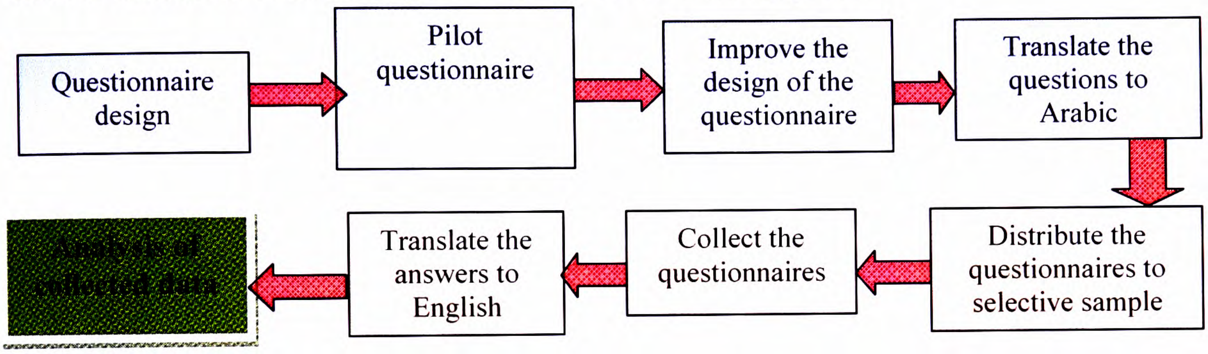


Figure 5.10: The survey process.

Questionnaires were used to collect householder's views of both types of housing, these were completed by interviews with householders from two case study areas located in different parts of the city: first, Tripoli old city and second, Tripoli contemporary city. The survey was carried out during August 2008. A 'Purposive sampling' technique was used in the survey so that the study would gain the most valuable data from specific people. 50 questionnaires were distributed in advance of the interview in the contemporary area of Tripoli and 20 in Tripoli old city. Respondents lived in a range of house types including villas, apartments, flats, small houses, etc. The strategy used in distributing the questionnaire in the old city was to visit with an officer who has been working in the area (for the institute responsible for conservation) of the old city. This was for security and social reasons, the author would have been seen as a stranger and distrusted, as well as helping in collecting the answers because the number of Libyan families in the old city is small and it is difficult to find the address of each family. The nature of conducting questionnaires in Tripoli needs explanation, accordingly, the author used contacts in each area in identifying suitable respondents and to explain the meaning of the questions. As shown in (Figure 5.11), the total numbers of questionnaires completed was 54 out of 70 distributed in the two sites. Some of the questionnaires were not completed and some of them were lost by the respondents.

The final questionnaire was divided into three main sections. Part A: General information; Part B: Housing situation; Part C: The relationship between houses and climate. The questions in the questionnaire are not the same in both areas it being designed according to the answers needed and included 15 questions.

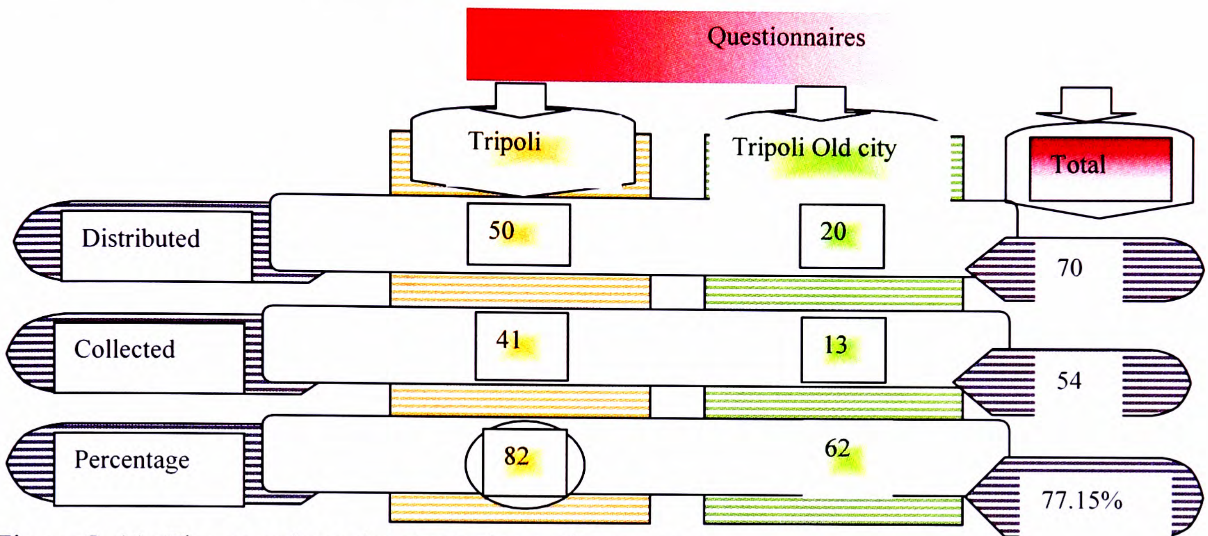


Figure 5. 11: The questionnaire strategies and responses.

5.8.2 Personal interview

This method of data collection is typically more associated with the qualitative research approach technique. It is one of the main techniques for collecting opinions and factual information. Also, it can provide a form of data collection for the researcher allowing for more scope, depth and control which can not be associated with a questionnaire. It can take place over the telephone or face to face. Naoum, (2007) stated that interviews can take three forms, unstructured, structured and semi-structured. (Table 5.4), illustrates the main definitions of interviews forms.

Table 5. 4: The main definitions of interviews forms. Source: Naoum, (2007)

Unstructured interviews	- Open-ended questions with no formal questions listed before meeting the interviewee;
Semi-structured interviews	- allow a big deal of freedom to explore different areas of research identified before meeting and to digress at tangents in order to actually establish the interviewee's opinions;
Structured interviews	- Set questions are asked in given order with no option to deviate throughout the interview. Naoum clarified that the structured interviews are where the "questions are presented in the same order and with the same wording to all interviewees".

The researcher choose to undertake semi-structured interviews with a series of professionals, as it was considered that this approach offered the opportunity to ask more exploratory questions about the advantages and disadvantages of vernacular and contemporary housing in Tripoli in relation to local microclimatic conditions. Due to the specific nature of the information required from those interviewed, this approach was considered the most appropriate.

5.8.2.1 Interview design

The interviews used an open-ended questionnaire consisting of different numbers of questions depending on their individual specialism in order to explore their opinions, as well as to give their advice about how to find solutions to the housing problems in Tripoli and it's relation to climate and sustainable housing. (Figure 5.12) clarifies the interview protocol.

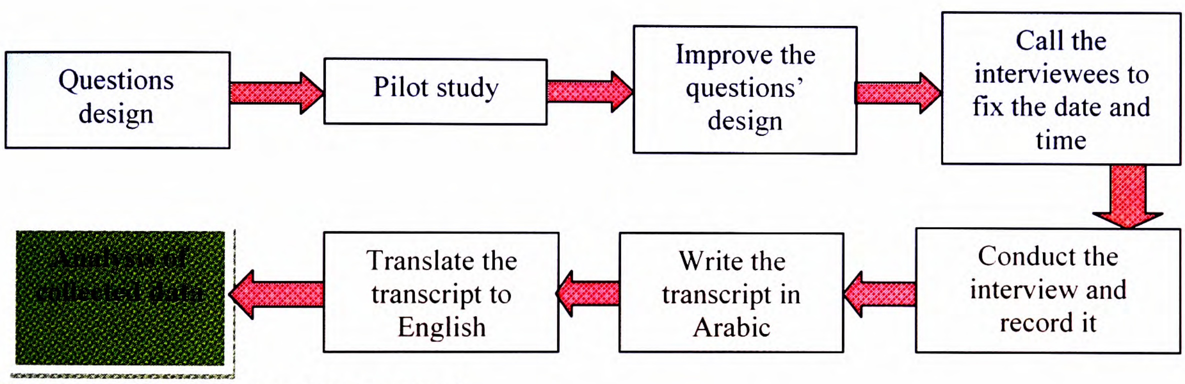


Figure 5. 12 : The interview protocol.

14 members from different professional groups who deal with real housing problems were interviewed. Information about the interviewees is illustrated in (Table 5.5).

Table 5. 5: Information about the interviewees.

Architects and urban Planners					
Interviewee	Gender	Position	Organization/	Experience	Date
1	Female	Assistant professor	Alfateh University- Architecture department	31 years	7/2008
2	Male	Assistant professor	Alfateh University- Architecture department	29 years	7/2008
3	Male	professor	Alfateh University- Architecture department	35 years	7/2008
4	Male	Lecturer and Manager	private architectural office	33 years	7/2008
5	Male	Assistant professor	Alfateh University- Architecture department	30 years	8/2008
6	Male	Assistant professor	Alfateh University- Architecture department	34 years	8/2008
7	Male	Assistant professor	Alfateh University- Architecture department	28 years	8/2008
8	Male	Assistant professor	Alfateh University- Architecture department	31 years	8/2008
9	Female	Lecturer doing PhD in- UK	Garyounis University – urban planning department	16 years	11/2008
10	Female	Assistant lecturer doing PhD in- USA	Alfateh University- Architecture department	22 years	9/2009
11	Male	professor	Alfateh University- Architecture department	31 years	9/2009
Civil engineer and property of materials					
12	Male	Civil engineer doing PhD in- UK	manger of private office	26 years	11/2008
13	Female	chemical engineer- Manager of building materials department	Industrial research centre- Building materials department	18 years	8/2008
14	Male	chemical engineer	Industrial research centre- Building materials department	22 years	8/2008

The interviews were carried out between July 2008 to September 2009 in Tripoli city and Manchester. The researcher contacted the interviewee beforehand to explain the nature and purpose of the research. The interviewee selected the place and time of the interview during the phone conversation. Each interview took approximately 40 to 90 minutes and was recorded on tape. The researcher obtained the permission of respondents for recording and using the collected information in this research. The interviews were in Arabic and author in the translation to English attempts to present the same sense of meaning of what the interviewees said (a sample of the interview responses can be found in appendix 2).

The interviews used open-ended questions consisting of different numbers of questions depending on the individual specialism of the professional in order to explore their opinions, as well as to record their advice about how to find solutions to the housing problems in Tripoli and it's relation to climate.

5.8.3 Panels, Focus group:

Panels are a very common research method. According to Fisher (2004) panels can be used in an open mode in which a group of people are brought together to have a free flowing, but focused discussion on a particular topic.

Jankowicz (2000) clarified that if the purpose of the interview is to understand the variety on a topic, a pair of focus groups will be useful. He suggests that the focus group is useful for:

- Needs assessment;
- The subsequent development of a questionnaire, where there is a need to identify the concerns of people.
- The understanding of previously obtained research results, especially where these may appear to be puzzling or contradictory.

Over the past decade, the focus group has become a popular technique for gathering qualitative data. It can be used as an independent method or in combination with surveys and other research methods (Morgan, 1996). Powell and Single (1996) clarified that the focus group was used as a market research technique in the 1920s, and nowadays, the focus group is used as a data collection technique in a range of social sciences. They explained that group who have been brought together to discuss a specific topic in-depth should be selected by researchers.

A focus group is a planned, facilitated discussion among a small group to obtain perceptions in a defined area of interest (Campbell, 2008). USAID (1996) added to this that the participants should be from similar socio-economic and cultural backgrounds. They should share common behaviour related to the discussion area. The number of participants is not fixed with many references citing different numbers. Campbell (2008) states in page 1 that focus groups typically consist of 7-10 people but in page 3 states the ideal size ranges from 4-12 persons depending on the topic and arrangement. USAID (1996) suggested 7-11 persons are the ideal number. Whilst Powell and Single (1996) suggest the number of participants can be between 6 and 10.They also state that the desirable number of focus group sessions depends on the subject and it stated from 1 to 10 sessions, while at some stage the group's discussion will replicate existing information, making more sessions unnecessary.

5.8.3.1 Why and when to use a focus group

Focus groups can be a useful tool for collecting applicable and informative data. When to use a focus group has been explained by several authors such as (USAID, 1996; Powell and Single, 1996; Campbell, 2008). Demand Metric (2009) summarised it as follows;

- Often used as a means of triangulation with other data collection methods;
- Good for initial concept exploration;
- Generating creative ideas;
- Need to collect data, evaluate services or testing ideas;
- Better understanding of opinion, believes and attitudes;
- Better understanding about a particular topic;
- Identifying gaps between different groups;
- Encouraging discussion about a particular topic;
- When the subject is complex and needs additional data collection methods to ensure validation;
- When the results of a quantitative survey are unclear and require clarification, explanation; and
- When recommendations and suggestions are needed from customers, partners, experts, or other stakeholders.

5.8.3.2 Preparing for a focus group

Before conducting the focus group discussion preparation is needed to help ensure good results. The following steps suggested by Campbell (2008) should lead to better results:

A1. Administrative tasks include:

- **Preparing and sending information materials to participants;**
  - Identifying the general topic;
  - The sponsor and the purpose of the research;

- Stress the value to you of obtaining her/his insights;
- Mention if a stipend or refreshments will be provided. Provide any relevant written materials in advance.

- **Organizing logistics (location, time, equipment, catering, travel arrangements, etc.)**
  - ➢ Select a location that is easy to find;
  - ➢ Minimize distraction;
  - ➢ Provide a neutral environment and one that ideally facilitates sitting in a circle;
  - ➢ A discussion takes one to two hours;
  - ➢ Set up and clean up after the event;
  - ➢ Distribution of per diems/repayment of travel costs.

A2. Research tasks include:

- **Preparing questions**;
  - ➢ Create a set of 5-10 questions;
  - ➢ Two principles should be followed: Questions on a given topic should be ordered from the more general to the more specific, and Topics of greater importance should be placed early in the discussion;
  - ➢ Questions should be clear; relatively short and use simple wording;
  - ➢ The questions should be open-ended rather than dichotomous
  - ➢ Ask participants for definitions, impressions, examples, their ideas of others' perceptions, and the like.

A3. Recruiting potential participants in the focus groups;

- **Choose participants** who are informed and can communicate effectively with the ideal focus group size ranging from 4-12 persons.
- **Recording proceedings**; Tape recorders are invaluable for focus group discussions however they are prone to pick up background noises. The moderator can attempt to make notes or an assistant can try to capture exact phrases and statements made by participants.
- **Analyzing data**; Analysis begins during the discussion:
  - ➢ Listen for incompatible comments and look for understanding.
  - ➢ Seek clarification when hearing vague comments.
  - ➢ Consider asking each participant a final preference question.
  - ➢ Offer a summary of key questions and seek confirmation.
  - ➢ Analyze the content of the discussion, look for emerging themes by question and then for the discussion overall. Compare the words used to answer specific questions, the

importance or concentration of the respondents' comments, and the reliability of comments and the specificity of responses in follow up searches.

- **Preparing report**; Make sure conclusions are made in a timely manner and that participants are aware of the results. Create a formal report including background, purpose, session details, results, and conclusions.

5.8.3.3 Conducting Focus Group Interviews

Before starting the focus group discussion, participants should have the opportunity to meet before the formal discussion begins by setting aside time for informal conversation and providing light refreshments for them. To maximise face-to-face contact in the formal session, participants should be seated in a circle. The facilitator should play a minimal part in events to avoid becoming a central focus of group attention (Powell and Single, 1996). The moderator has to allow participants to talk to each other, ask questions and express doubts and opinions, while having very little control over the interaction other than generally keeping participants focused on the topic (Morgan 1988). Several points that should be taken into consideration while conducting the interview have been clarified by USAID (1996, p3) as follows;

- **Establish understanding**; outline the purpose and format of the discussion at the beginning of the session, and set the group at ease; *Participants should be told that the discussion is informal, everyone is expected to participate, and different views are welcome*;
- **Phrase questions carefully**; *Open-ended questions are more useful because they allow participants to tell their story in their own words and add details that can result in unanticipated findings*
- **Use questioning techniques**; When participants give incomplete or irrelevant answers, the facilitator can search for clearer responses by using the following techniques: *Repeat the question- Adopt complicated naiveté- Pause for the answer- Repeat the reply- Ask when, what, where, which, and how questions- Use neutral comments*
- **Control the discussion**; in most groups, a few individuals dominate the discussion. To balance out participation: *Address questions to individuals who are reluctant to talk- Give nonverbal signs (look in another direction or stop taking notes when an individual talks for an extended period) - get involved, politely summarize the point, then refocus the discussion- Take advantage of a pause and say, Thank you for that interesting idea, perhaps we can discuss it in a separate session. Meanwhile with your permission, I would like to move on to another item.*

- **Minimize group pressure**; when an idea is being adopted without any general discussion or disagreement, more than likely group pressure is occurring. To minimize group pressure: *the facilitator can search for alternate views, the facilitator can raise another issue, or say, we had an interesting discussion but let's explore other alternatives.*

5.8.3.4 Analysis of Focus Group Data

USAID (1996) provided methods that can be used to analyze data as follows;

- Read summaries all at one time;
- Read each transcript; emphasize parts that correspond to the discussion guide questions and mark comments that could be used in the final report.
- Analyze each question separately; write a summary statement that describes the discussion.

Powell and Single (1996) stated that the process of analysis can be done as follows;

- Code and classify the data by reviewing the transcribed discussions for potential conceptual categories, using the questions as initial categories.
- Regroup coded data or index along the lines of the nature of the responses provided;
- Analyze the original data in conjunction with the transformed conceptual data.

A focus group was completed in August 2008 with one professional group (architects and urban planners) to discuss the climatic design strategies in hot and hot-humid regions that are documented in the literature and applied in many western and Arabic countries. The detailed information about the focus group conducted in this study shown in (Table 5.6). The underlying reason for choosing focus groups is because most of these strategies have already been tested and approved by the professionals and institutes, accordingly, the focus group discussed whether these strategies can be adapted to the Tripoli microclimate from climatic, social and economic points of view and offered suggestions in how these strategies could be improved.

Table 5. 6: the application of the focus group strategy in the case study.

TASKS	The application
Why use a focus group	-Used as triangulation with other data collection methods. -The underlying reason for choosing focus groups is because most of these strategies have already been tested and approved by the professionals and institutes, accordingly, focus groups discussed whether these strategies can be adapted to the Tripoli microclimate from climatic, social and economic points of view and offered suggestions in how these strategies can be improved.
Preparing for a focus group • **Administrative tasks include:** - preparing and sending information materials to participants - Organizing (location, equipment, catering, arrangements, etc.)	- Invitations sent to the 13 participants with general information about the topic and what to discuss in the meeting, number of participants attended the session were 6 (3male and 3 female). - The participants have more than 16 years experience and most of them are teaching in the architecture department at Alfateh University, and others studied in the same department, accordingly the location was in the office of one participant at the University. - A technician from the same department helped to prepare the equipment (computer, projector and camera). - The discussion took one hour and fifteen minutes.
-**Research tasks include:** preparing questions recruiting potential participants in the focus groups recording proceedings analyzing data	- prepare the discussion points and presentation of the research; - Select the participants from architects and urban planners who are working in academia and industry and have worked in housing and no less than 15 years experience; -Prepare a DVD camera to record the meeting; - Review the findings with the focus group and analyse data after the meeting.
- **In the day**	- 6 of the invited participants attended the session and one technician in addition to the researcher, all of them are architects and urban planners, one of them is working in industry and five are working in academia and industry, two of them have more than 16 years experience and the other four have more than 20 years experience. - the discussion started by the presentation explaining the main points of the research including the research methods and the main reason of using the focus group as one of the methods to discuss the possibilities of using climatic design strategies collected from the literature in Tripoli. - the discussion went through the strategies and had a debate around each point verbally and using drawings when necessary to clarify ideas; -summaries of the main points were taken in consideration in the proposed guidelines.

5.8.4 Documentary research

Proverbs and Gameson (2008) suggested that documents can be letters, minutes of meetings, drawings and kind of reports. They clarified that such kind of documents can be useful in helping to corroborate evidence from other sources and obtaining some basic factual information about the case at hand.

Document review was also used as a supplementary technique to semi-structured interviews and the questionnaires survey. Moreover, it will provide a means of triangulating data collection techniques. Document review was mainly used to gather relevant documents from the householder in order to be able to understand specific details of the case study as an individual case.

5.8.5 Observational research

Close observation of individuals can generate data which might support, contradict or substitute for any oral records (Manning, 1987). Robertson and Mchlaughlin (1996) clarified that observational methods are one of the strategies used to collect data and information in the social sciences.

In this study, observational techniques were used to collect information about the building case studies. In the observation of the built environment, notes were taken about the physical character of the architecture and urban forms and the physical attributes of homes and streets. These were recorded through direct observation using field work note books as well as recording on maps and plans. Informal interviews were conducted during observation with residents. This involved asking people about their opinions about their homes, what they like and do not liked. A photographic survey was conducted to record certain aspects of architecture and urban forms. The survey provided valuable information about the nature of the physical environment such as light, ventilation, building form, height, building materials, construction techniques, types of roof and architectural characteristics as well as equipment used to achieve internal thermal comfort.

5.8.6 Measuring internal temperature in selected case study houses in Tripoli

As stated in (section 5.5.2) the quantitative research approach seeks to collect accurate data by adapting a scientific method in which initial study of the theory and the literature yields analysis to be measured through specific aims and objectives with a hypothesis to be tested. In this research this method was used to clarify the conflict between the theory and the professionals' opinion with the householders' opinion about the performance of the courtyard houses. Accordingly, sampling the temperature inside selected local and contemporary houses in Tripoli was selected to clarify actual internal and external conditions.

Two case study houses were selected as appropriate research vehicles for further investigation in each housing area (Figure 5.13). The purpose of this detailed study was to understand the reasons for the residents and experts views of the performance of these building in more detail. Detailed analysis of the houses was carried out by collecting base data (the design concepts, layout drawings, equipment details of the systems of cooling and heating, building materials and methods of construction). This was supported by sampling the interior and exterior temperature to compare with residents perceptions of the conditions. Air temperature measurements were taken by the author between the 7th of August 2008 and the 7th of July 2009, by using EasyLog USB sensors version 4, which recorded day and night temperature at 30 minutes interval (Figure 5.14).

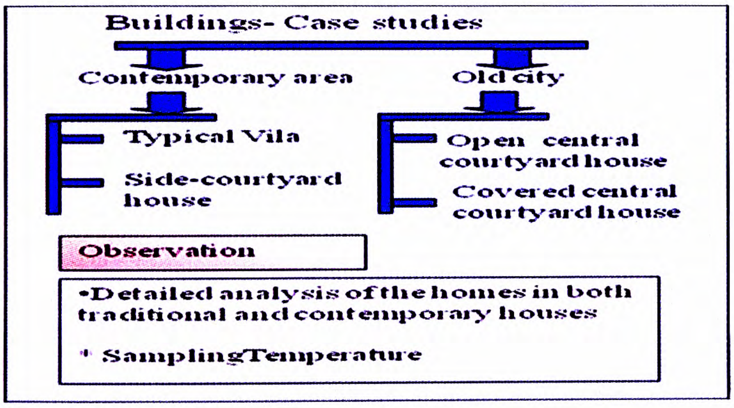


Figure 5. 13: Multiple case studies design.

Figure 5.14: EasyLog USB sensors version 4.

Measurements were recorded in the living room in four selected case studies; two are located inside the old city and two outside the old city (Figure 15) the first case is a two story courtyard house inside the old city and the residents have covered the courtyard. The second case is a one story courtyard house inside the old city with open courtyard. The third case is a one story courtyard house with covered courtyard located in outside the old city and built in 1964. The last case is contemporary two story villa built in 1983.

All of the cases are using natural ventilation and fans to cope with the high temperature and humidity. Eight days from starting measuring the temperature, two of the case studies started using air conditioning (case two and three). detailed information can be found in the next chapter (section 6.4).

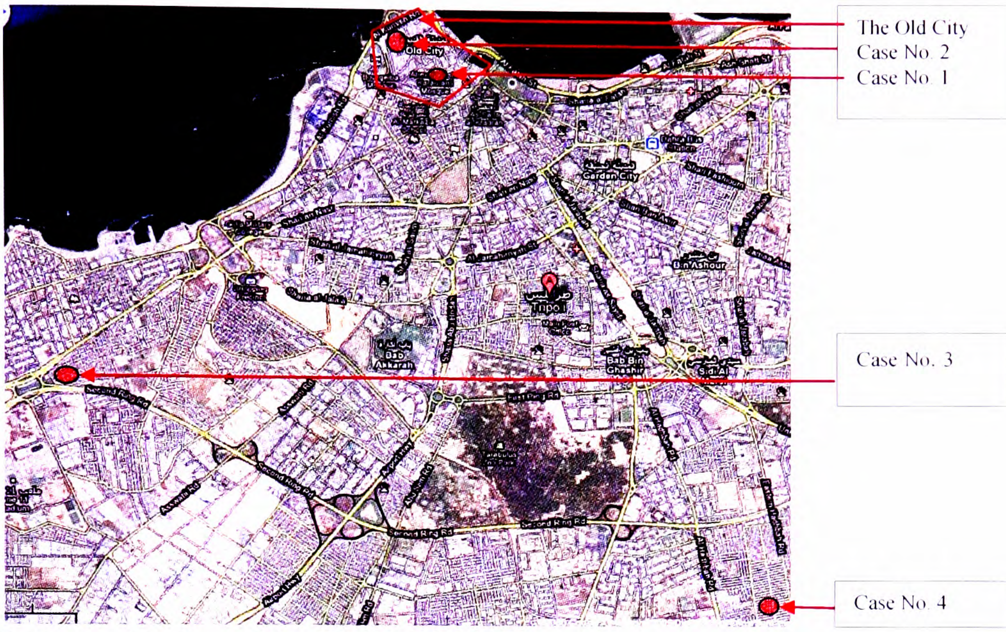


Figure 5. 15: Aerial view of the city of Tripoli shown the cases' location.
Source : maps.google.com

As stated in the previous chapter, the housing types in Tripoli are classified into four major types (1-Courtyard houses, 2-Row houses, 3-Flats and 4-Villas). The case studies were selected from type 1, 2 and 4 and exclude type 3 because this type generally more than two stories and is different from other types in design concept, sharing functions with other occupants, also it is usually built by the government. This type still presents potential problems with overheating if climatic design principles not used. The data logger was located in the living room of the selected houses because it is the place used by all the family almost all of the daytime.

5.8.6.1 The main reasons for selecting the cases

- This method (measuring temperature) is not the main method in this study, the main methods are observation, interviews and questionnaire, and this method is one aspect of the study used to support the findings of the previous methods;
- The cases cover all kinds of private housing in Tripoli;
- The cases cover different period of times;

5.8.6.2 Limitations

- It is not easy to find cases where the occupiers agree to put unknown instruments in their buildings;
- It is difficult to find cases that have similar characteristics such as orientation, floor area, kind of service equipment used, and number of people living in the cases.
- Size of study was limited by time available for analysis.

5.9 DATA ANALYSIS

Data analysis of a research project is one of the important parts of any research as it helps to examine the collected information and to draw up conclusions based on them. Yin, (1994) encouraged researchers to make every attempt to produce an analysis of the highest quality. In order to achieve this, he presented four principles that should draw the researcher's attention:

- confirm that the analysis relied on all the relevant proof;
- Include all major challenger interpretations in the analysis ;
- Address the most important feature of the case study; and
- Use the researcher's prior, expert knowledge to further the analysis.

Sanders et al., (2003) stated that there is no fixed approach to analysing qualitative data and many strategies exist in this respect. Collis and Hussey (2003) divided the main methods of analysing qualitative data into two categories; quantifying methods and non- quantifying methods (Table 5.7).

Table 5.7: Main methods of analysing qualitative data.
Collis and Hussey (2003:260)

Quantifying methods	Non- quantifying methods
Informal methods Formal methods Content analysis Repertory grid	General analytical procedure Cognitive mapping Data displays Grounded theory Quasi-judicial methods

Collis and Hussey (2003) clarified that many authors have attempted to identify what they regard as the main elements of an analysis of qualitative data and stated that general analytical procedures can be use with any methodology in the following way;

1- Convert any rough field notes into the form of written record;
2- Ensure that any materials collected are properly referenced;
3- Start coding the data as early as possible;

4- Start grouping the codes into smaller categories;
5- Write summaries at various stages
6- Use the summaries to construct generalisations which can confront existing theories or be used to construct a new theory; and
7- Continue the process until satisfied that data collected are sufficiently robust to stand the analysis of existing theories or the construct of a new theory.

As stated previously, this study is qualitative in nature and analysed using Non-quantifying methods by the (general analytical procedure). In this study, the researcher began the analysis after conducting the fieldwork, using the following processes:

- Work-paper 1: Converting all the data collected into text, thus the transcripts of the data were made ready for analysis;
- Work-paper 2: Reading through work-paper 1 and summarising it.
- Work- paper 3: Reconstruct the data in work paper 2 to create a picture across all key points. Categories and classify the collected data into meaningful categories;
- Work- paper 4: Data display, this was done by using (Excel 2007, Nvivo8 and EasyLog software.
- Work- paper 5: Gather all data findings from the field study and analysed together to set the final guidelines.

In more detail, the questionnaire results are presented using; frequency distribution tables, charts and coding of the comments and examples given by the respondents. Analysis of the data was undertaken using the descriptive statistics method, this will allow occupant perceptions and any common causes of discomfort to be clearly identified. Excel software have been used to analyse the data collected from the questionnaire.

The interviews have been analysed using Nvivo software. The process started by

- Transfer of the oral interview to Arabic hand writing version;
- Translate the text to English and type up using Word 2007;
- Import all transcripts written in word to the sources document folders in Nvivo (Figure 5.16);
- Open new folder in Nvivo sources to collect the information that related to each specialist and each question (Figure 5.17);
- Code the main information related to each question in the free nodes file (Figure 5.18);
- Code the final findings from each question in the three nodes file (Figure 5.19).

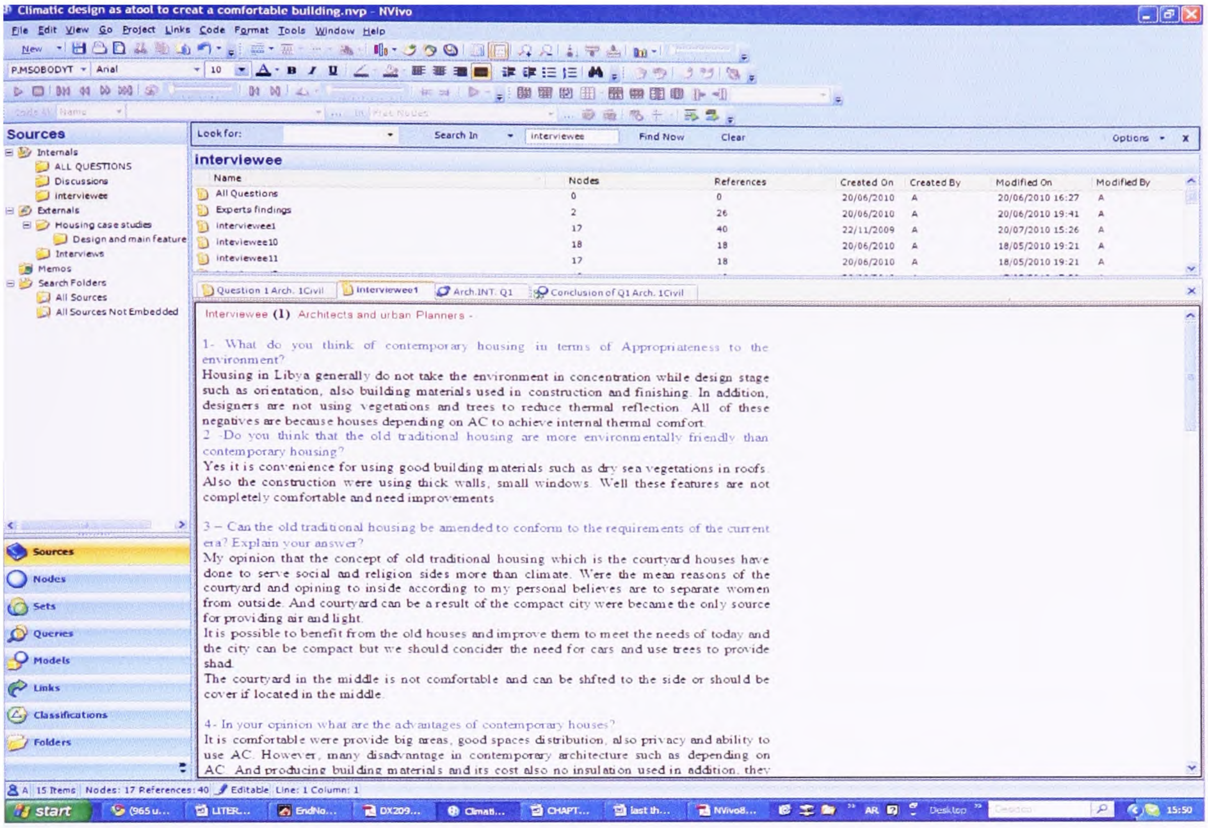


Figure 5. 16: First step in using Nvivo, Import all scripts in sources folders.

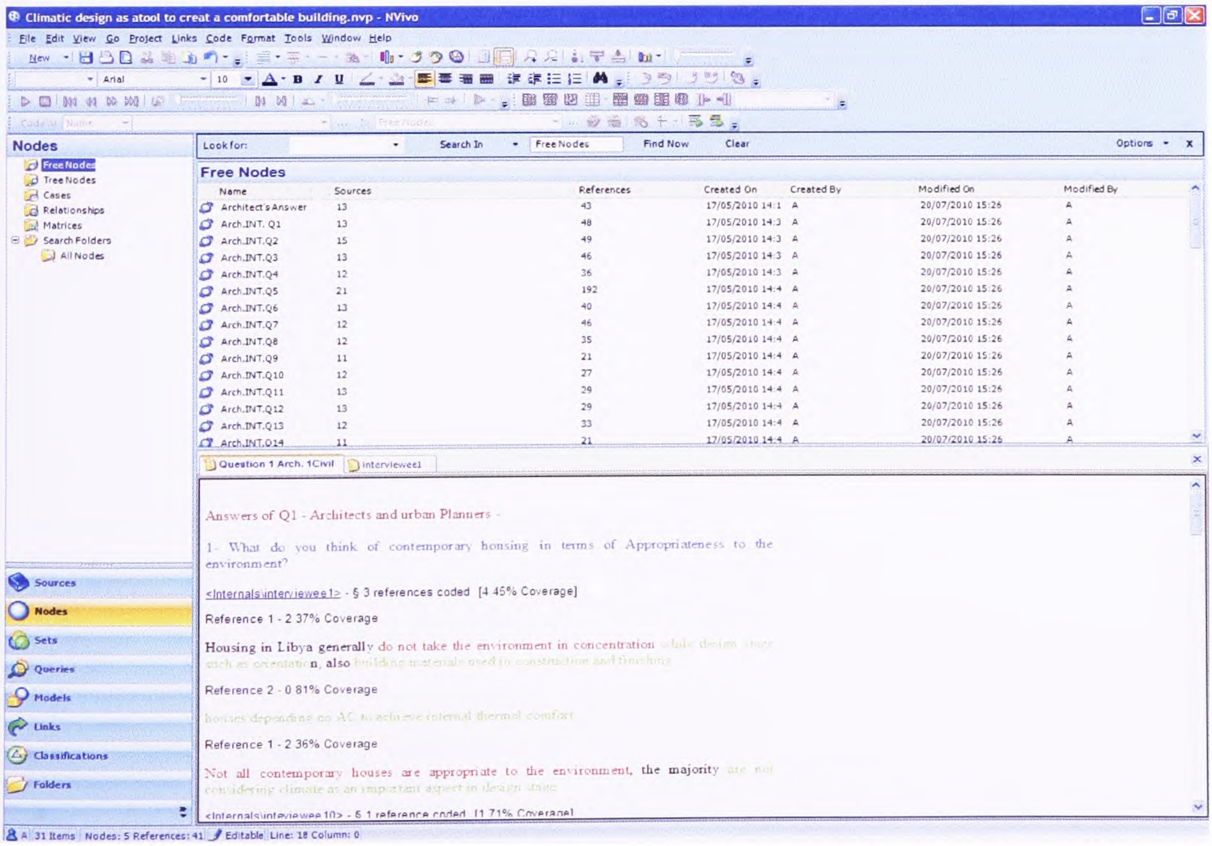


Figure 5. 17: Collecting the information that related to each specialist and each question.

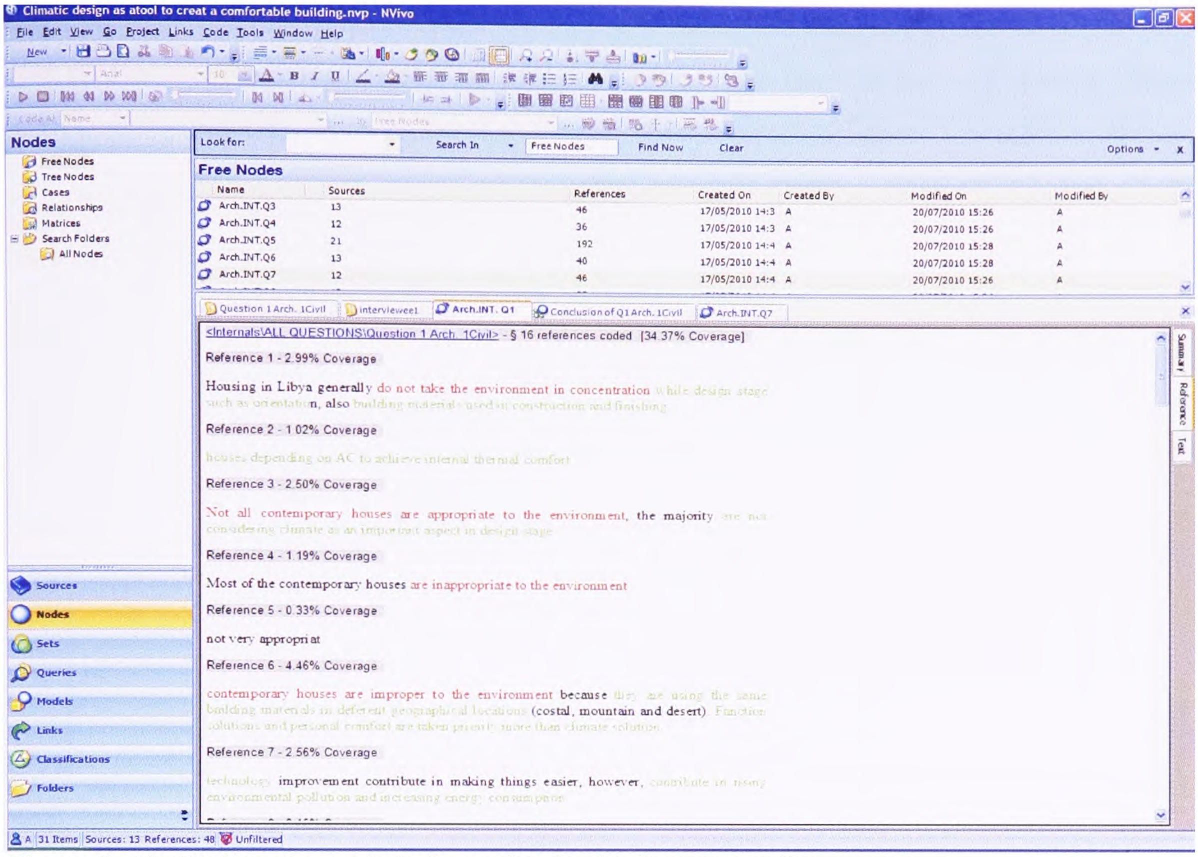


Figure 5. 18: Coding the main information in the free nodes file.

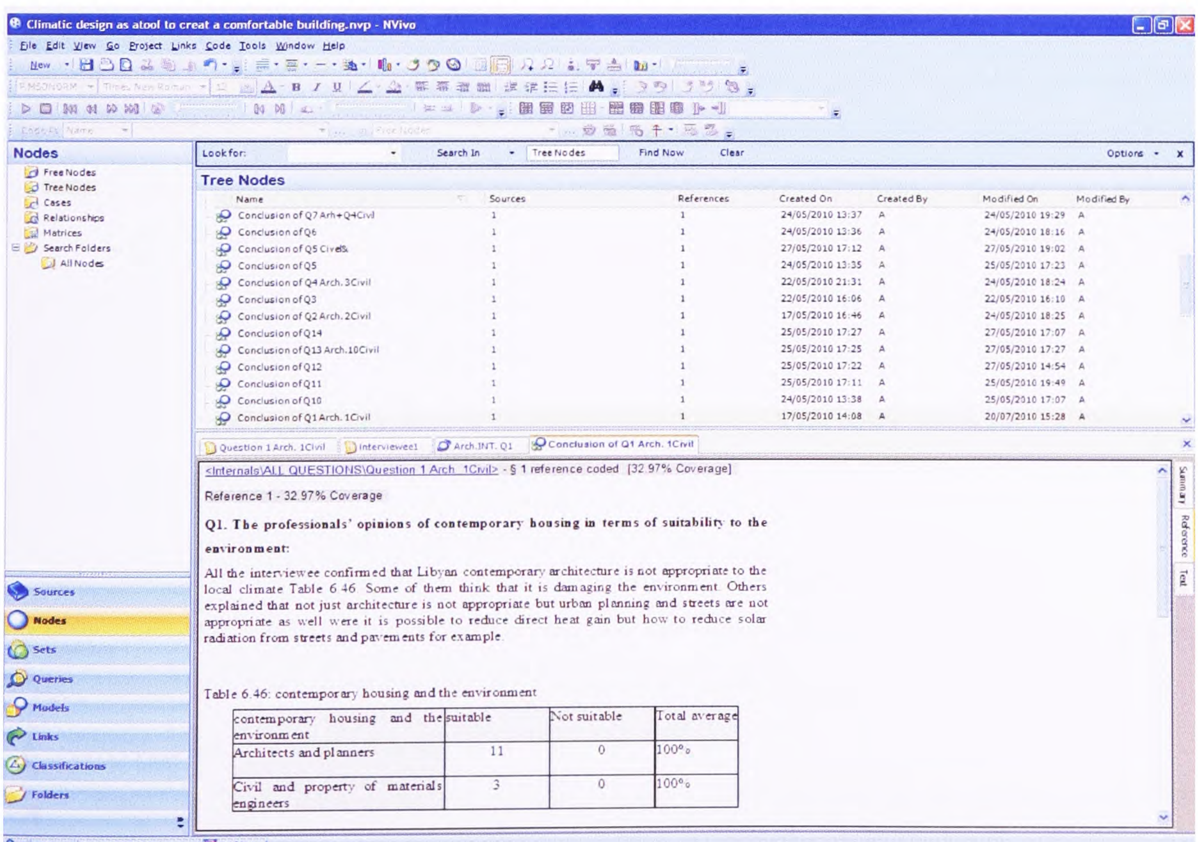


Figure 5. 19: Coding the final findings from each question in the three nodes file.

EasyLog USB sensors version 4 were used for measuring internal temperature in the selected case studies, they provided ready data in graphs and tables that can be used directly (Figure 5.20) (see appendix 4).

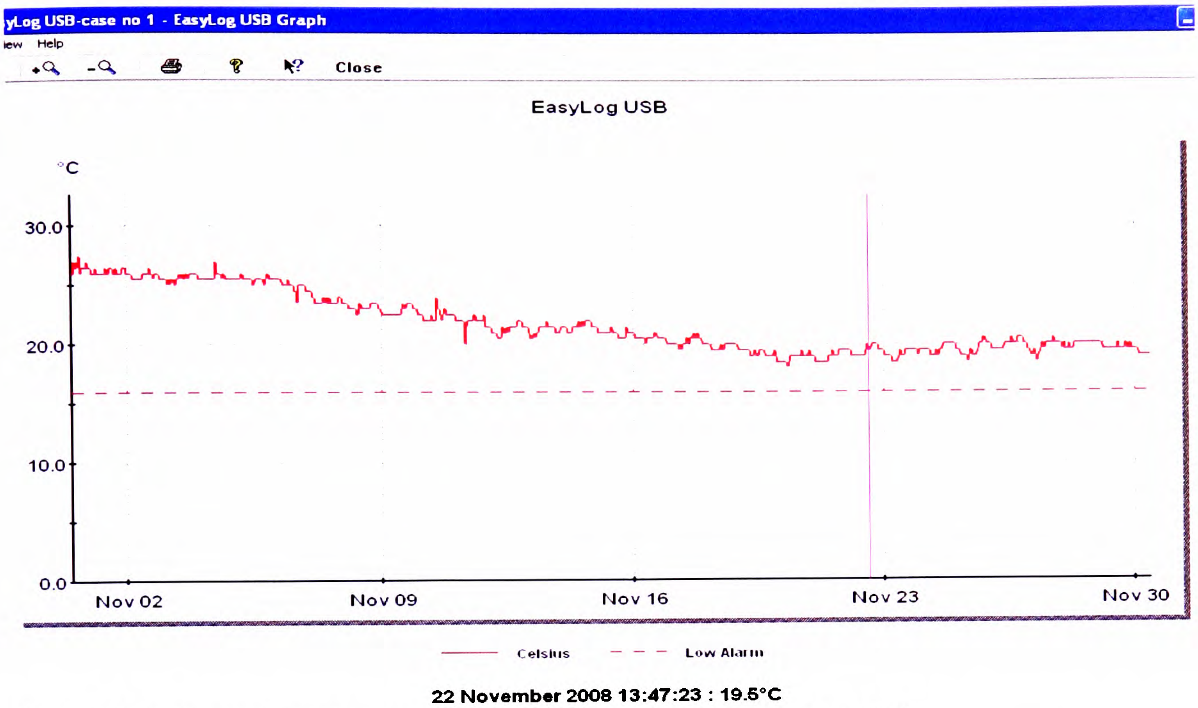


Figure 5.20: Internal temperature measured in case 1 during one month.

Therefore, as a result of the analysis procedure, the findings from the data analysis were employed with the other sources that were obtained during the data collection such as literature, drawings and photographs and according to the research methodology. Tables, figures and photographs were used for illustration and analytic purposes. By using as many approaches and techniques for investigation as possible, the risk of mistakes and bias that might occur were reduced to a minimum.

5.10 EXPERT GROUP

In order to validate the proposed guidelines, a group of 6 Libyan architects and planners experts (the same experts used in the focus group discussion) who have experience in housing design and construction were invited to validate the guidelines.

The process used in connecting the experts are as follows:

- Face to face discussion with three experts, met two of them during sustainable architecture and urban development conference held in Amman, Jordan, between 12-14 July, 2010 and met the third one in Manchester.

- Sent the proposed guidelines by e-mail, and clarified some points to experts by e-mail. (Figure 5.21) shows a copy of one respondent.

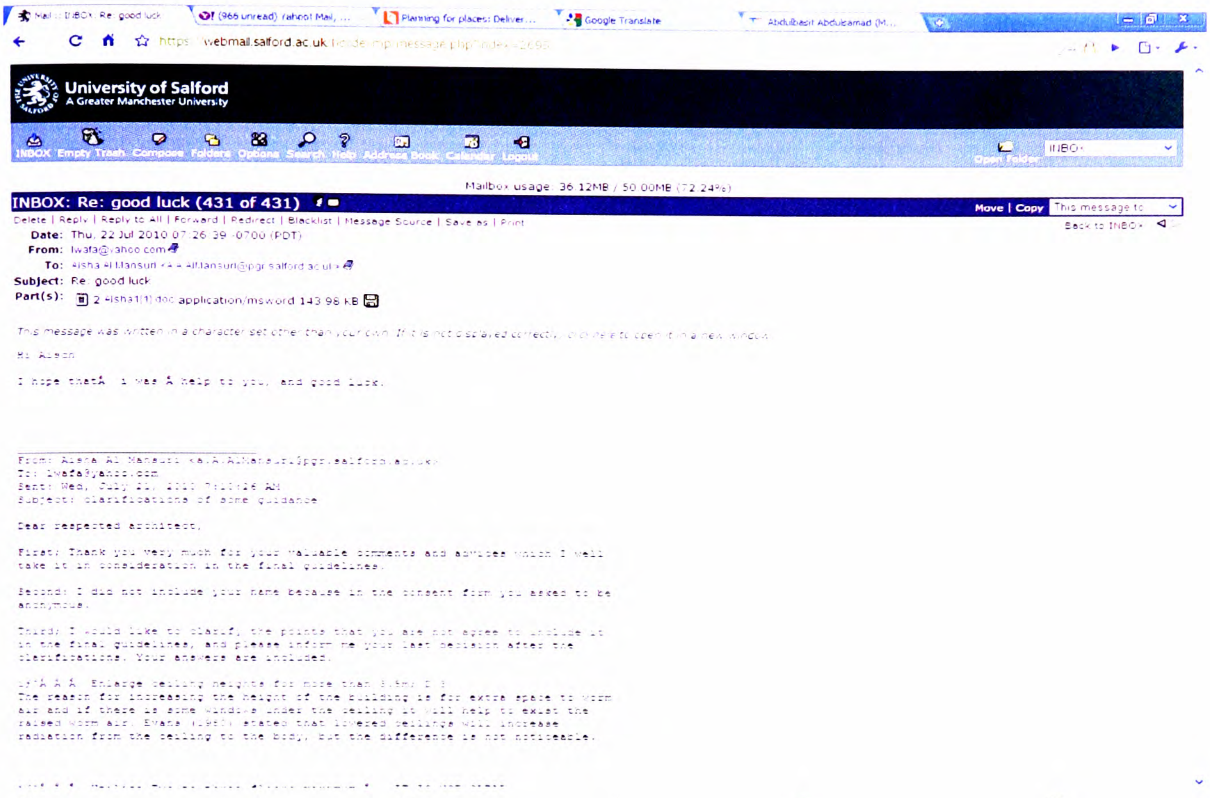


Figure 5. 21: copy of e-mail discussion.

The comments obtained from the experts have been very helpful for improving the final guidelines. The main comments that were taken into consideration in the final guidelines are as follows;

- Avoid repetition in the information;
- Re order the main points;
- Avoid long sentences;
- Reduce explanation in guidance that well known;
- All points should have high priority.
- Avoid linking to sources.

5.11 CONCLUSION

This chapter discusses the research methodology and the processes used to undertake the research. The author has adopted a number of research strategies and techniques for developing the guidelines that contribute to climatic design. A triangulation approach was established to reduce the biases inherent in the case study strategy if such strategy had to occur. Both positivist and phenomenological paradigms have been adopted to meet the requirements of this research where appropriate.

Using triangulation of methods in this research helps to contribute an additional piece to the puzzle in the way that different methods complement each other (Figure 5.22). It will enable data temperature measurements to be compared with the occupants satisfaction and expert opinion.

Each of the different methods (questionnaire and semi-structured interviews, focus group as well as direct observation, sampling and the collection of supporting documentation) helps capture a more complete, holistic and contextual portrayal of the cases and reveal the varied dimensions of the best way to conduct passive design in our future housing. Multiple data collection was used in this research to minimise the researcher's bias and improve the validity of the findings.

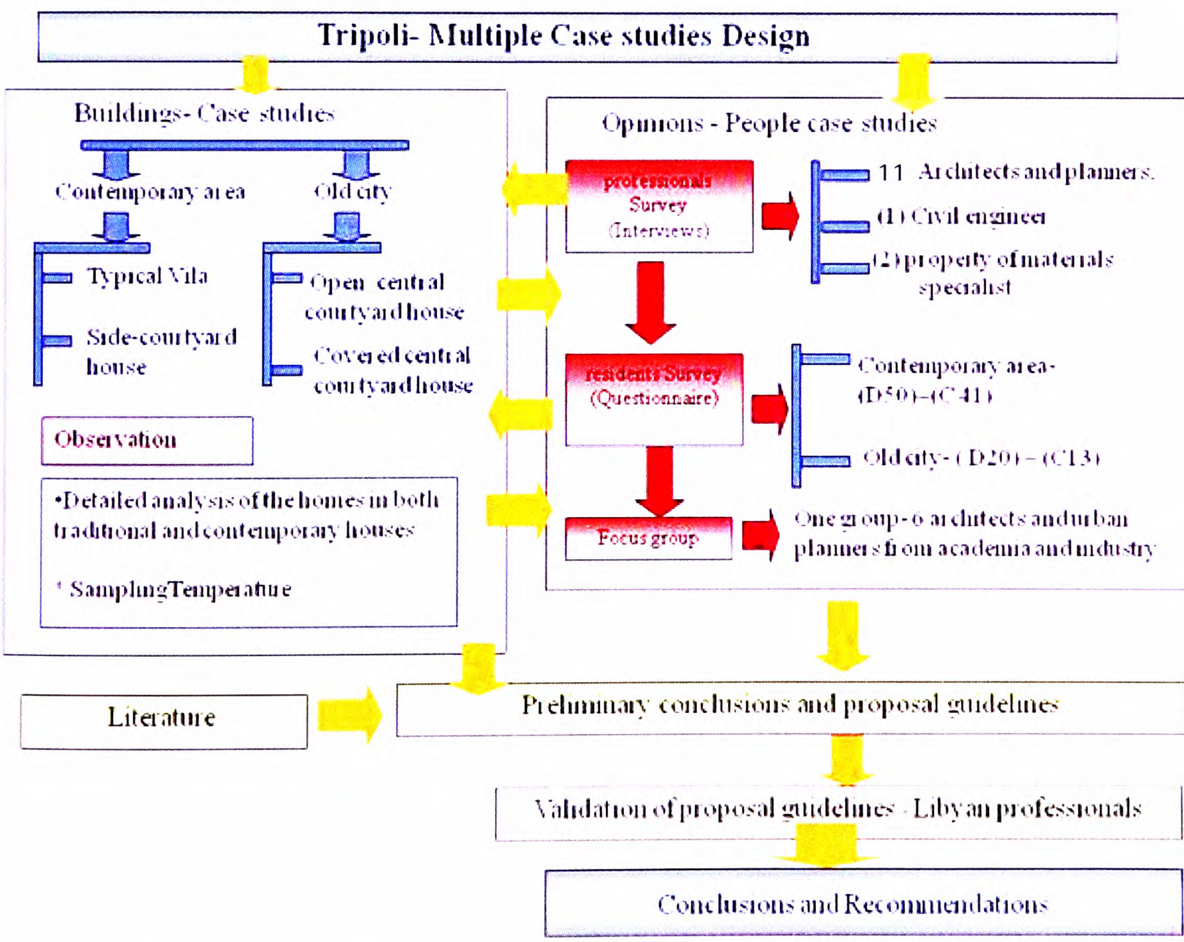


Figure 5.22: summary of data collection methods used in the research.

CHAPTER SIX

CHAPTER ONE:	**INTRODUCTION**
CHAPTER TWO:	**SUSTAINABLE DEVELOPMENT**
CHAPTER THREE:	**CLIMATIC DESIGN**
CHAPTER FOUR:	**LIBYA- GENERAL BACKGROUND**
CHAPTER FIVE:	**RESEARCH METHODOLOGY**
CHAPTER SIX:	**ANALYSIS OF THE FINDINGS OF THE QUESTIONNAIRE, INTERVIEWS AND TEMPERATURE MEASUREMENTS**
CHAPTER SEVEN:	**THE FINAL CLIMATIC DESIGN GUIDELINES FOR HOUSING**
CHAPTER EIGHT:	**CONCLUSION AND RECOMMENDATIONS**

CHAPTER SIX: ANALYSIS OF THE FINDINGS OF THE QUESTIONNAIRE, INTERVIEWS AND TEMPERATURE MEASUREMENTS

6.1 INTRODUCTION

This chapter consists of the analysis and interpretation of the data collected for this study. As outlined in the methodology chapter, the investigation is divided into two main areas: people's opinions and building performance. The contents of the current chapter and how it feeds into the guidelines in following chapters is illustrated in (Figure 6.1). As clarified in chapter five this thesis uses a non-quantified method and the data collected was analysed by using Excel and Nvivo software.

The chapter includes the following parts:

- An analysis of the residents' questionnaire responses in the contemporary and vernacular areas in order to investigate the degree of satisfaction the residents feel about their housing and its suitability for local climate;
- An analysis of the interviews conducted with Libyan experts in order to explore their opinions about design and construction in terms of the climatic design of modern housing for Tripoli society;
- An analysis of the opinions of the Libyan experts emerging from the focus group explaining the possibilities of adapting climatic design strategies in hot regions (that are published in the literature) to the Tripoli microclimate;
- An analysis of the temperature measurements taken inside selected vernacular and contemporary houses, in addition to giving the results of observing houses in both areas to clarify actual internal and external conditions and to what extent they are suited to the climate condition and to the Libyan people's way of life.

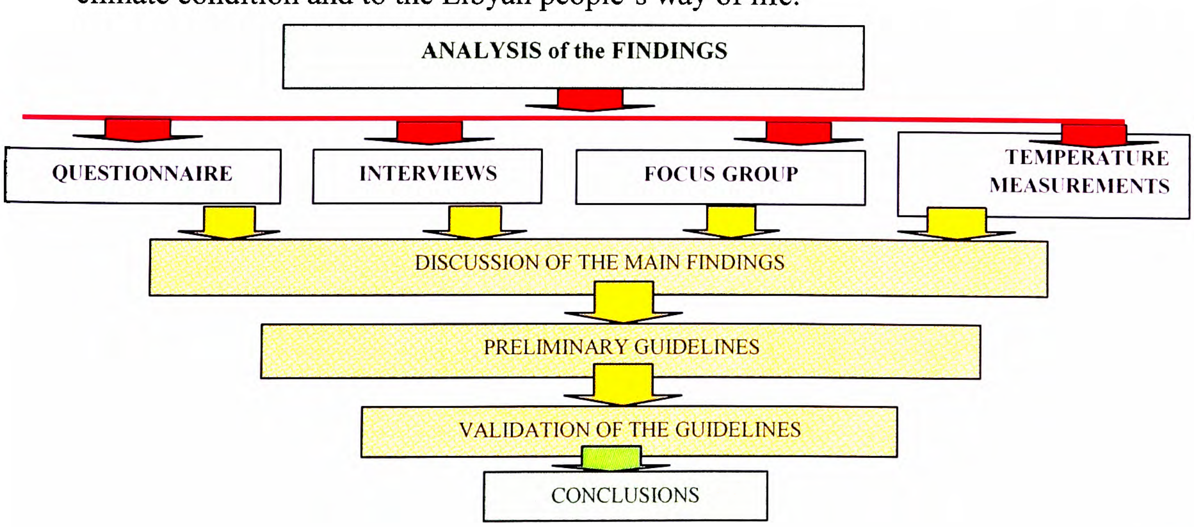


Figure 6.1: The contents of the current and following chapters.

6.2 THE QUESTIONNAIRE SURVEY

This part of the survey study reviews the results of the questionnaire. Each question will be taken separately and briefly considered in the light of all respondents who completed the survey.

The questionnaire analysis is divided into three parts:

- Part A: General information: in this part the analysis of the respondents' answers from both areas are presented together;
- Part B: Housing situation: in this part and in the next part, the analysis of the responses from the respondents are presented separately, commencing with the contemporary area residents followed by the vernacular area residents.
- Part C: The relationship between houses and climate

6.2.1 Part A: General information

Gender and age within the households: As shown in (Table 6.1 and Figure 6.2), the gender distribution in this survey in the contemporary area section was 32 males and 9 females, whereas the number of females in the vernacular part was more than half of the number of men taking part in the survey.

The respondents were divided into 5 age categories. The variety of the ages of the respondents helped to elicit a range of viewpoints as to how they see their houses. The main age group interviewed (87.1%) ranged from over 41 years old from both genders. 5.5% came from the age group between 21-40 years old and the smallest group (1.9%) was from ages less than 20 years old. The majority of the participants were male. The percentage of females taking part (26%) were of sufficient number to give a satisfactory reflection of their opinions.

Table 6. 1: Gender and age in both areas.

	Age	10 - 20	21 - 30	31 - 40	41 - 50	> 50	Total	%
Contemporary part	Male			3	17	12	32	59.3
	Female				7	2	9	16.6
Vernacular part	Male	1	1		4	2	8	14.8
	Female		2		2	1	5	9.4
Percentage		1.9	5.5	5.5	55.6	31	100%	

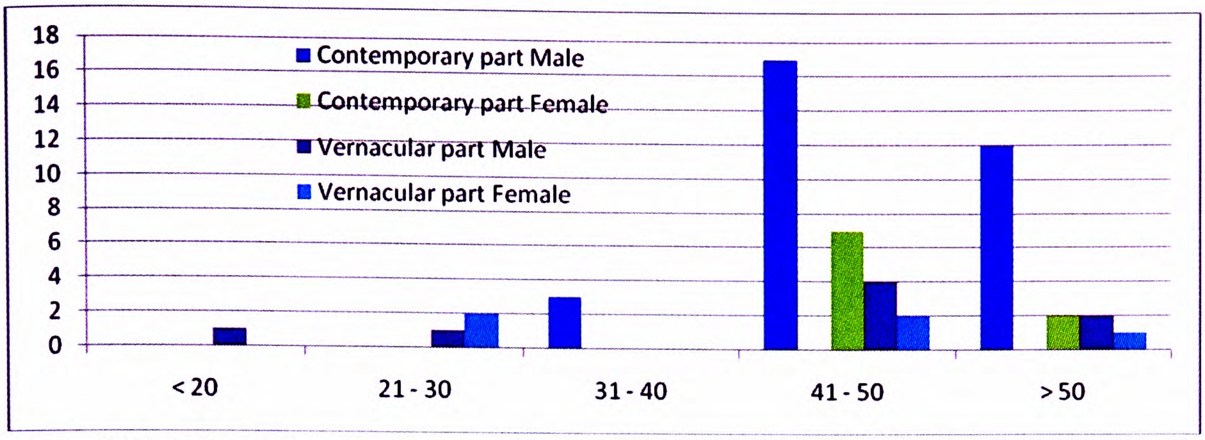


Figure 6.2: Gender and age in both areas.

Marital status: As can be seen from (Table 6.2 and Figure 6.3), 87.1% of the respondents were married, 5.5% were single and 5.5% were widows, while 1.9 % were divorced.

Table 6.2 : Marital status in both areas.

Location	Marital status	Single	Married	Divorced	Widow	%
Contemporary part	Male		32			59.3
	Female		6	1	2	16.6
Vernacular part	Male	2	6			14.8
	Female	1	3		1	9.4
Percentage		5.5%	87.1%	1.9%	5.5%	

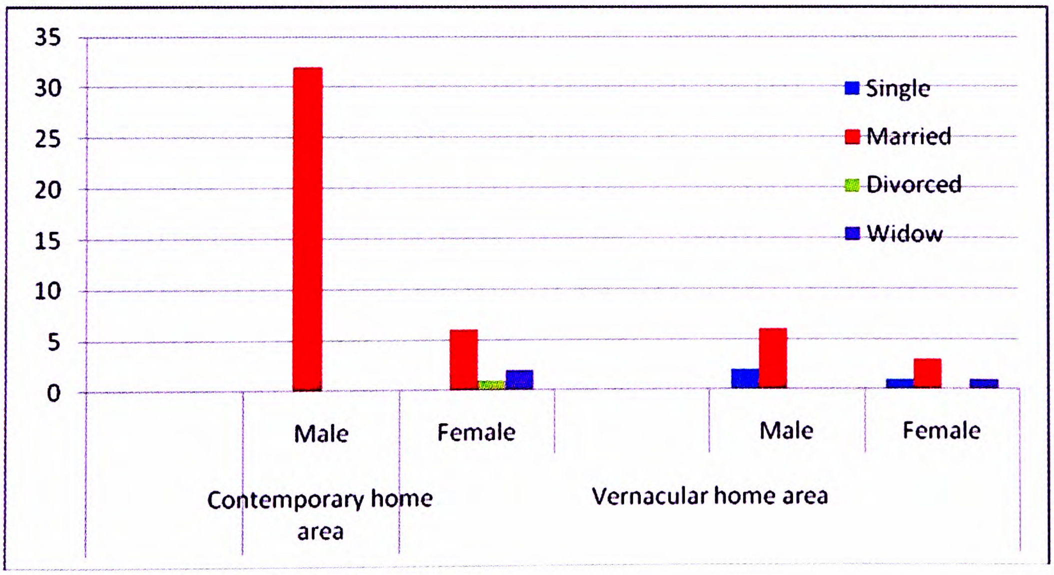


Figure 6.3: Marital status in both areas.

Occupation: Many different occupations are represented in the results. To simplify matters the occupations, as shown in (Table 6.3 and Figure 6.4), were grouped into seven general groups. A high percentage of the total sample were professionals (44.4%), 29.6% were employees while 3.8% were students.

Table 6.3 : Occupation.

Work	Professional	Employee	Retired	H/ Wife	Student	S/Employ
Contemporary part	24	11	1	3		2
Vernacular part		5	3	2	2	1
Percentage	44.4%	29.6%	7.4%	9.3%	3.8%	5.5%

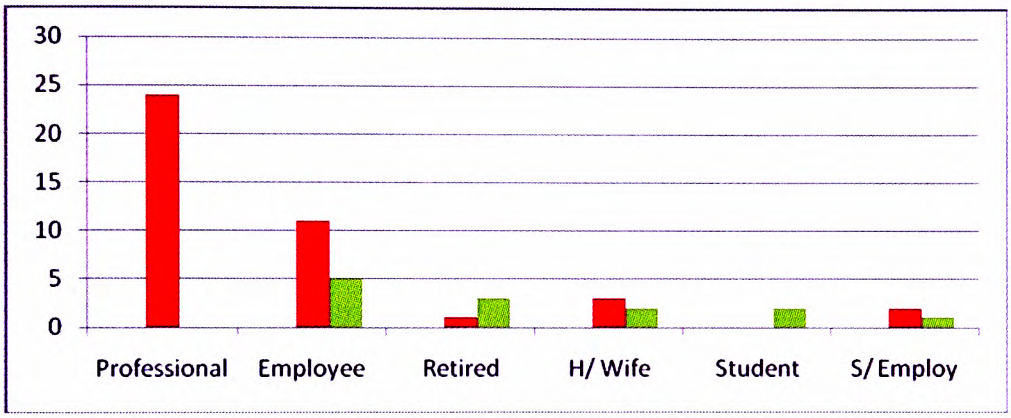


Figure 6.4: Occupation in both areas.

Academic Education level: The level of education is considered as an important aspect that may influence respondents' opinions towards housing conditions. (Table 6.4 and Figure 6.5) show the different education levels achieved by the respondents divided into four main groups. As shown in the table the majority of the respondents in the contemporary area (70.7%) hold master or PhD degrees followed in number by those who hold a university certificate. This means that the respondents are be able to understand the questions. On the other hand the majority of the respondents in the local area hold only primary and secondary certificates; accordingly they needed help in understanding the questions.

Table 6.4: Academic Education level.

Education	Primary		Secondary		University		Postgraduate	
Areas	No	%	No.	%	No.	%	No.	%
Contemporary part	1	2.5	3	7.3	8	19.5	29	70.7
Vernacular part	8	61.5	4	30.8	1	7.7	0	0
Percentage	16.6%		13%		16.7%		53.7%	

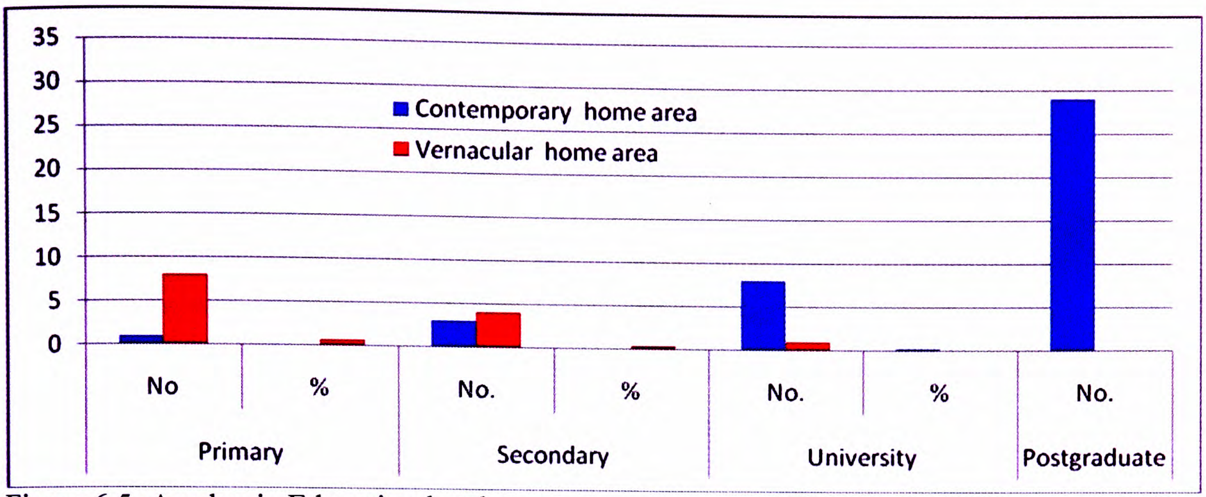


Figure 6.5: Academic Education level.

Number within the family: (Table 6.5 and Figure 6.6) demonstrate and classify the number of family members who live in the same house into four groups. The results show that 5-8 persons' families account for 64.8% of family make up in both areas and that 3-4 persons' families and more than 9 people in a family account for almost 16.7%. Amer (2007) found that 50% of his respondents lived in houses of 5-8 persons. This number of people when gathering together in a living room can help increase indoor temperature.

Table 6. 5: Number within the family.

Number of the family	1-2	3-4	5-8	More than 9
Contemporary home area	1	7	28	5
Vernacular home area	0	2	7	4
Percentage	1.8	16.6	64.8	16.8

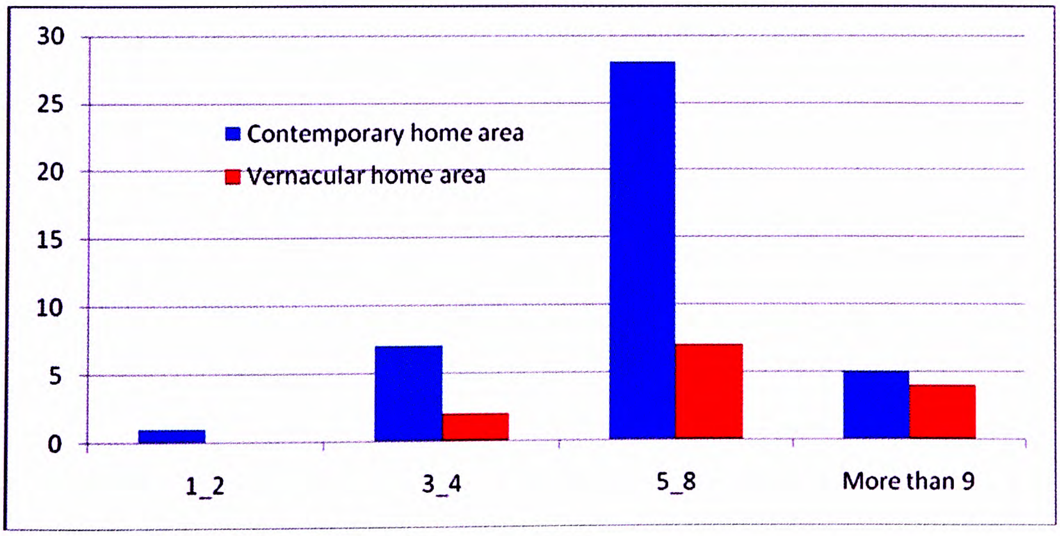


Figure 6. 6: Number within the family.

6.2.2 Part B: The housing situation in the contemporary area

This part of study relates to the residents who live in the contemporary area and used to live in courtyard houses.

Q1. The dwelling situation:

This question was asked in order to gain more information on the dwelling situation. It was divided into three subsections: the first was to identify the kind of houses the respondents currently use; the second was to learn how long they had been living in the dwellings and the third was to know how old these dwellings were.

Q1. A – The dwelling type:

In (Table 6.6 and Figure 6.7), the kind of dwellings is classified into four groups, according to the dwelling typology in Tripoli city. It shows that most of the residents live in villas and that 34.2% live in houses; 26.8% live in flats and no one lives in courtyard houses. The differences in the dwelling types could help in providing different views of the residents' satisfaction level concerning their current dwellings.

Table 6. 6: Type of current dwellings.

Kind of dwellings	Villa	House-attached house	Flat	Courtyard house
Respondents	16	14	11	0
Percentage	39	34.2	26.8	0.0

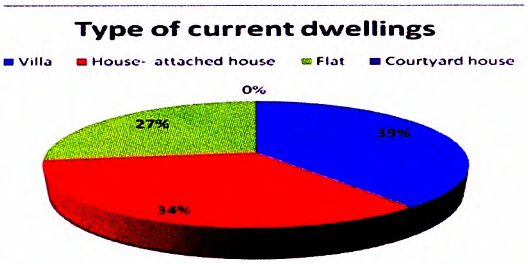


Figure 6. 7: Type of current dwelling.

Q1. B- Respondents' period of residence in their current house:

The respondents were classified into four groups, according to their length of stay in their dwellings. These differentiations indicate a variety of perceptions and adaptation to the way of life in Tripoli. As can be seen in (Table 6.7 and Figure 6.8) most of the respondents have lived in their dwellings for more than 11 years. This gives a good indicator that the residents have had enough experience to judge their dwelling.

Table 6.7: Number of years the respondents have been resident in their current dwelling.

No. of years	< 3	3-6	7-11	>11
Respondents	6	10	5	20
Percentage	14.6	24.4	12.2	48.8

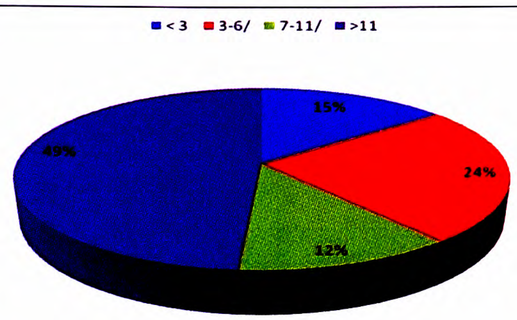


Figure 6.8: Number of years.

Q1.C- Age of current house:

(Table 6.8 and Figure 6.9) show that most of dwellings are older than 11 years, which guaranteed that respondents had a thorough knowledge of their houses and whether there were any problems in these dwellings.

Table 6. 8: Age of current house.

The age of dwellings	<3	3-6	7-10	11-15	>15
Respondents	2	8	10	10	11
Percentage	4.8	19.6	24.4	24.4	26.8

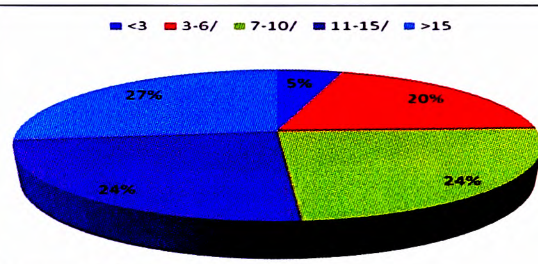


Figure 6.9: Age of current house.

Q 2- The question was asked to find out whether the respondents used to live in a courtyard house for a period of time before they moved into the contemporary one. The question was divided into three sub questions; the first was to discover the kind of house they were living in before moving; the second was to discover the period of time they experienced living in such dwelling and the third was to discover the age of their current house.

Q2.A- Previous dwellings situation:

(Table 6.9 and Figure 6.10) show that 100% of the respondents used to live in a courtyard house and that about 26.6% of them had moved from courtyard houses to flats or houses before settling in the current houses; this guaranteed that they could give a good comparison between their current and old houses.

Table 6.9: Kind of dwellings lived in before moving.

Kind of dwellings	House- attached house	Flat	Courtyard house
Respondents	6	5	41
Percentage	14.6	12	100

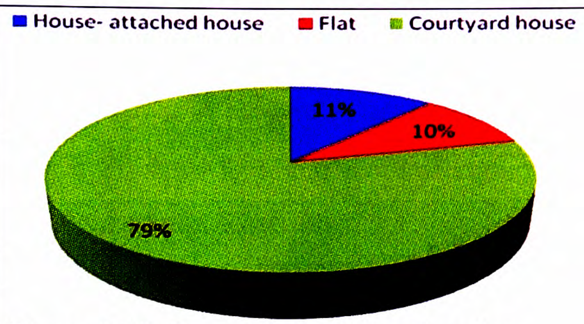


Figure 6.10: Previous dwelling situation.

Q2-B- Respondents' period of residence in the previous house:

As shown in (Table 6.10 and Figure 6.11), 78% of the residents lived in the courtyard houses for more than 11 years and 22% lived there for more than 7 years. This meant that they had experienced the advantages and disadvantages of this kind of dwelling.

Table 6.10: Number of years in the previous houses.

No. of years	< 3	3-6	7-11	>11
Respondents	0	0	9	32
Percentage	0	0	22	78

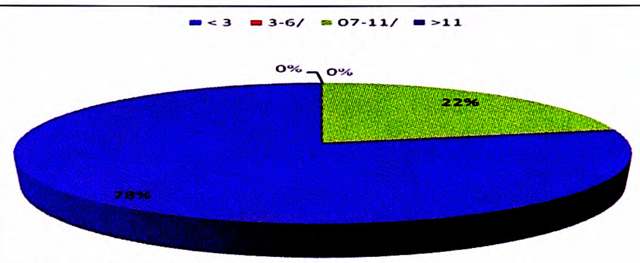


Figure 6.11: Number of years living in the previous house.

Q2-C- Age of previous house:

(Table 6.11 and Figure 6.12) show that 75.7% of the respondents confirmed that their previous house was older than 41 years old and 9.7% said that their previous house's age ranged between 21 to 30 years. This shows that the majority of respondents had had experience of living in a courtyard house.

Table 6. 11: The age of the previous dwellings.

The age of dwellings	<15	16-20	21-30	31 - 40	41-50	>50
Respondents	0	0	4	6	9	22
Percentage	0	0	9.7	14.6	22	53.7

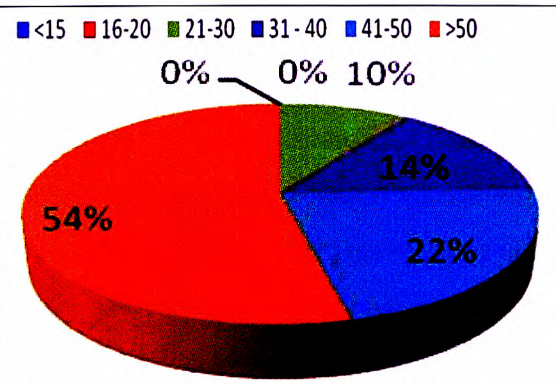


Figure 6.12: Age of previous house.

Q3- Reasons for changing previous houses:

This question was asked in order to understand the reasons as to why residents had moved from their former dwellings. (Table 6.12 and Figure 6.13) show that 36.6% of the respondents said that the main reason was the style and design of the house. However, 39.1% said that the decision to move was due to all the reasons given by the author and cited in the table. They also gave other reasons such as changes in social circumstances such as marriage; a change of work place and the fact that they considered the old house a temporary place to live until they built a new one. Amer (2007) found that 40.3% of his respondents had changed their house because they need more space. He also gave other reasons such as preferring to live near relatives and the fact that old houses need regular maintenance.

Table 6. 12: Reasons for moving from previous houses.

Reasons	Style and design	Size - areas	Technology	Construction	Building materials	All the previous reasons
Respondents	15	4	4	2	0	16
Percentage	36.6%	9.7%	9.7%	4.9%	0%	39.1%

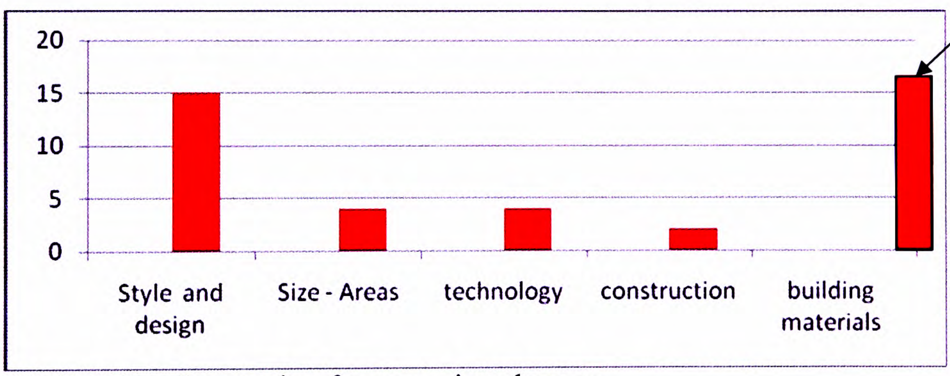


Figure 6. 13: Reasons for moving from previous houses.

Q4- Reasons for whether to live or not in the vernacular houses:

This question was asked in order to encourage respondents to give reasons whether it is possible to live in a vernacular house or not. The results shown in the (Table 6.13 and Figure 6.14) indicate that 87.8% of the respondents said they cannot live in vernacular house. The reasons they gave for this are shown in the same table. This result conflict with the results of Amer (2005) who stated that most Libyan families prefer to live in private houses rather than flats; this was because 50% of his respondents lived in flats, whereas only 26.8% of the respondents who took part in this study lived in flats.

Table 6.13: Reasons as to whether or not people liked to live in old-style housing.

Answers	Reasons
Yes	•It is good to live in old-style housing if some changes are undertaken. •It is well designed and constructed
No	•The number within the family has increased. •It is not comfortable in summer and winter. •The location of the courtyard in the middle without cover is not comfortable for people in terms of internal circulation. • The infrastructure needs to undergo regeneration. •Future extension is difficult. •It is not healthy •It is not suitable for using new technology. • The orientation of the house is not suitable to make the most of climatic conditions. •Need continuous maintenance. •All reasons given in Q3

Figure 6. 14: Living in the old-style house.

Q5- Suitability of building materials for the climate:

The reason for asking this question was to discover whether had an understanding of the building materials used in their houses. As can be seen from (Table 6.14 and Figure 6.15) more than 53% of the respondents thought that the building materials were not suitable for the local climate and 29% had no idea about the relationship between building materials and climate. The rest of the respondents (17%) think that it is appropriate. They gave reasons as summarized in the table.

Emhemed (2005) found in his survey that building materials were highly rated as suitable material by his respondents and that local materials used in traditional houses are very successful in providing suitable internal comfortable conditions and at low cost.

Table 6.14: Suitability of building materials for climate.

Answers	Reasons
Yes	• The building materials conform to international specifications.
No	• Building materials are not resistant to high external temperature; • The second floor level is always very warm in summer and cold in winter; • Building materials are expensive because they are imported; • Most contemporary houses are not comfortable without air conditioning
Do not know	• No comments

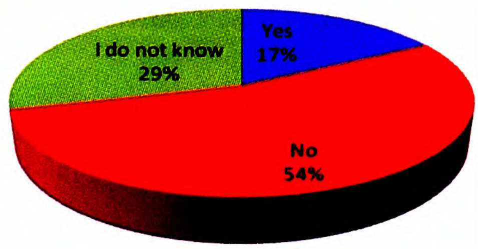


Figure 6.15: Suitability of building materials to the climate.

Q6- Sustainable houses:

This question was designed to investigate the respondents' understanding of sustainable houses. It was subdivided into two subsections. The first subsection was to find out the percentage of those respondents who have an understanding of sustainable houses and the second subsection concerned the expense of producing these kinds of houses.(Table 6.15 and Figure 6.16) show that more than 90.3% of the respondents had no knowledge concerning sustainable houses. This means that people are unaware of the importance of sustainable houses and thus need to be more informed on sustainability through different kinds of media.

Table 6. 15: Knowledge concerning sustainable housing.

sustainable house	Yes	No
Respondents	4	37
Percentage	9.7	90.3

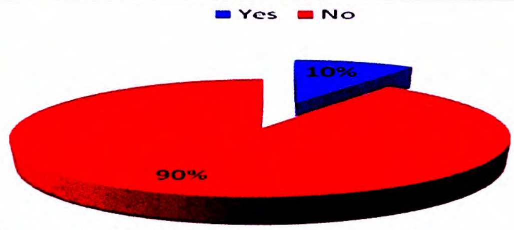


Figure 6. 16: Knowledge concerning sustainable house.

The second subsection indicated that 50% of those who answered yes thought that sustainable houses are more expensive than their current houses and the other 50% thought that they were cheaper. They gave the reasons presented in (Table 6.16 and Figure 6.17).

Table 6. 16: Sustainable house expenses.

Answers	Reasons
More expensive	• It needs special materials • The building materials used are very expensive; • It depends on using new technologies;
Less expensive	• The results of using these kind of building concepts can be seen after a period of time ; • It is dependent on using natural resources; • It is very expensive because the building materials are imported.

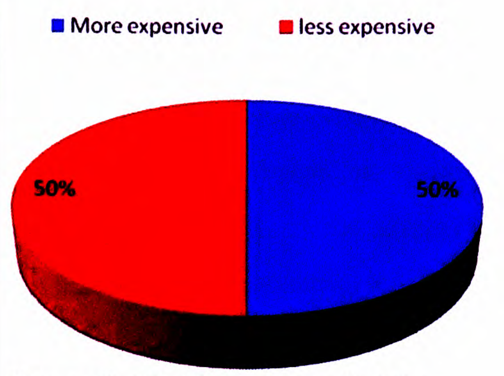


Figure 6. 17: Cost of sustainable houses.

Q7. Preferred types of houses:

Respondents were asked about what kind of houses they preferred. (Table 6.17 and Figure 6.18) show that 85.5% of the respondents preferred to live in modern houses with traditional with an option to use appropriate technology. About 10% preferred to live in modern houses which had a traditional style. Amer (2007) found that 46% of his respondents preferred villa type housing and 37% preferred the style combining both traditional and modern. This means that the respondents are likely to accept the final guidelines where solutions will be suggested that include both vernacular architecture and passive solutions.

Table 6.17: Preferred types of houses.

Preferred dwellings	Old Traditional houses	Modern houses	Modern houses with traditional style	Combined (tradition+ modern+ technology)
Respondents	0	2	4	35
Percentage	0%	4.8	9.7%	85.5%

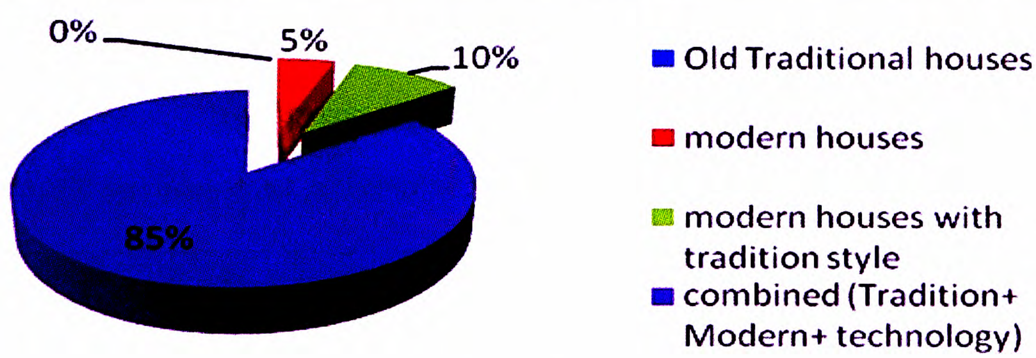


Figure 6.18: Preferred types of houses.

6.2.3 Part C1: The relationship between houses and climate in the contemporary area:

Q8- Environmental problems and building construction:

As can be seen in (Table 6.18 and Figure 6.19) almost half of the respondents (48.8%) thought that building materials and building construction contributed to increased environmental problems for the reasons presented in the Table. 34.2% of the respondents thought that the problems comes from the way the building materials are manufactured.

Table 6. 18: Reasons for building construction and environmental problems.

Answers	Reasons
Yes it increase the problems	• Current building materials are not appropriate for the local climate; • Manufacturing building materials contribute to polluting the air; • Extensive use of air conditioning helps increase energy consumption and increase warming the external air.
No relationship between building construction & environmental problems	• Any kind of building material can help in polluting the environment; the problem comes from the way they are manufactured and distributed.
I do not know	• No comments

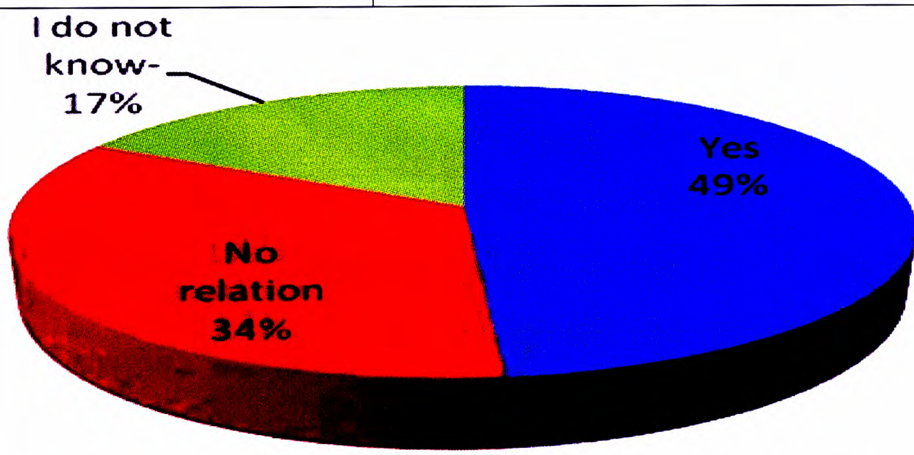


Figure 6. 19: Environmental problems and building construction.

Q9- Households' opinions about their houses in summer:

This question was asked to investigate the respondents' satisfaction level with their houses from the climatic point of view and to discover which kind of house can provide better climatic solutions. The question was divided into two subsections to give further detail on the respondents' choices. (Table 6.19 and Figure 6.20) show that 90.3% of respondents chose the courtyard house as being more comfortable in summer, whereas less than 10% preferred a contemporary dwelling. They gave the reasons illustrated in the table. Amer (2007) found that about 50% of his respondents in contemporary houses were satisfied and the other half were not, whereas more than 75% were satisfied with traditional houses and the rest were not. These results confirm the awareness of the respondents of the importance of the courtyard house in providing a pleasant indoor thermal comfort.

Table 6.19: Respondents' satisfaction with their houses from the climatic point of view.

Answers	Reasons
Courtyard house	• Good resistance to temperature; • Provides good lighting and ventilation; • Compact city concept helps reduce direct heat gain; • Healthy houses.
Current house	• Easy to use air conditioning; • Provides good lighting and ventilation.

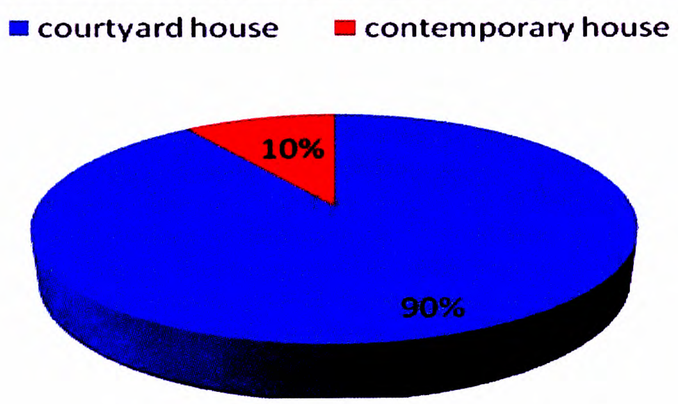


Figure 6. 20: Respondents' opinions about their houses in summer.

Q10- Using air conditioning:

This question was asked in order to investigate to what extent the residents depended on using air conditioning to achieve internal comfort. It was divided into three subsections. The first section was to discover the percentage of the respondents using air conditioning; the second section was used to discover the location of the air conditioning, and the third section was used to find out how long a period of time the respondents use air conditioning.

Table 6.20 and Figure 6.21show that 97.6% of the respondents use air conditioning and, as can be seen in (Table 6.21 and Figure 6.22), 68.3% of them using air conditioning in the whole house. (Table 6.22 and Figure 6.23) show that 34% of the respondents use air conditioning in the summer time and 39% of them use air conditioning when the temperature is very high. These results give an important indicator that using air conditioning is vital to achieve internal thermal comfort in contemporary houses. This, therefore, confirms the need to use climatic design principles in future houses in order to reduce dependency on air conditioning.

Table 6. 20: Using air conditioning.

Using air conditioning	Respondents
Yes	40
No	1

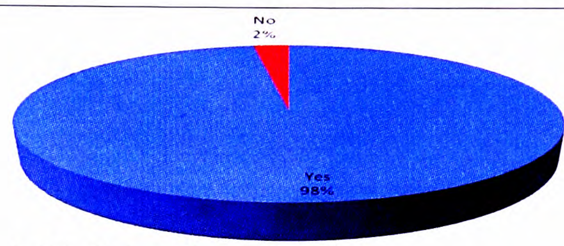


Figure 6. 21: Using air conditioning.

Table 6. 21: Position of the air conditioning

In which rooms	Respondents
Guest room	4 - 9.8%
Living room	7 - 17%
Bedrooms	2 - 4.9%
The whole house	28 - 68.3%

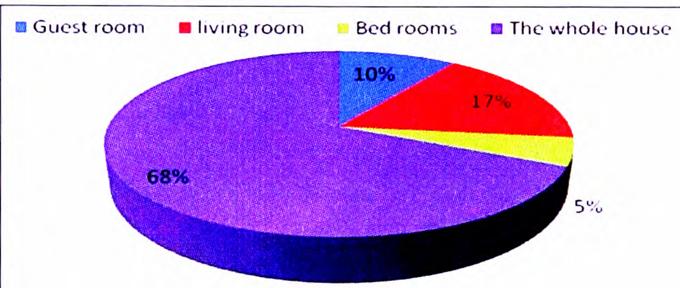


Figure 6. 22: Position of the air conditioning.

Table 6. 22: When respondents use air conditioning.

When using air conditioning	Respondents
All the year	11 - 26.8%
All summer time	14 - 34.2%
When the temperature is very high	16 - 39%
When the temperature is very low	0 - 0%

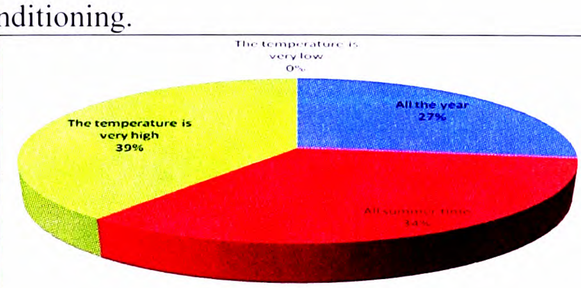


Figure 6. 23: When air conditioning is used.

Q11- Internal thermal comfort:

This question was asked in order to know what degree of temperature the respondents feel is very high where they feel they need to use means of cooling in order to achieve internal comfort. The results in (Table 6.23 and Figure 6.24) indicate that the majority of the respondents feel discomfort when the internal temperature is more than 30°C and 22% felt discomfort when the temperature is more than 25°C.

Table 6. 23: Internal thermal comfort levels.

Thermal comfort	Respondents
18 °C – 24 °C	0 - 0%
25 °C – 30 °C	9 - 22%
Above 30 °C	32 - 78%

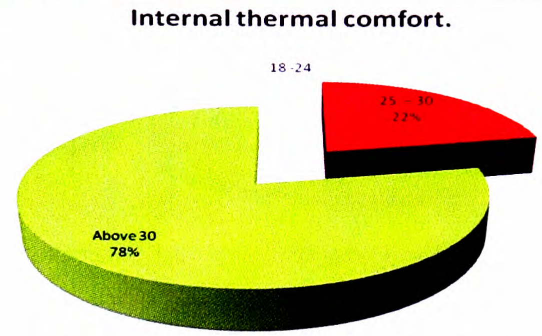


Figure 6. 24: Internal thermal comfort levels.

Q12- Households' opinions on how to escape high temperatures:

This question was to investigate respondents' solutions on how to escape high temperatures in cases where air conditioning was not used. The respondents gave the suggestions reported in (Table 6.24 and Figure 6.25). The majority of them (82.9%) chose to open windows to get cross currents of air; this indicates the importance of the orientation of the dwelling in providing a suitable air movement.

Table 6.24: Solutions for escaping high temperatures.

Solutions	Respondents
Open windows to get cross air currents.	34 - 82.9%
Visit a family that have an air conditioner.	0 - 0%
Sit in the garden	5 - 12.2%
Go to the coast.	2 - 4.9%

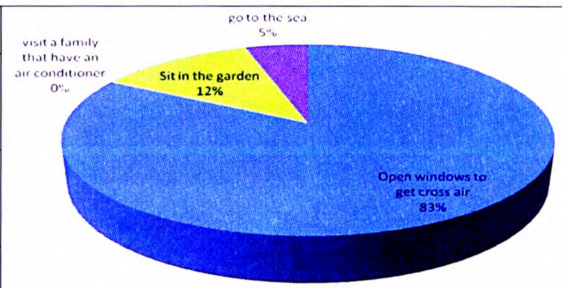


Figure 6.25: Solutions for escaping high temperatures.

Q13- Respondents' opinions on the relationship between health and building type:

This question was asked in order to investigate the opinions that the respondents held concerning the impact of buildings on peoples' health. (Table 6.2.25 and Figure 6.26) show that 63.5% of the respondents thought that the kind of building built can affect peoples' health and they gave reasons reported in the table. The rest of the respondents had no comment to make on the relationship between health and buildings.

Table 6.25: Impact of buildings on peoples' health.

Answers	Reasons
Yes	• Humidity in walls can cause health problems; • Sun and ventilation are very important to human health.
No	No comment
I do not know	No comment

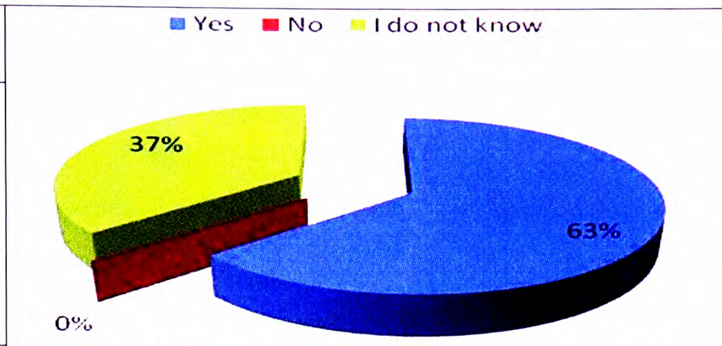


Figure 6. 26: Impact of buildings on peoples' health.

Q14- Respondents' opinions on the future houses:

This question was asked in order to investigate what the respondents felt they needed in their houses in the future. They were given suggestions and they were allowed to choose more than one suggestion or add their own suggestions.

The results shown in (Table 6.26 and Figure 6.27) show that 61.5% chose all the reasons cited in the table and the most popular choices were for safety, beauty and comfort, which accounted for 30.7%.

Table 6.26: Needs in future houses

Future houses	Respondents
Comfort	8
Beauty	4
Economic	2
Safety	4
Sustainability	0
All the prior reasons	38

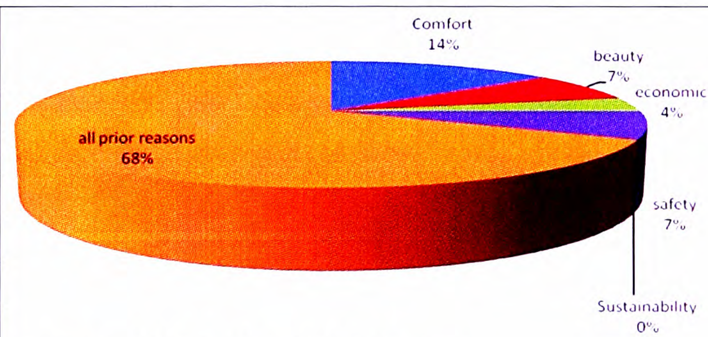


Figure 6. 27: Needs in future houses.

Q15- Problems or solutions that were not cited in the previous questions:

This question was asked in order to find out the householders' viewpoints on weather problems affecting their homes which were not covered by previous questions in the questionnaire. Respondents brought forward some issues that they saw as important for developing the microclimate condition in the city. These issues are summarised in the following points:

- Providing good landscape design and using trees can make a pleasant environment;
- Provide shaded areas can reduce heat gain;
- Using bright colours in facades helps to reflect sun.

6.2.4 Part B2: The housing situation in the vernacular area

This part of study relates to the residents who are still living in the vernacular area in courtyard houses.

Q1-A- B and C-The dwelling type, age and period of residence in current house: All respondents stated that they had been living in a courtyard house in the old city for more than 11 years. They confirmed that all the dwellings were older than 50 years. This information gives a good indicator of the residents' long experience of living in this kind of dwelling and thus of their apt suitability to judge their dwellings. The age of these dwellings means that any problems that might occur would have occurred in this time span and thus will have been experienced by the people living within them.

Q2.A- Living in the contemporary houses:

This question was asked in order to ascertain the reasons why people still live in the old city and what they felt the benefits were of living either in a courtyard house or in a contemporary one. (Table 6.27 and Figure 6.28) show that 69% of the residents wanted to change their current house to a contemporary one and 31% said that they were happy with their current house. Both sets of respondents gave reasons for their choices and these are presented in the table.

Table 6.27: Do the respondents wish to change their current house.

Answers	Reasons
Yes	•The old city has become a place for poor; •The space within the rooms are not appropriate for the furniture; • Circulation in the courtyard is difficult in summer and winter time; •Maintenance is difficult because of using different building materials; •The dwellings do not meet today's social needs, for example on sad or pleasant occasions; •Difficult to use desired technology such as cars or air conditioning.
No	•They cope with life in the courtyard house; •Most of their relatives live in the same area; •If they had money, they would rather cover the courtyard and keep maintaining their current house.

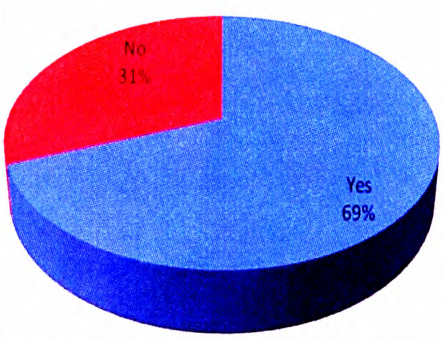


Figure 6. 28: Do correspondents wish to change their current house.

Q3- Covering the courtyard:

This question was asked to investigate the percentage of families that had covered the courtyard and to understand the reasons behind covering or not covering the courtyard. (Table 6.28 and Figure 6.29) show that more than 50% of the residents have covered the courtyard and others have not covered it; both groups gave reasons for this, which are presented in the table.

Table 6. 28: Covering the courtyard.

Answers	Reasons
Yes	•Protect the family from hot summers and rain and cold winters; •Allows them to use air conditioning; • The weather conditions became more polluted and many insects came from the courtyard.
No	•For economic reasons; •The courtyard is the only source of lighting and ventilation.

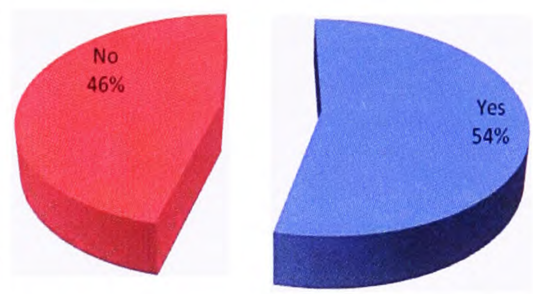


Figure 6. 29: Covering the courtyard.

Q4- Suitability of building materials to the climate:

As shown in (Table 6.29) all the respondents confirmed that the building materials were suitable for the microclimate, and they gave some reasons which are cited in the table.

Table 6. 29: Suitability of building materials for climate.

Answers	Reasons
Yes	• The thickness of walls delay the movement of temperature from outside to inside; • The external windows are too small and covered by Musharabia which provides light and; • Bright colours help to reflect the sun.
No	-

Q5- Sustainable houses:

This question was asked to know if people living in the vernacular area have some knowledge on sustainable houses. The results show that 100% of the respondents have no knowledge on sustainable houses.

Q6- Preferred types of houses:

(Table 6.30 and Figure 6.30) show that most of the respondents would prefer to live in modern houses with traditional style, 23% of them preferred traditional homes and the same percentage would prefer a modern house. This shows that people do like the advantages of modern and vernacular types of housing.

Table 6.30: Preferred types of houses.

Preferred dwellings	Old traditional houses	Modern houses	Modern houses with traditional style	Combined (tradition+ modern+ technology)
Respondents	3	3	5	2
Percentage	23	23	38.5	15.5

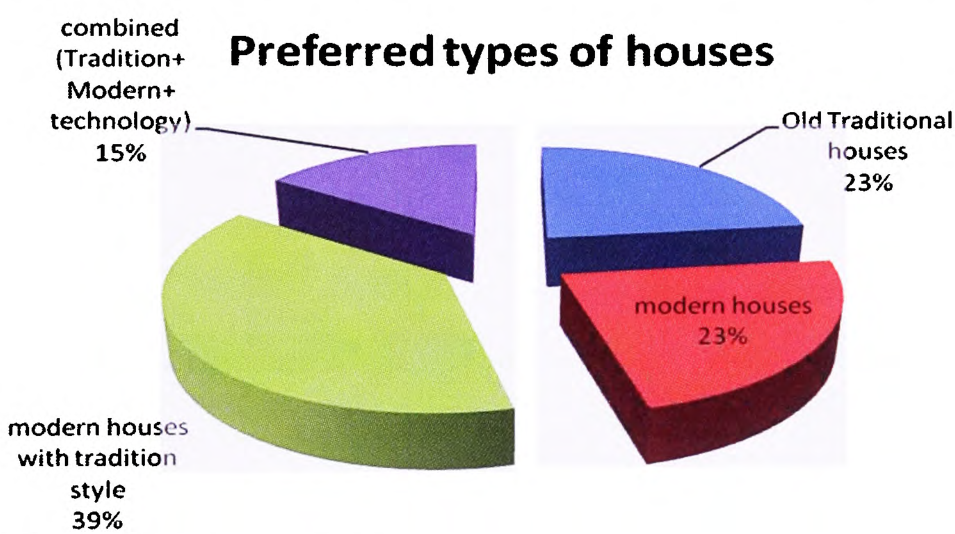


Figure 6. 30: Preferred types of houses.

6.2.5 Part C2: The relationship between houses and climate in the vernacular area

Q7. Environmental problems and building construction:

(Table 6.31 and Figure 6.31) show that the majority of the respondents thought that building materials and construction do not contribute to polluting the environment. And those who thought that it had contributed did not give any reasons for this belief. This means that people living in this area had no knowledge on the effects of building materials and the type of construction in polluting the environment.

Table 6.31: Building construction and environmental problems.

Answers	Reasons
Yes	• They feel that new kinds of housing increases health problems.
No	• No comments
I do not know	• No comments

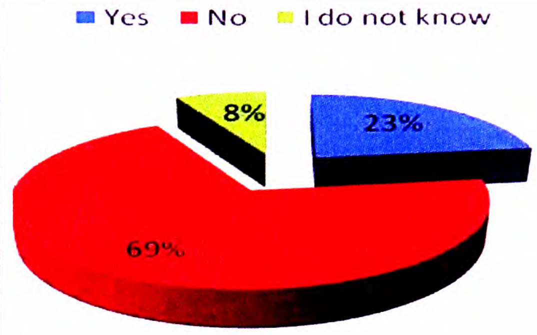


Figure 6. 31: Building construction and environmental problems.

Q8-Households' opinions about their houses in summer:

As can be seen in (Table 6.32 and Figure 6.32) 62% of the residents thought that courtyard houses are more comfortable in summer, whereas the rest (38.5%) thought that the contemporary houses are more comfortable. Both groups gave reasons which are presented in the table.

Table 6. 32: Respondents' satisfaction with their houses from the climatic point of view.

Answers	Reasons
Courtyard house	• Good resistance to high temperature; • Provides good lighting and ventilation; • Healthy houses.
Contemporary house	• Easy to use air conditioning; • Provides good lighting and ventilation.

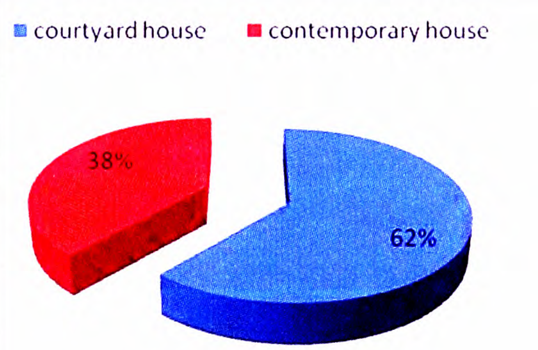


Figure 6. 32: Respondents' satisfaction with their houses.

Q9- Using air conditioning:

(Figure 6.33) shows that 38.5% of the respondents use air conditioning and 61.5% of them do not use it. (Figure 6.34) shows that 60% of those who use air conditioning use it in the living area and the rest use it in the guest room. Also, 100% of the residents who use air conditioning use it in the summer time when the temperature is very high. These results indicate that using air conditioning in vernacular houses is not felt to be as important using it in the contemporary houses where it is needed to achieve internal thermal comfort. This confirms the need for using climatic design principles in houses in the future in order to reduce dependency on air conditioning.

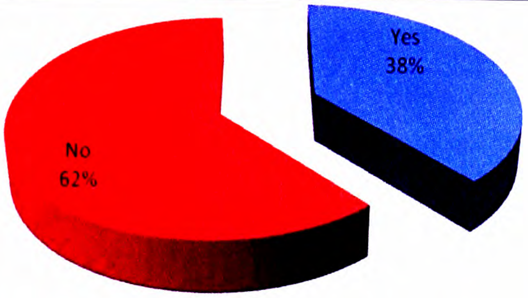


Figure 6. 33: Using air conditioning.

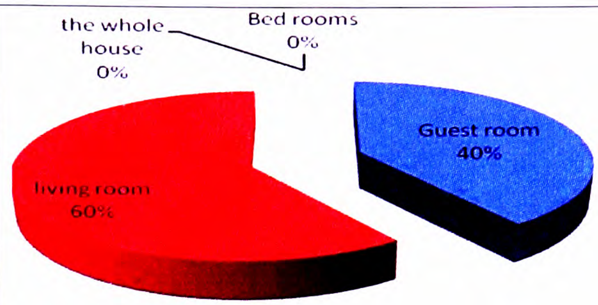


Figure 6.34: Location of the air conditioning

Q10- Internal thermal comfort:

All respondents felt discomfort when the internal temperature was more than 30°C. This means that there is a difference in the feeling of thermal comfort between the vernacular and contemporary residents, where 22% of the contemporary residents said they felt discomfort when the temperature was more than 25°C. This can be because of the dependency on using air conditioning which makes the residents feel uncomfortable when temperature reaches above 25°C.

Q11- Households' opinion in terms of escaping high temperatures:

To escape high temperatures, as (Table 6.33 and Figure 6.35) show, the majority of the respondents (77%) chose to open windows to get cross air currents, and 33% chose to go to the coast; this may be because the location of the old city is near the sea. The results confirm the importance of the orientation of the house in providing a suitable air movement.

Table 6.33: Solutions to escape high temperatures

Solutions	Respondents
Open windows to get cross air currents	10 - 77%
Visit a family that have an air conditioner	0 - 0%
Sit in the garden	0 - 0%
Go to the coast	3 - 33%

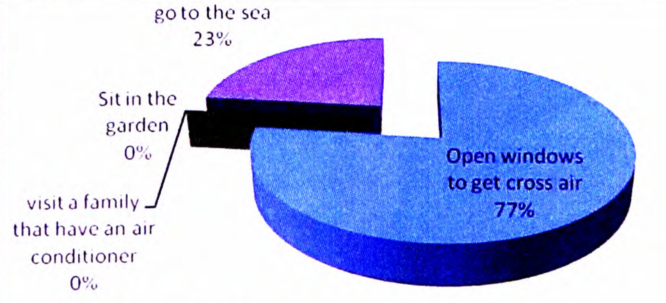


Figure 6. 35: Solutions to escape high temperatures.

Q13- Respondents' opinions about the relationship between health and building type: (Table 6.34 and Figure 6.36) indicate that 69% of the respondents thought some buildings can affect peoples' health and gave the reasons reported in the table. The rest did not know of any relationship between health and buildings. These results are similar to the outcomes from the residents in the contemporary area. This indicates that residents may accept new kind of houses that can offer more healthy spaces.

Table 6. 34: Impact of buildings on peoples' health.

Answers	Reasons
Yes	• Humidity increases health problems; • Lack of light and air may lead to affecting people psychologically.
No	-
I do not know	-

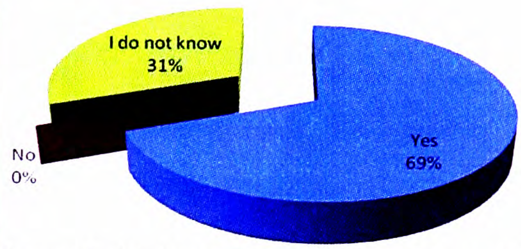


Figure 6. 36: Impact of buildings on peoples' health.

Q14- Respondents' opinions about the houses in the future:

The requirements that people desired in their houses in the future are shown in (Table 6.35 and Figure 6.2.37) and are exactly similar to that in (Table 2.26) which show that 61.5% chose all the reasons cited in the same table and that the priority choices went to safety and comfort which accounted for 30.7%. This shows that residents in both areas are looking for the same needs in houses in the future and thus the suggested guidelines will be useful for the all residents in Tripoli.

Table 6. 35: Needs in future houses.

Future houses	Respondents
Comfort	4 - 30.7%
Beauty	0 - 0%
Economic	0 - 0%
Safety	4 - 30.7%
Sustainability	0 – 0%
All prior reasons	8 - 61.5%
Total of choices	16 -

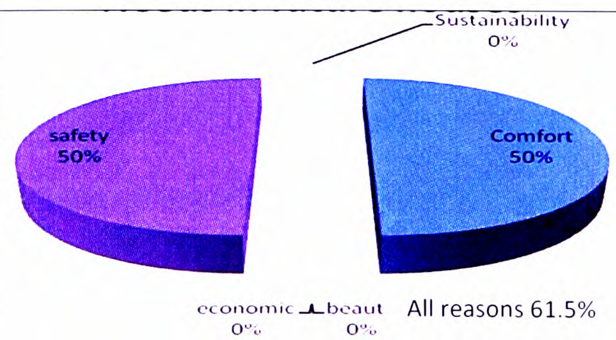


Figure 6. 37: Needs in future houses.

Q14- Problems or solutions not cited in the previous questions:

No answers were given for this question.

6.2.6 Summary of the findings of the views of householders

As stated previously, the questionnaire was distributed in two areas in Tripoli; the contemporary area and the old city area. The following discussion presents the main findings from each of them.

Part A: General information

- The main age group was over 41 years and was from both genders. The majority of the respondents were married. 26% of respondents were females, which is a sufficient number to give a satisfactory reflection of their opinions.
- The majority of respondents from the contemporary area held Postgraduate certificates and a high percentage of them were employees. On the other hand, the majority of the respondents in vernacular area held primary and secondary certificates.
- 64.8% of families in both areas lived in houses of 5-8 persons.
- From the general information provided by the householders, it is clear that all the respondents from the contemporary area have experienced living in courtyard houses and others still live in courtyard houses;, all of them are able to provide reliable opinions on the conditions of living in traditional and contemporary housing.

An assessment of the respondents' opinions about the dwelling conditions in both areas can be summarized as follows:

Part B: Housing situation:

- All the respondents from the contemporary area had experienced living in a courtyard type house for more than 7 years which ensured they had knowledge about both their current house and about local houses;
- The respondents who had changed their house to a modern house type had done so because they were not satisfied with the style, space, courtyard design and the inability to use new technology in the courtyard house.
- The majority of the respondents who lived in contemporary houses (88%) did not want to live in the courtyard type for social and climatic reasons. Others thought that they could live in a courtyard type house if some changes were made to meet current life needs. 69% of the respondents from the vernacular area were of the same opinion were the majority of them are covered the courtyard.
- 53.6% of the respondents from the contemporary area and 100% of the respondents from

the vernacular area thought that current building materials are not suitable for the local climate.

- About 90% of the respondents from the contemporary area and 100% of the respondents from the vernacular area have no knowledge on sustainable houses. This means that more attention should be paid to inform people about the importance of applying sustainable concepts in their houses.
- 85% of the respondents from the contemporary area and 38.5% of the respondents from the vernacular area preferred to live in houses that combined traditional and modern styles and included modern technology.

Part C2: The relationship between houses and climate

- 48.8% of the respondents from the contemporary area thought that building materials and methods of construction could increase environmental problems. Whereas 69% of respondents from the old city thought that there was no relationship between building materials and pollution. This result is not strange because the majority of the respondents from the contemporary area held postgraduate degrees. majority of the respondents from the local area had received less education (holding primary or secondary certificates only) and therefore were likely to be less aware of environmental issues.
- 90% of the respondents from the contemporary area thought that courtyard houses were more comfortable in summer. Whilst only 61.5% of respondents from the vernacular area were of the same opinion. This indicates that those who have experienced living in both kinds of dwelling can judge the housing performance better than those who have lived in one type of house.
- 97.6% of the respondents from the contemporary area use air-conditioning. 68.3% of them use it in the whole house and 26.8% use it all the year. On the other hand, 38.5% of the respondents from the old city use air-conditioning only in the living room or in the guest room when the temperature is very high. These results indicate that air-conditioning has become an important element in achieving internal thermal comfort.
- 78% of the respondents from the contemporary area and 100% of the respondents from the vernacular area stated that they feel uncomfortable when the temperature goes above 30°C.
- 82.9% of the respondents from the contemporary area and 77% of the respondents from the vernacular area chose to open windows to get cross air currents as a solution to escape high temperatures when there is no air-conditioning. This indicates the importance of the windows' location and size in achieving suitable light and air movements.

- 63% of the respondents from the contemporary area and 69% of the respondents from the vernacular area thought that building design and materials can affect people's health.
- 30.7% of the respondents from both areas chose safety and comfort as the main factors that should be taken into consideration in their future houses. 61.5% of the respondents from both areas chose comfort, beauty, cost, safety and sustainability as the main factors that should be taken in consideration when choosing future houses.

6.2.7 Final findings from the residents' survey

- Respondents had changed from their traditional houses because they were not satisfied with the style, space, the courtyard location and also because it is difficult to use new technology in such houses.
- The majority of the respondents (more than 69%) did not want to live in the courtyard type house for social and climatic reasons. Whereas less than 31% thought that they could live in a courtyard type house if some changes were made to meet current life needs.
- Most of the respondents thought that current building materials are not suitable for the local climate.
- The majority of the respondents (more than 90%) had no knowledge of sustainable houses.
- Most of respondents preferred to live in houses that consisted of a combined house style (that is, a style containing both traditional and modern features and including modern technology.
- About half of the respondents from the contemporary area thought that building materials and methods of construction can increase environmental problems, whereas 69% of the respondents from the vernacular area thought that there is no relationship between building materials and pollution.
- 90% of the respondents from the contemporary area thought that courtyard houses are more comfortable in summer, whereas only 61.5% of the respondents from the vernacular area were of the same opinion.
- Almost all the contemporary area respondents use air-conditioning all the year. 38.5% of the respondents from old city use air-conditioning only when the temperature is very high.
- About 83% of the respondents from the contemporary area and 77% of the respondents from the vernacular area chose open windows to get cross air currents as a solution to escape high temperatures when there is no air-conditioning.
- 61.5% of the respondents from both areas chose safety, comfort, beauty, cost and sustainability as the main factors that should be taken into consideration in future houses.

6.3 INTERVIEWS WITH THE PROFESSIONALS

This section presents the analysis of the interviews conducted with Libyan experts (11 architects and planners and 3 civil and property of materials' professionals) to explore their opinions on design and construction in terms of climatic design of modern housing for Tripoli society.

The interviews were carried out during July and August 2008 and in May 2009 in Tripoli city. Each interview took between 40 to 90 minutes and was recorded on tape. The interviews were in Arabic and the author in translation attempts to present the same sense of the interviewees' meaning. The background of the interviewees is presented in (chapter 5, Table 5.5).

6.3.1 Architects and planners

All 11 Libyan architects and planner professionals were working in academia and in industry. 8 of them were male and 3 were female. All of them have from 16 to 35 years of experience. The interviews consisted of 14 questions (see Appendix 1). The same 5 questions that were asked of the civil and the property of materials' professionals are analysed in the same section where the results of these 5 questions asked of the architects/planners are also analysed.

Q1. The professionals' opinions of contemporary housing in terms of suitability to the environment:

(Table 6.36) shows that all the interviewees confirmed that Libyan contemporary architecture is not appropriate for the local climate. Some of them thought that it is damaging the environment. Others explained that not only the architecture is not appropriate but that urban planning and streets are not appropriate as well. Interviewee 4 stated '*The problem is not only how can we reduce direct hear gain but also how we can reduce solar radiation from the streets and pavements, for example*'

Table 6. 36: Contemporary housing and the environment.

Contemporary housing and the environment	Not suitable	Suitable	Average
Architects and planners	11	0	100%
Civil engineer and specialist materials' professionals	3	0	100%

The reasons behind these ratings given by the professionals are summarised as follows:

- Designers do not considering climate as an important aspect in the design stage;
- Building materials used in construction and finishing are not of good quality and the same building materials are used in different geographical locations, also the building materials are not compatible with international specifications;
- Depending on air conditioning to achieve internal thermal comfort causes health problems and increases pollution and energy reservation became international demand;
- Functional living and personal comfort take priority over climate;
- The extensive use of technology contributes to rising environmental pollution and to increasing energy consumption.
- Marketing such as 'designers, labour and available building materials and its cost' are controlled by the government or dealers;
- Houses are usually not designed by architects but rather by some draftsman copying from previous work without taking the climate or the environment into consideration;
- The organisation and direction of the architectural work by the government.

These findings confirm the general opinion that current architecture contributes to increasing energy consumption and pollution, and explains the need to include climatic design in the design of housing in order to produce better building performance.

Q2. Old traditional housing and its suitability to the environment:

As it can be seen in (Table 6.37), 100% of the professionals stated that the old traditional houses are more environmentally friendly than the contemporary ones. However, all of them confirmed that these houses' major usefulness was in the past time and not in today's world because lifestyle has changed and people's needs are different. Accordingly, design concepts and building materials should be improved to meet today's needs. For example, Interviewee 3 stated that 'we are talking about past emotionally and feel that it is always better, but if we experienced living there currently, we would face problems that would change our opinion. In the past, life was difficult and people were poor; nothing from these difficulties remains in our mind and the only things remembered are some features (courtyard, fountain, shadows and vegetation)'.

Table 6.37: Old traditional housing and its suitability to the environment.

Old traditional housing and the environment	Suitable	Not suitable	Average
Architects and planners	11	0	100%
Civil engineer and specialist materials' professionals	3	0	100%

Professionals explained the reasons for their thinking as:

- Traditional houses are more suitable for the local climate, taking into account the kind of building materials used;
- Traditional houses use local natural materials, compact forms, thick walls and small windows;
- They have been observed for a long time and have proved their suitability to the climate.
- Courtyard houses usually feature an internal garden consisting of trees and a fountain that help to regulate internal climate.
- Old traditional houses have evolved as results of experiments and continuous experiences.
- Compact forms help to reduce direct heat gains where narrow streets increase shading and most surfaces are protected from the direct sun.

The findings again confirm the importance of vernacular architecture and the many lessons that can be learned. The professionals stated that traditional houses in their old style may not be as useful as before; however, if these houses are improved to meet modern needs they will help in improving current houses to meet needs more efficiently.

Q3. Improve traditional housing to conform with current requirements:

All interviewees held the opinion that this kind of architecture had existed for centuries and that it had proved its suitability to local climate. However, they believe that the existing old traditional houses cannot be amended, because the old city lacks the appropriate infrastructure (sewerage, electricity, telecommunication) and also the spaces and areas are too small and can not be changed to meet today's needs. In addition to these problems, Amer (2007) found other negative aspects of traditional houses such as:

- Unsuitable for the winter climate when the rain and cool wind enter the open courtyard;
- Limited in its vertical and horizontal extension capacity;
- Weakness of ventilation in the kitchen and the bathroom;
- Lack of privacy in the house and poor organisation between elements of the house. The

experts explained that in current times people live in very different circumstances from those who were living in traditional houses; many social manners today have changed, now there are new houses built for a new lifestyle. Changes in lifestyle and the appearance of technology can makes change very difficult, however, the features of traditional houses can be used in future housing by understanding the main reasons cited in question 2 and improving the building style. The following are the suggestions put forward by the interviewees;

- Certain features of vernacular houses can be used in contemporary houses and indeed certain features in vernacular houses can be improved upon and also used in contemporary houses.
- The city can be compact but the need for cars should be taken in consideration, and trees can help to provide shade.
- The position of the courtyard in the middle of the house does not maximise comfort and it can be shifted to the side or should be covered if located in the middle.
- The understanding is that the main reason for the courtyard is to serve social and religious aspects of life more than for climatic reasons. The courtyard can also exist for many other reasons: the land area is small; only one elevation faces the street; shared walls have been built because of economic factors and the compact form makes it the only source for providing air and light. Accordingly, the concept of the courtyard started as a need to have a source of light and air. However, it cannot be ignored that the concept of the courtyard has been experimented and improved through centuries and has proved its suitability to local climate.
- The principles learned from vernacular architecture should be used as a reference and should include building laws.
- Specify the advantages of vernacular house and re-applicant the positive features in a modern way so that people can be convinced by examples and experiments.
- Study building materials used in the vernacular houses and improve it to be used in a modern way.

In addition to the previous suggestions, Amer (2007) found that the most important strengths of the vernacular houses are: suitability for the climate, good privacy particularly from the streets and the fact that they provide more safety in terms of children's playing area.

The suggestions of the professionals confirm the importance of using improved features from vernacular houses in future housing projects.

Q4- The advantages and disadvantages of contemporary houses:

Almost all the professionals confirmed that the advantages of current houses are greater than their disadvantages. The main advantages are as follows:

- They provide for the needs of a person and his/her family;
- They are appropriate to the needs of today's life style;
- They provide internal comfort;
- They provide privacy (the capability to separate men and women);
- A good distribution of space;
- They provide appropriate areas which are suitable for all functions and furniture, and for privacy;
- more safe; and
- They have a good quality of finishing.

Amer (2007) listed other advantages such as: can allow for possible future extension; good ventilation and lighting; the fact that they offer safe construction and allow the use of new technology.

On the other hand, the main disadvantages of contemporary houses as given by the professionals are as follows:

- Contemporary houses do not respect climatical and geographical circumstances, and kill green areas;
- They are more expensive;
- They are not healthy;
- They do not depend on using local materials;
- They depend on air-conditioning to achieve comfort.

In addition to the disadvantages within contemporary houses listed above, Amer (2007) found other disadvantages such as: building materials are unsuitable for the local climate; ignores privacy from the street and neighbours.

Q5- Improvement of contemporary housing to be more sustainable:

Interviewees were asked about how to develop contemporary housing to achieve the needs of citizens and the environment. This question would help in clarifying the main factors that can affect houses in the future, and would also assist to find out the answer to the main research question (how to implement climatic design principles in future housing).

The interviewees stated that developing current houses in order to reduce environmental impacts is not an easy objective in a locality where climate is one of the main aspects that is needed to be taken in consideration alongside social, economical and political aspects when planning the building of houses in the future. Accordingly, interviewees stated that there are four other important factors that should be considered when building houses in the future and these are: designers, users, marketing and government. They offered suggestions to improve matters and these are summarised as follows:

Architects:

- Design concepts should consider people's behaviour, changes in lifestyle and the needs of a person and a family such as the need for comfort (thermal, visual, functional and safety aspects);
- Sustainable architecture and climatic design principles (such as location, land topography, orientation, openings' sizes and position and building materials) should be considered while at the design stage;
- Reduce energy consumption by using renewable energy as the main driver to achieve comfort. Use passive design techniques such as solar panels, double walls and a solarium within the house;
- Protect houses' external skins from direct heat gain by providing good orientation, shading, air ventilation and curved surfaces with more attention given to roof design as the sun is located on it almost all the day. The shape of roofs can have some angles or curves or, if it is flat, it can be shaded by vegetation or any light materials;
- Reduce energy and cost by increasing the internal walls' height and add upper openings to allow hot air to exit. Pre-plan the house's utilities so as to reduce the number of pipes dealing with water and sewage;
- Improve on traditional solutions' concepts such as using staircases as wind catchers. Reuse the courtyard concept in modern way;
- Consider the house and its surrounding by understanding the land use, the landscape, buildings' locations and building design. City design should consider the need for cars, and the city can be compact by using trees and different kinds of shading devices;
- Select appropriate building materials with more attention given to using thermal insulation;
- Avoid disadvantages of current houses as listed in question 4;
- Architects should be creative and be free minded thinkers;

- More studies are needed to improve local materials.

Users:

- Reduce dependence on air conditioning to achieve internal thermal comfort;
- Be aware of the concepts and benefits of sustainable design;
- Understand and respect the building laws;
- Be aware of the importance of climatic design.

Market and Procurement:

- Provide suitable building materials at appropriate cost;
- Provide good labour;
- Examine current building materials and improve upon them.
- Reduce energy consumption when producing building materials
- Reuse the building waste.

In addition, Amer (2007) identified that imported materials suffer from a lack of control over the construction market which leads to the lack of adequate shortage proportion of building materials required in the area of housing.

Government:

- Implement houses' projects using sustainable concepts and encourage people to look at sustainability, experiment with it and convince them of its benefits. These projects should be developed continually;
- Use the media to convince people to accept sustainability concepts;
- Set competitions to select the best projects and test these projects by people/experts who are able to specify the advantages and disadvantages of each project;
- Building laws should be changed and include strict roles that designers and users can follow and this, in turn, will assist in reducing wrong procedures;
- Provide codes related to building materials;
- Ensure architects are included in the design process and organize take part in regulating the profession;
- Ensure that there are groups who will protect Libyan heritage;
- Produce building materials of appropriate cost.

In 2007 Amer stated that the government and individual civil servants are not willing to new approaches to providing housing.

Q6- Effect of building cost on the shape and methods of construction;

All the interviewees confirmed that cost is a very important factor in construction. However, they indicated that the cost of housing in Libya cannot be taken as a sign of its architectural value because it can affect positively or negatively; it all depends on the architects, the customers and supervision. They summarized the main points relating to cost and buildings as follows:

- The availability of building materials_can reduce or increase the overall cost; accordingly, it can affect the choices of appropriate building materials.
- The costs of providing the framework do not vary enormously, but the differences in cost can be found in the finishing.
- Climatic solutions need special cost studies, for instance for using double walls, different kinds of shading devices and materials. However, the extra costs of providing climatic solutions do not exceed 5% of the total cost of normal buildings and its future impacts are great.
- Economics play a great role in the creation of new buildings as people desire to get away from their old thinking and look for comfortable spaces to reflect their wealth by increasing the number of spaces, areas and decoration. On the other hand, people want to complete their houses in any way that overrides environmental consideration. And if someone has a lot of money, the customer wants to show their wealth in any form which can result in strange types of architecture.

Q7- Suitability of construction materials used in contemporary housing to the climate of the region:

This question was asked of all interviewees (architects and the civil engineers) and all of them clarified that there were no local studies related to this topic in Libya and also that suitable building materials are not usually offered. They confirmed that current Libyan buildings are depending on using reinforced concrete that has a bad effect on environment while being manufactured and constructed. In addition, the same building materials are used in different geographical regions. Amer (2007) found that 75% of his respondents confirmed that building materials used are not suitable for the climate and the rest of the respondents thought that they are good in quality and perspective.

The interviewees clarified that current building materials have some advantages such as strength and availability; however, they are not suitable to the climate because they consume energy while being producing and do not include any thermal insulation. They confirmed that more studies on available building materials are needed to reduce the use of concrete and consequently reduce its cost. Sand can be used as an alternative material.

Q8- Implementing sustainable housing concepts by ordinary inhabitants:

Answering this question, the interviewees described sustainable architecture as an economic expression meaning to protect current energy for the next generations and provided a reasonable definition for it (Existing energy has not been given to us by our ancestors; we have merely borrowed it in order that we can pass it on to our grandchildren).

They had different opinions about the ability of ordinary inhabitants to implement sustainable housing concepts. 45.5% of them thought it would be easy to implement sustainable housing concepts if some needs were provided, and the rest of them thought it was not so easy. Both sets provided the reasons cited in (Table 6.38).

Table 6. 38: Implementing sustainable housing concepts by ordinary inhabitants.

Sustainable concepts	Experts	Reasons
Easy to Implement	5 – 45.5%	• If the materials are provided and at reasonable price. • If inhabitants are fully aware of the concepts and ideas of sustainability. • If the inhabitants can incorporate good design and have enough money. It depends on their understanding and wages.
Difficult to implement	6 – 54.5%	• There is no clear direction towards these kinds of concepts, • The Libyan market does not provide suitable building materials. • It will cost the inhabitants extra money.

Q9- Influences of western architecture on modern Libyan house designs:

All the interviewees confirmed that western architecture had influenced the style of modern architecture in Tripoli. It had affected the style negatively by ignoring the concept of traditional houses and the courtyard has disappeared from new buildings. Consequently, new architectural styles have appeared such as balconies and large glass windows and current houses miss a Libyan/local identity. It also affects people's attitude towards society and vernacular houses are increasingly being regarded as a sign of poverty and non-civilized living. On the other hand, western architecture provides user satisfaction by increased area, numbers of rooms and privacy. Amer's research (2007) confirmed these opinions.

Q10- Suitable building forms for Tripoli's climate:

Interviewees were asked why flat roofs are commonly used in Libyan houses and what is the best suitable form for the Tripoli climate. They explained that the main problem of houses in hot regions is the shape of roofs. The sun is located on the roof almost all the day; therefore, it is better if roofs have some angles or curves to reduce the amount of direct sun. Roofs can also be shaded by vegetation or any light materials. The interviewees stated that the main reasons for using flat roofs in Tripoli is that they are technically easier to be erected, easier if future extensions are desired, they collect rainwater, they are economic and flexible in providing extra spaces such as providing extra space to host wedding guests overnight during the summer).

The second part of this question was on the best form or architecture for the Tripoli climate. The interviewees stated that suitable building forms can be rectangular where the longest side should face north, that curved surfaces are better than flat surfaces and square compact forms with courtyard. They confirmed that the form should be designed in such a way to meet climatic needs by providing the following:

- Reduce surfaces facing direct sun by shading (within the building itself, shading devices and trees);
- The longest elevation should face north and south;
- Ensure internal cross ventilation;
- Vegetation and shading roofs.

Q11- Using elements from local vernacular architecture in future housing:

All interviewees agreed that vernacular architecture had provided very good solutions in the past and had proved its suitability to the climate. They confirmed that if features from vernacular houses were developed and used in a suitable way it could well help in improving future houses and in providing a special local identity. They also pointed out the importance of convincing people to accept these ideas.

Q12- Using elements from international vernacular architecture in future housing:

The interviewees were asked about using features from international vernacular architecture in Libyan houses in the future. The respondents were not against using such features if they were suitable to the climate and could help improving building performance. However, they insisted that such features should be used in a careful way because it could improve future housing if used in a suitable way, and it could create new architecture that is not connected to local vernacular architecture. They believed that it is all about the architects' and users' understanding of using these elements and how to improve the concept of these elements not just the shape of the building.

Q13- The best model of house:

All the interviewees were asked their opinion about the best housing model. All confirmed that there is no specific best housing model because housing is a complex issue and depends on personal needs. However, they thought that the following elements should exist in a best housing model: it should include sustainable housing concepts, provide for people's needs, offer comfort, safety and beauty and should help in reducing energy consumption. Additionally, some interviewees stated that the best model should respect building laws and consider the need for thermal resistance, use technology and developed building materials, use vernacular architectural features such as the courtyard concept with some modifications, curved roofs and use malgaf and mashrabia.

Q14- Designing a special architectural model with special specifications appropriate to the particular region and climate:

The interviewees were asked about the possibilities of designing a model that can be used as a reference that can help architects when designing in the same circumstances. The majority of the interviewees did not welcome the idea of a fixed model because of the different views and needs; one model may not be suitable for everyone. Additionally, the availability of unlimited information and the variety of buildings materials available means that designing such a model would not be easy. However, instead of designing a model, it could be useful to provide general strategic guidelines that include scientific facts that can be used as references to help architects when they are considering designing a house in Libya's climatic conditions. This guideline can be described as zoning concepts which gives appropriate guidelines and leave the design to each architect to put in their views when implementing these guidelines.

Amer (2007) clarified that design guidelines are sometimes seen as a control to designer's freedom, accordingly, the designers would often, therefore, resist such a control. On the other hand, three of interviewees stated that they could design a flexible model which could be used as a guidance for designing houses that are located in the same climatic conditions.

6.3.2 The civil engineer and property of materials' professionals

The architects and the planning professionals confirmed the importance of the use of building materials in achieving climatic design. 3 extra interviews were also undertaken with I civil engineer working in the industry and 2 specialists in building materials working in the building materials department of an industrial research centre. All of them had from 18 to 26 years of experience. The interviews consisted of 10 questions (See Appendix 3). 5 of the questions asked were similar to 5 asked of the architects and were analysed above and the rest are analysed below.

Q5- Local building materials' and reducing the load of air-conditioning:

The interviewees were asked about local building materials and their contribution in reducing the burden of air- conditioning in contemporary housing. They stated that there are no studies about local building materials to know more of their performance. However, it can generally be assumed that improving local building materials with specific classifications and appropriate diminutions could help in reducing the use of air conditioning. In addition, thicker walls and roofs can help in delaying heat transfer.

Q6- Improving local building materials:

All interviewees confirmed that in order to improve the performance of local building materials, extensive research and laboratory experiments on current and traditional materials are needed.

Q7- Development of the building materials industry in Libya:

All interviewees confirmed that there is improvement in producing building materials such as steel, cement and hollow concrete bricks. However, attention is still not paid to those building materials that relate particularly to the climatic aspects of building such as insulation. Local building materials are improving slowly; there is some improvement in the manufacturing of hollow red brick but its effect on the environment is uncertain.

Q8- New studies in developing local building materials:

The interviewees clarified that there are some studies at an initial stage as an attempt to improve the quality of sand but these developments have not been used in a real building as yet.

Q9- Responsibility for developing local building materials:

All the interviewees confirmed that the development of building materials is the responsibility of both people and the government. The government should provide appropriate building materials and people should know how to use them.

6.3.3 Summary of the main findings of the professionals' opinions

This part summarizes the main findings of professionals' views. It is divided into two sections; the first presents the general findings and the second gives the findings related to the application of climatic design in Tripoli.

Part One: The general findings are summarised by the following points:

- All the interviewees confirmed that Libyan contemporary architecture, urban planning and streets' design are not appropriate to the local climate.
- All the interviewees agreed that vernacular architecture provides very good solutions which have been practiced through centuries and these have proved their suitability to the local climate. Accordingly, they stated that old traditional houses are more environmentally friendly than the contemporary ones.
- Almost all professionals confirmed that the number of advantages provided by current houses are greater than the number of disadvantages.
- The interviewees indicated that, in order to reduce environmental impacts and apply climatic, social, economical and political aspects to future housing, four factors that can contribute in developing current houses are: designers, users, marketing and government.
- About half of the interviewees thought that ordinary inhabitants have the ability to implement sustainable housing concepts whereas others thought it would not be so easy.
- All the interviewees confirmed that western architecture has influenced the style of modern architecture in Tripoli both negatively and positively.

- All the interviewees confirmed that there is an improvement in the production of building materials such as steel, cement and hollow concrete bricks. However, more studies are needed to look to improving local materials. The development of building materials is the responsibility of both people and the government.
- The majority of the interviewees (9 out of 11) stated that architects should be creative and free minded. They suggested that instead of designing a fixed model, it would be more useful to provide general strategic guidelines (that include scientific facts) which can be used as references to help architects when designing and wishing to take on board climatic considerations.

Part Two: findings relating to the application of climatic design in Tripoli:

As stated previously, many factors have an important role in the implementation of climatic design in Tripoli where the interviewees believed in the importance of architects' and users' understanding of how to use these elements in addition to a knowledge of available building materials and government support. They offered suggestions to improve these factors and these are summarised as follows:

Factor 1: Architectural and planning design: The design concept should consider the following strategies:

For social needs:

- ➢ Respect people's behaviour, changes in lifestyle and the needs of persons and their families for comfort (including thermal, visual, functional and safety factors;

For economic needs:

- ➢ Reduce energy consumption by using renewable energy and passive design techniques such as solar panels, double walls and solarium house. Also by increasing the internal walls' height with upper openings to allow hot air to exit;
- ➢ Reduce the cost by gathering together the services (kitchen and toilets etc) to reduce the number of water supply pipes and sewerage pipes.

For climate reasons:

- ➢ Apply sustainable architecture and climatic design principles at the design stage;

- Use and improve on traditional concepts such as using staircases as wind catchers. Also reuse the courtyard concept in a modern way.
- Consider the house and its surroundings by understanding the land use, landscape, buildings' locations and building design.
- The city design should consider the need for cars, and in this scenario the city can be made more compact by using trees and different kinds of shading devices.
- Using national and international vernacular architectural features such as the courtyard concept with some modifications; curved roofs; malgaf and mashrabia in Libyan houses in the future in a careful way.
- Buildings should be designed in such a way to meet climatic needs by considering the following:
- Curved surfaces are better than flat surfaces particularly with attention to roof design;
- Provide good orientation;
- Study openings' sizes and position;
- Reduce the amount of surface facing direct sun by shading (by the building itself and by shading devices such as trees and vegetation);
- The longest elevation should face north and south;
- Ensure there is internal cross ventilation;
- Consider the need for thermal resistance;
- Use technology and developed building materials with more attention to using thermal insulation;

Factor 2: End users: To improve current housing users should consider the following:

- Reduce dependency on air conditioning to achieve internal thermal comfort;
- Be aware of the concepts and benefits of sustainable design;
- Understand and respect the building laws;
- Be convinced of the importance of climatic design; and
- Understand that the extra costs of climatic solutions do not exceed 5% of the total cost of normal buildings and its future impact is great.

Factor 3: Marketing: To improve current housing the following should be considered:

- Provide suitable building materials at appropriate cost;
- Provide experienced labour;

- Examine current building materials and improve upon them;
- Reduce energy consumption when producing building materials;
- Reuse building waste.

Factor 4: Government: To improve current housing the government should consider the following:

- Implement housing projects with sustainable concepts and encourage people to use them, experiment with them and convince people of the benefits. These projects should be developed continually. Use the media to convince people to accept sustainable concepts;
- Provide construction schools for training skills;
- Offer competitions to select the best projects and test these projects by people who are able to specify the advantages and disadvantages;
- Building laws should be changed and should include strict rules that designers and users should follow and thus reduce the number of unsuitable procedures;
- Provide codes related to building materials;
- Ensure architects are included in the design process and organize professional practice to consider these issues;
- Provide groups that will undertake the protection of Libyan heritage;
- Encourage scientific researchers to develop local building materials ;
- Produce building materials at an appropriate cost.

6.4 THE FOCUS GROUP RESULTS

A focus group was completed in Tripoli at Alfateh university in August 2008. This consisted of a professional group (6 architects and urban planners) which was asked to discuss the climatic design strategies in hot and hot-humid regions that are produced in the literature and applied in many western and Arabic countries. The collected climatic design strategies in hot and hot-humid regions that can be adapted in Tripoli and were discussed with the professionals' focus group are presented in the next Table, (Table 6.39).

Table 6.39: The main strategies captured from the literature review and discussed with the Libyan professionals' group in Tripoli in August 2008

Keys:

✓	Agree	🗎	Agree with reservations

Principles	Component	Strategies	Opinion of experts
Local micro-climate	Building size and location	• *To reduce the surfaces exposed to solar radiation and increase shaded areas, the compact city is the ideal city form.*	✓
		• *Narrow streets can behave as cooling ducts by venting away hot air.*	✓
		• *The spacing of buildings should be carefully considered to avoid obstructing wind flow around buildings.*	✓
		• *The lower the ratio between the building volume and the width of spaces, the lower the temperature in buildings and outdoor spaces.*	✓
	Landscaping and kind of vegetation	• *Green squares and tree-lined streets get nature into the heart of the city.*	✓
		• *Green spaces will help to stitch together the urban fabric.*	✓
		• *Shading by natural means (e.g. via trees) reduces the radiation entering adjacent buildings and the effects of wind.*	✓
		• *The pergola system restrains the rate of heat gain and reduces diffuse reflection to the surrounding dwellings.*	✓
		• *Provide open spaces such as streets, squares and courtyards.*	✓
		• *Trees create different airflow patterns and can be used to direct or divert the wind advantageously by causing a pressure difference.*	✓
		• *The shade created by trees and the effect of grass and shrubs reduce air temperatures adjoining the building and provides evaporative cooling.*	✓
		• *Trees and other plants represent a natural protective element against solar radiation as well as wind control.*	✓
		• *Vegetation may be used like a sunshade, eg, palm trees whose leaves are able to block solar radiation and their tall trunks will easily allow unimpeded ventilation.*	✓
		• *The most appropriate plants for landscaping in hot-humid climates are a mixture of grasses, low flower beds and shade trees with high trunks.*	✓
Building design	Plan design concept	• *Open-plan living areas with high ceilings to maximise air movement and reduce radiant heat to occupants.*	✓
		• *Earth-sheltered and underground housing are ideally suited to this climate.*	✓
	Patio/ courtyard	• *A courtyard house is an ideal solution to hot climate regions.*	✓
		• *Internal and semi-enclosed courtyards can prove a liability under hot arid conditions; orientation and proportions matter.*	✓
		• *The courtyard serves as a reservoir of coolness.*	🗎
	Building heights	• *Ceiling heights - ventilation of the roof space should be put in place to reduce heat build-up there: increased heat loss in the cooler season is less important.*	✓
		• *Two to three floors maximum.*	✓

	Building form	• *The building should be elongated on an east-west axis.*	✓
		• *The square house is not the optimum form in any location.*	🗎
		• *The whole building should be lightweight to allow rapid cooling down at night.*	🗎
		• *A two storey building can reduce the roof area.*	✓
		• *Raising the building off the ground can potentially improve ventilation.*	✓
		• *To reduce the size of any air conditioning equipment, the building should be made compact in order to minimise the surface areas of its envelope and thus to reduce the heat gain.*	✓
		• *a spread-out building with large windows enables more natural cross ventilation.*	🗎
		• *The ideal building plan is a detached, elongated building with a single row of rooms with openings in the two opposite walls.*	🗎
Room	*orientation*	• *The living-room and the guest room can be located in the south or north of a home.*	✓
		• *Bedrooms can be located in the east.*	✓
		• *Services such as kitchen and toilets can be located in the west.*	✓
Main Building Components	*Roofs*	• *Vaults and domes are climatically superior to flat roofs;*	✓
		• *Use light colours for walls and roof to reflect the heat of the sun.*	✓
		• *Use metal roofs which cool rapidly at night. Daytime heat gain can be minimised by using sheeting with a reflective coating on its underside.*	🗎
		• *Shade the roof with suspended reed matting or timber boards or by vegetation above the roof.*	✓
		• *Using an insulation layer on the outside of a concrete slab can increase the thermal time lag to eight hours.*	✓
		• *Lightweight roofs have important effects on the thermal performance of buildings (even with extra-heavy walls).*	🗎
		• *The outer surface of the roof and the thermal resistivity of its materials are of primary importance.*	✓
		• *Properly designed roof gardens help to reduce heat loads in a building.*	✓
	Walls	• *The external envelope should have a high thermal mass.*	✓
		• *The walls should be reflective and/or well insulated.*	✓
		• *Use vertical wing walls to shade windows and walls from the low west-southwest and east-southeast sun.*	🗎
		• *Locate internal walls with respect to cross-ventilation;*	✓
		• *Incorporate walls with cavities that act as air ducts for heat-exchange purposes.*	✓
		• *Use wall materials with good insulation properties.*	✓
		• *Light internal walls are preferable in rooms which are used by day such as the living room and the kitchen.*	✓
		• *The heat storage capacity and the heat conduction property of walls are key to meeting desired thermal comfort conditions.*	✓
	Floors	• *A suspended floor with a large well ventilated under-floor cavity will give a quicker response when temperatures drop slightly in the evening than a floor directly in contact with the ground.*	🗎
	Doors	• *For open plan dwellings, privacy can be provided by designing doors made like shutters blocking the view but giving passage to airflow, and by leaving the upper part of a room-height door open via hinges at the top.*	🗎

	Shading devices	*•The 'mashrabia' has five functions: (1) controlling the passage of light, (2) controlling the air flow, (3) reducing the temperature of the existing air, (4) increasing the humidity of the existing air, and (5) ensuring privacy.*	✓
	Finishing	*•To reduce the effects of the sun on buildings the outside walls should be painted white or in light colours.* *•The reflectivity of a facade with respect to insulation could be increased by painting it white or utilising glazed brick-facings.*	✓ 🖹
Building materials		*•Choose roof and wall types with high insulating properties (U-values).* *•Adobe buildings are better suited for hot regions.* *•Insulation can improve indoor conditions provided thermal mass is not excessive.* *• Extreme thermal mass (typical of stone and mud) can have an important positive effect on the thermal performance of buildings.*	✓ ✓ ✓ ✓
	Wind catcher	*•Windcatchers can help in increasing the flow of air in houses* *•The malqaf is suitable to catch wind because it rises up high in the air.* *•The malgaf can be incorporated into modern buildings aesthetically.*	✓ ✓ ✓
	Sun space/	*•A solarium employs a combination of direct gain and indirect gain system features.*	✓
	Fountain	*•A fountain discharges water and mixes it with the surrounding air to increase humidity and to cool the air by evaporation.*	✓
	Solar panel	*•Solar panels can be used for hot water and heating spaces.*	✓
	Balconies	*•Balconies can provide protection to walls and windows from sun and rain.* *•Rooms should have direct access to open balconies or verandas on one or two sides.*	✓ 🖹

6.4.1 Findings of the focus group's opinions

The focus group confirmed most of the design strategies collected from the literature and gave comments for some of them as follows:

- **Local microclimate:**

The panel was asked about their opinion on points related to landscaping, types of vegetation, building size and location. They confirmed the importance of landscaping in providing shading areas and reducing heat gains. They also mentioned the lack of water resources in Libya and thus the need to choose the appropriate kind of vegetation is very important.

They agreed that a compact city could help in reducing the surfaces exposed to solar radiation. However, they mentioned that it is not easy nowadays to live in a compact city because of new forms of transportation and architects should find other solutions to reduce the surfaces exposed to solar radiation such as shading devices, trees or even to cover parts of streets.

- **Building design**

The strategies related to floor plan design concepts, building heights, building forms and room orientation were discussed with the focus group to explore their opinions on implementing these strategies in housing in the future. The panel confirmed all these points with some comments:

- The courtyard is the ideal solution in the case of using appropriate building materials and proportions that can provide adequate shading. However, the courtyard's position should not be in the middle of the house unless a movable or openable cover is provided to avoid excessive summer heat and winter rain.
- A square house can be appropriate if it is not compact and there are some shaded voids with small windows facing east and west that can provide air movement.
- Heavyweight construction (ie, thicker walls etc) is most appropriate because of the increase in the thermal time lag.
- Large windows may provide good ventilation but at the same time can allow more exposure to heat gain.
- Detached buildings are good if the east and west elevations are shaded.

- **Main Building Components**

The panel was asked about strategies for designing building components such as doors, floors, walls, roofs, finishing and shading devices. The panel confirmed most of the strategies presented in (Table 6.39) with some further comments as listed below:

- A metal roof is not the ideal solution because it increases heat gain and needs much more shading.
- A lightweight roof is not appropriate because of its short thermal time lag properties.
- Shading east and west elevations can be undertaken by using shading devices, vegetation or by the design of the building.
- A suspended floor is not advised because it needs careful use and maintenance.

- For cultural reasons doors are important in almost all houses; however, the design of the doors can be changed by providing upper or lower openings to allow air movement.

- **Building materials**

The panel confirmed all the strategies related to building materials and commented that more research in improving local building materials is needed.

- **Additional Building Components**

The panel was asked about strategies related to additional building components (whether they should be included or not) such as using a wind catcher, a solarium, a fountain, solar panels and balconies. The panel confirmed all the points presented in the previous table with some additional useful suggestions summarized as follows:

- The solarium house is a good solution and a courtyard can be used as a solarium when using moveable covered windows.
- Balconies are important for providing shading. However, socially they are not often used by occupants unless a big part can be enclosed by *musharbia.*

6.5 BUILDING CASE STUDIES

As stated in the research methodology chapter air temperature measurements were first taken by the author between 7th August 2008 and 7th July 2009 by using EasyLog USB sensors version 4, which recorded day and night temperatures at 60 minutes' interval. Measurements were recorded in the living room in four selected case studies; two of the case studies were located inside the old city and two outside the old city. The first case study was a two story courtyard house inside the old city and the residents had covered the courtyard. The second case study was a one story courtyard house inside the old city with open courtyard; these first and second cases were built somewhere between 1744 and 1832.

The third case study was a two story row house with a small courtyard at the back and a small garden at the front, located outside the old city and built in 1966. The last case study was a contemporary two storey villa built in 1983. All of the cases used natural ventilation and fans to cope with high temperatures and humidity. Eight days from the start of measuring the temperature the householders in two of the case studies started using air conditioning (case two and three) in the main hall which is usually located near to the living rooms. The location of the case studies are shown in chapter 5 (Figure 5.15).

6.5.1 Case study number 1:

Location:

Located inside Tripoli old city in Mahalt Kushat Alsghar (Figure 6.38) facing Alfransis Street near to Algarmanly house.

Date of construction: built in the same period as that of Algarmanly house sometime between 1744 and 1832. (Almansuri, 2000).

General information:

Land plot area = 246.51 m^2

Ground floor area = 236.85 m^2

First floor area = 241.11 m^2

Number of occupants = 6 persons

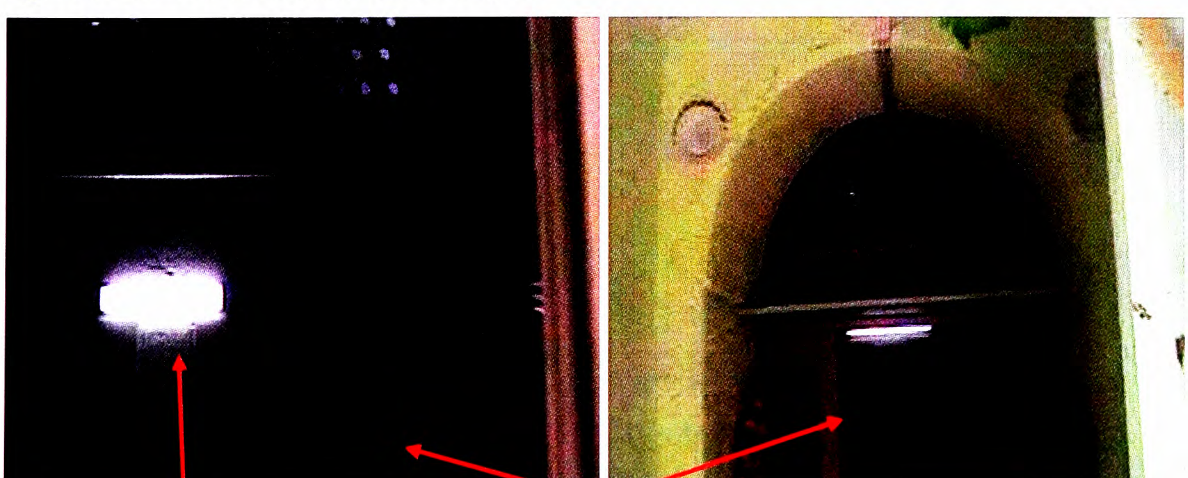
Electrical equipment used:

Television, satellite receiver, cassette, fridge and roof fan, (Figure 6.39).

Methods used to achieve comfort:

Fans, natural ventilation and a cover on the courtyard

Figure 6. 38: The location of case study 1.



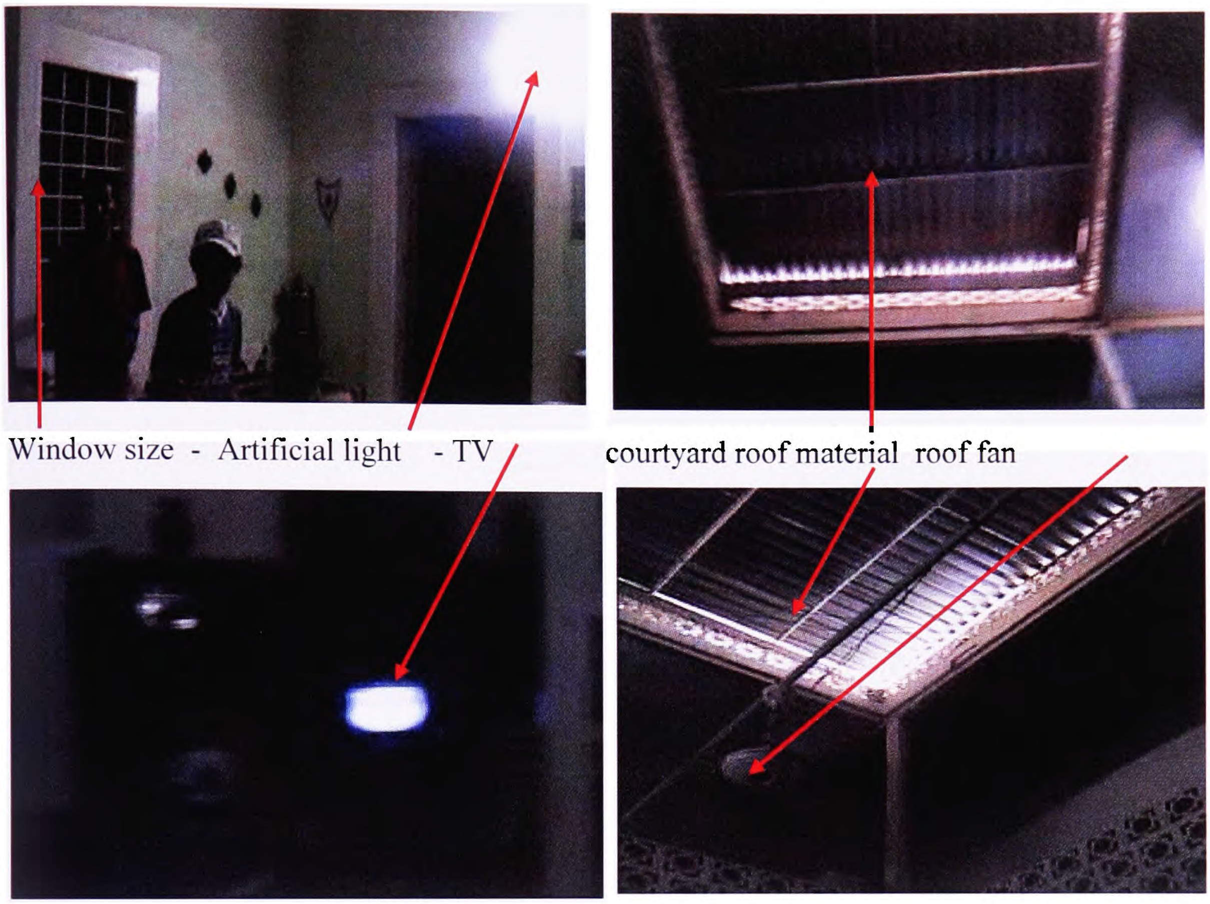


Figure 6. 39: The interior space after covering the courtyard, the roof material, the roof fan, the artificial light and the equipment.

Design concept:

A two-storey central courtyard house connected with neighbours' houses on three sides. The layout of the ground floor (Figure 6.40) comprises the main entrance that leads directly to the courtyard, the kitchen and the male guest room in the entrance hall, the courtyard which was recently covered and is surrounded by arcades on four sides, three rooms and staircase and the bathroom located under the staircase. It also contains a small shop open to the street. The second floor includes five rooms; two of them have openings onto the street.

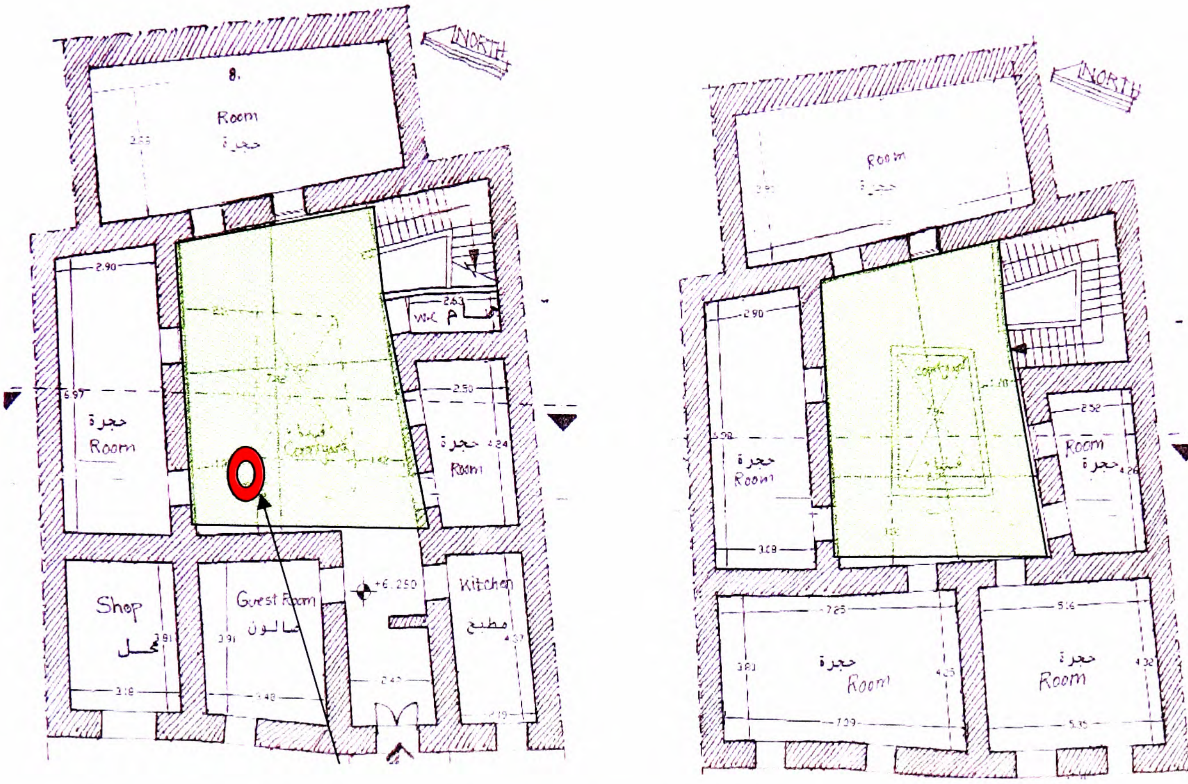


Figure 6. 40: Ground and second floor plan showing the position of the instrument.

Elevations: (Figure 6.41)

External elevation areas = 104 m2

Solid areas = 90.25m^2 = 86.8%

Openings=13.75 m^2 = 13.2%

Windows = 4.09 m^2, doors = 9.66 m^2

Internal elevation areas = 163.4 m^2

Solid areas = 140.18 m^2= 85.8%

Openings= 23.22 m^2 = 14.2%

Windows = 5.36 m^2, doors = 17.86 m^2

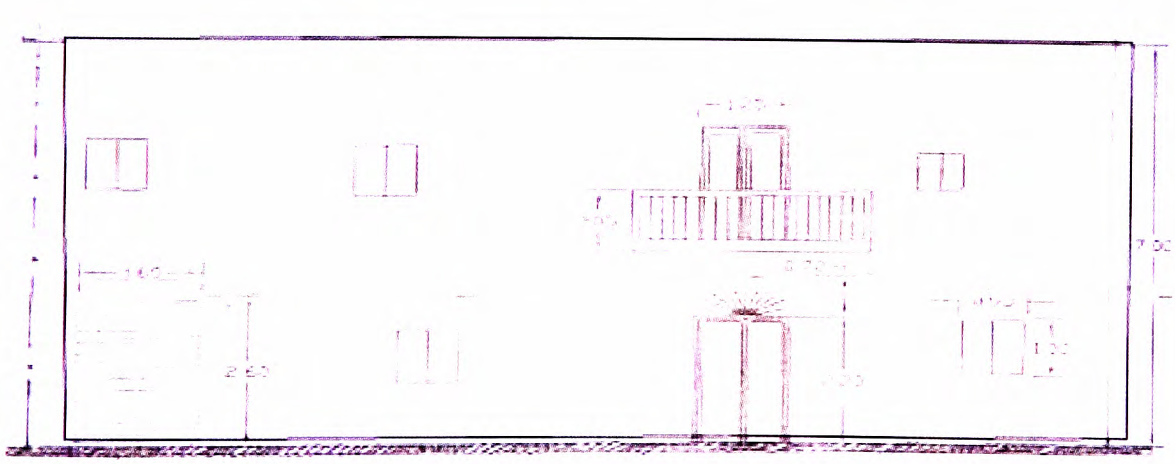


Figure 6. 41: The main elevation showing the kind of openings.

Building materials and methods of construction:

The main method of construction in case studies one and two (Figure 6.42) is thick load bearing walls with flat roofs. The thickness of walls is 70cm and they are made of irregular stone mixed by lime; the spaces between them are filled with small stones and clay mortar and the wall is finished with a plaster coating. The roofs of these houses are usually flat; the rooms are rectangular, with four walls supporting beams of steel and wood. Aluminium corrugated sheets are used to cover the courtyard.

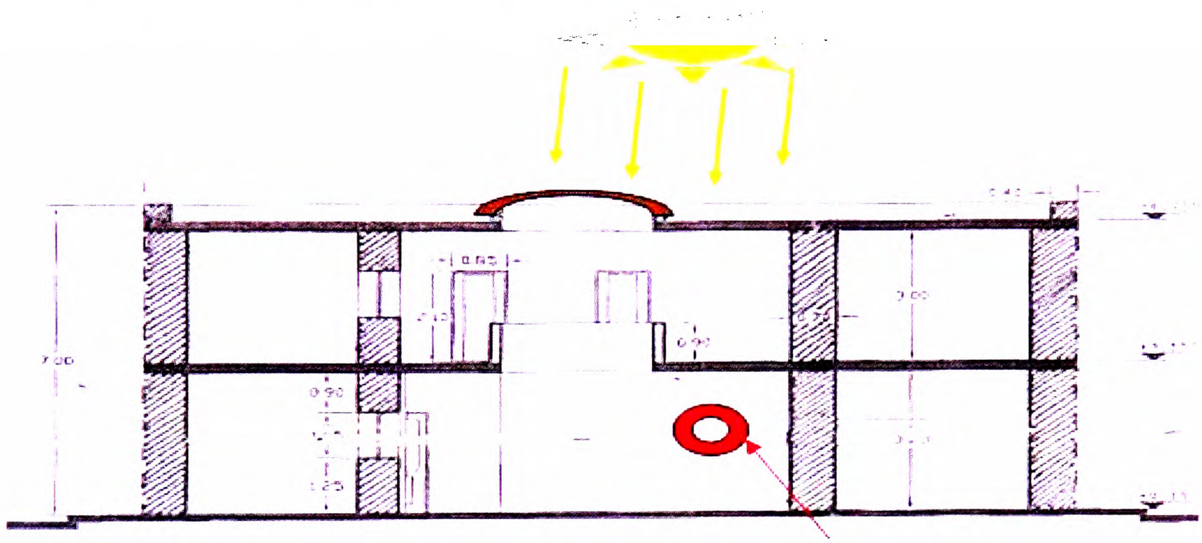


Figure 6. 42: Longitudinal section showing the thickness of the walls, the covered courtyard and the position of the sensor and Data Logger.

Comments from the householders (the head of the household and the wife of the head of household):

They covered the courtyard for many reasons:

- The roof protects them from winter rain and cold and very warm days.
- It provides a large area for family and relatives to gather.
- They would prefer to have a courtyard on one side of the house or to cover the courtyard by movable windows to allow light, ventilation and light from the rising sun to get inside when needed and to prevent it when not needed.
- They would prefer to emulate the modern type of housing and they saw their own house as old fashioned.
- Covering the courtyard in this case caused a dark space, a lack of ventilation and an increase in moisture in the walls with a corresponding need for continuous maintenance.

Average indoor temperature:

According to the measurements taken daily during one year at 12.22 pm and 24.22am (and presented in Table 6.40 and Figure 6.43) the highest difference between the two temperatures taken in indoor temperature measured in case study 1 was in June which recorded 6.22°C and the lowest temperature difference was measured in January (0.97°C).

The difference in indoor temperature between the day and night temperatures measured showed a decrease in the morning temperature of less than 0.2°C in most months. However the indoor morning temperature increased by less that 0.67°C in four months (October, March, April and July)

Table 6. 40: Indoor temperatures measured in case study 1.

Dates		08/08	09/08	10/08	11/08	12/08	01/09	02/09	03/09	04/09	05/09	06/09	07/09
Max. Average External Temp.		33.7	32.2	29.2	23.5	18.0	18.3	18.2	21.6	24.9	28.6	32.0	34.0
Min. Average External Temp.		22.2	22.9	19.2	13.5	09.2	10.2	8.9	10.8	13.1	16.7	20.4	22.8
Average Internal Temp.	12.22 pm	29.43	27.7	25.3	21.66	17	17.53	17.07	17.9	20.73	22.69	25.78	27.83
	24.22 am	29.36	27.15	24.93	21.63	16.95	17.33	16.94	17.61	20.8	22.72	25.65	27.82
Differences in internal tem. between Pm & am		- 0.07	- 0.55	-0.10	-0.03	-0.05	-0.20	-0.13	+0.29	+0.07	+0.03	-0.13	-0.01
Differences in external tem. between Pm & am		4.27	4.5	4.27	1.84	1	0.97	1.13	3.7	4.17	5.91	6.22	6.17

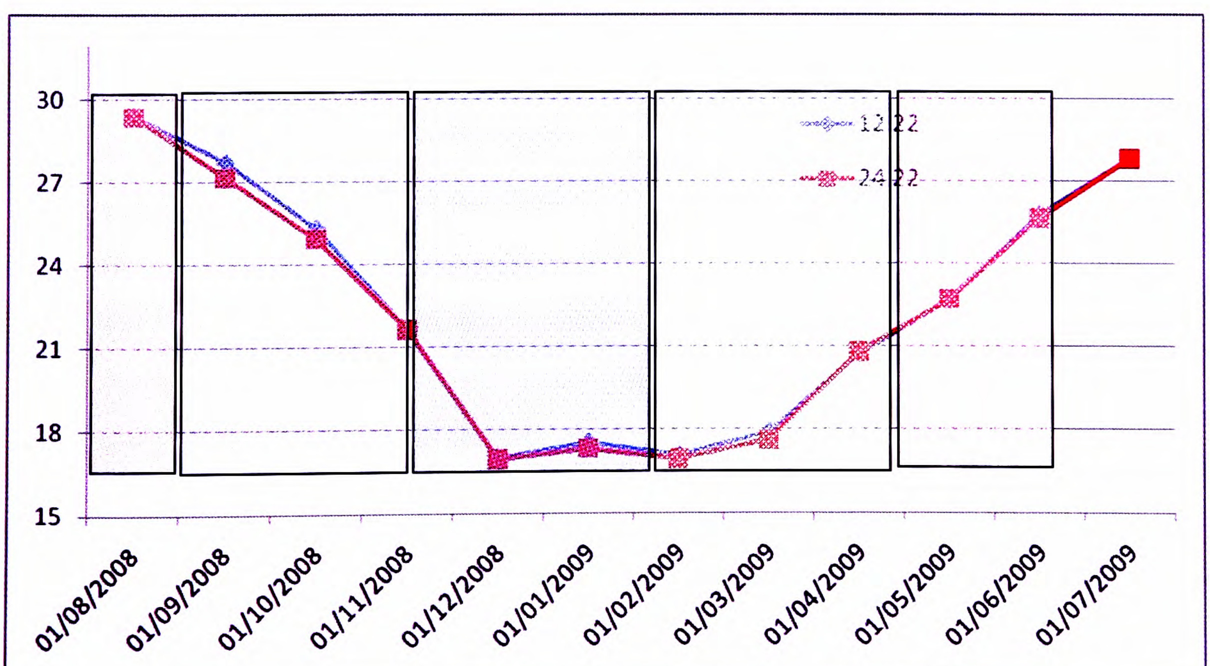


Figure 6. 43: Indoor temperatures measured in case study 1.

6.5.2 Case study number 2:

Location:

Located inside Tripoli old city in Bab Elbahr (Zenghet Sidi Salem No25) near to Sedi Alshaab street (Figure 6.44)

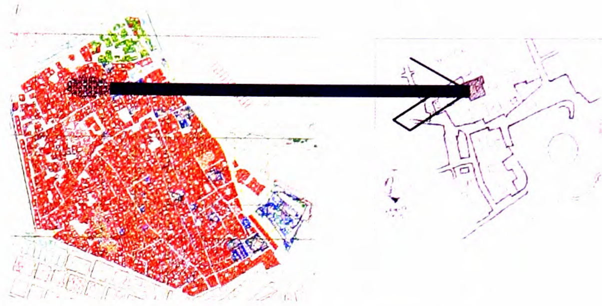


Figure 6.44:The location of case study 2.

Date of construction:

Built between 1744 and 1832.

General information:

Land plot area = 217.3 m^2

First floor area = 176.4 m^2

Courtyard area = 40.9 m^2

Number of occupants = 5 persons

Methods used to achieve comfort: Fans, natural ventilation

Electrical equipment used:
Television, computer, receiver, cassette, fridge, fan and lately AC. (Figure 6.45).

Figure 6. 45: The equipment used in the living room.

Design concept:

A one storey central courtyard house with a single room on the first floor used for male guests; the house adjoins with neighbours' houses on four sides (Figure 6. 46). The main entrance only opens onto the street.

The layout of the ground floor (Figure 6.47) consists of the main entrance hall leading directly to the courtyard, the kitchen and the bathroom with the main family rooms surrounding the courtyard.

Figure 6. 46: The courtyard and the wood skeleton used to cover the courtyard when it is raining. This figure also shows the openings type

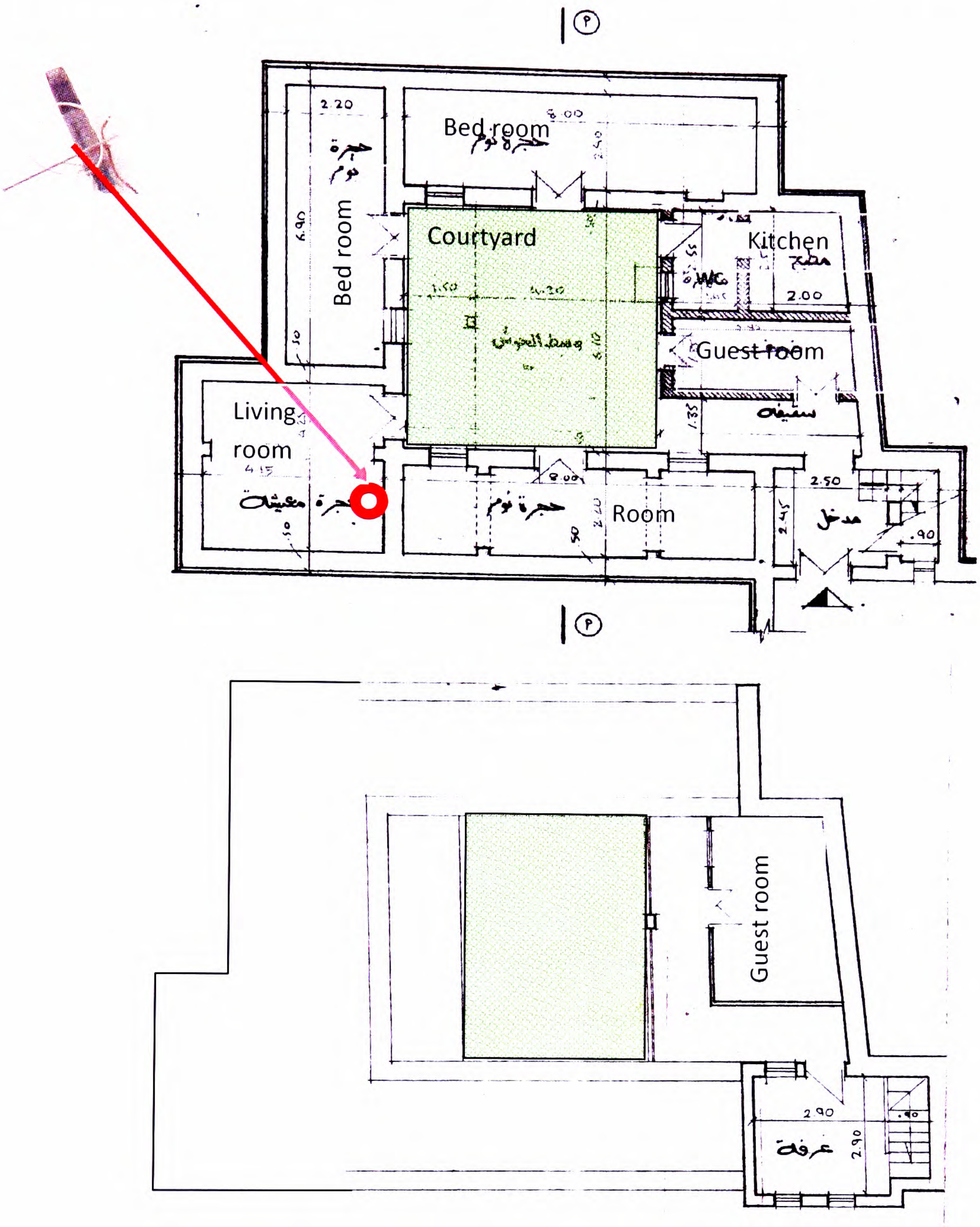


Figure 6.47: Ground and first floor plan showing the position of the survey instrumentation.

Elevations: (Figure 6.48)

External elevations areas = 19.75 m^2
Solid areas = 16.6 m^2 = 84.1%
Openings = 3.14 m^2 = 5.9%
Windows = 0.74 m^2, doors = 2.4 m^2
Internal elevations areas = 100.29 m^2
Solid areas = 85.72 m^2 = 85.5%
Openings = 14.57 m^2 = 14.5%
Windows = 3.44 m^2, doors = 11.13 m^2

Figure 6. 48: Front elevation and internal window size.

Building materials and methods of construction:

As mentioned previously, the main method of construction in case studies one and two are thick load-bearing walls with flat roofs. The thickness of walls is 70cm, (Figure 6.49) made of irregular stone mixed by lime; the spaces between them are filed with small stones and clay mortar and the wall is finished with a plaster coating. The roofs of these houses are usually flat; the rooms are rectangular with four walls supporting beams of steel and wood as can be seen in (Figure 6.50).

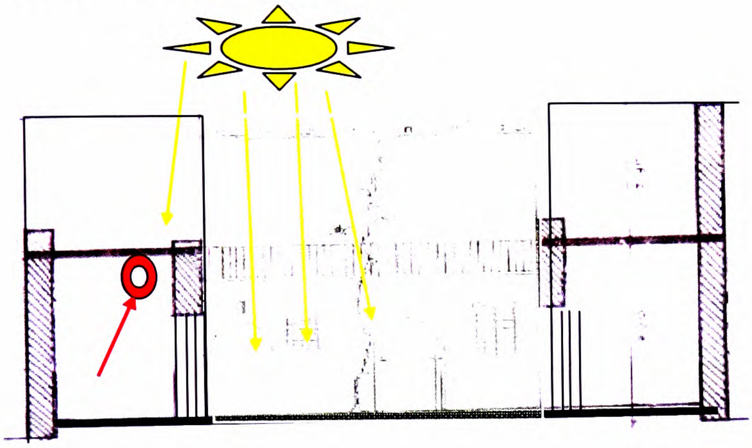


Figure 6. 49: Section showing the thickness of the walls, the courtyard and the position of the sensors - Data Logger

Figure 6. 50: Roof construction and materials.

Comments from the householders (the wife of the head of the household):

The occupants of the house liked the courtyard environment. However, they raised some comments about what they did not like in the house and how they managed it themselves, as follows:

- The courtyard provides a pleasant atmosphere on a fine weather days but on rainy days they cover the courtyard by removable plastic sheets as shown in (Figure 6.46).
- To achieve comfort in the winter time they use the traditional heater and in summer time they usually depend on cross ventilation but recently, in late August 2009, they have started to use air conditioning when temperature is very high.
- The size and shape of the rooms are not suitable for the modern sized furniture.

Average indoor temperature:

The temperature measurements undertaken in case study 2 are presented in (Table 6.41 and Figure 6.51) and show that the indoor temperature changed according to the internal environment. In summertime when the average outdoor temperature was very high (such as

34°C in July) the average indoor temperature recorded was 27.73°C. That is a temperature decrease of more than 6 °C. In wintertime where the minimum average external temperature recorded in December, January and February was 18°C, the internal temperature measured an increase of about 2°C. The differences in indoor temperature between day and night in the seven coldest months recorded an increase in temperature in the morning of less than 4.05°C. On the other hand, the indoor temperature decreased every morning by less than 2.97°C in the summer months.

It is clear that this case provided a comfortable indoor temperature throughout the year, whereas case study 1 recorded some indoor temperature reduction in the summertime but there was no increase in temperature in the wintertime.

Table 6. 41: Indoor temperatures measured in case study 2.

Dates		08/08	09/08	10/08	11/08	12/08	01/09	02/09	03/09	04/09	05/09	06/09	07/09
Max. Average External Temp.		33.7	32.2	29.2	23.5	18.0	18.3	18.2	21.6	24.9	28.6	32.0	34.0
Min. Average External Temp.		22.2	22.9	19.2	13.5	09.2	10.2	8.9	10.8	13.1	16.7	20.4	22.8
Average Internal Temp.	12.22 pm	29.07	27.29	26.8	23.75	19.58	20.09	21.11	23.75	25.45	27.65	27.73	27.73
	24.22 am	29.4	26.62	23.83	19.7	19.65	20.44	21.38	23.56	25.58	27.03	27.76	27.76
Differences in internal tem. (between Pm & am)		+ 0.33	- 0.67	-2.97	+4.05	+0.13	+0.35	+0.27	-0.19	+0.13	-0.62	+0.03	+0.03
Differences in external tem. (between Pm & am)		4.63	4.91	2.4	+0.25	+1.58	+1.79	+2.91	+2.15	+0.55	0.95	4.27	6.24

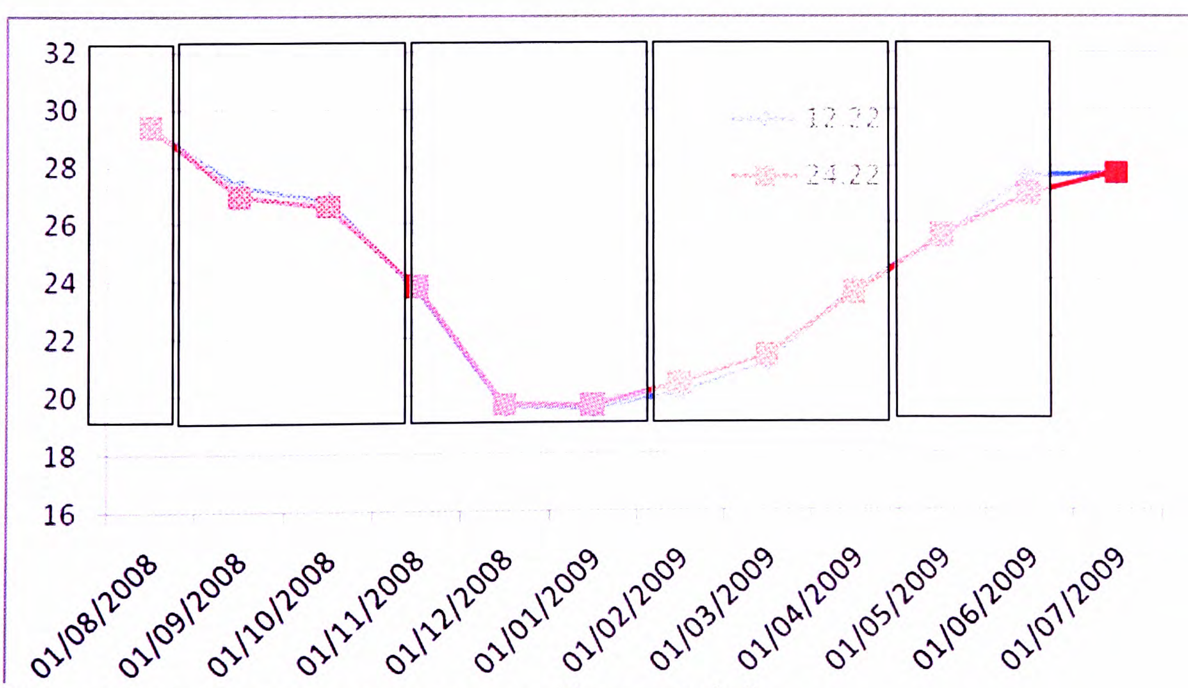


Figure 6. 51: Indoor temperatures measured in case study 2.

6.5.3 Case study number 3:

Location

Located outside Tripoli old city in Ghorgy.

Date of construction:

The ground floor was built in 1970 and the second floor was built in 1986 (Figure 6.52).

General information:

Land area = 240 m^2

Ground floor area =164 m^2

First floor plot area=176 m^2

Roof floor plot area= 25 m^2

Court Area =16 m^2

Front garden = 48 m2

Number of occupants = 8 persons

Electrical equipment used:

Television, satellite receiver, cassette, fridge, fan and air conditioning (Figure 6.52).

Methods used to achieve comfort:

Air conditioning fans and cross ventilation.

Figure 6.52: The location of case study 3.

Figure 6. 53: The window and the equipment in the living room and the position of the air conditioning located in the main hall.

Design concept:

A two storey row house. It can be seen from (Figure 6.54) that a courtyard is positioned at the back of the house and a small garden is located in the front. The back courtyard is linked to the location of the staircase and the kitchen and provides light and ventilation to the rooms.

This concept is considered as the starting point of an alternative type of the open courtyard house.

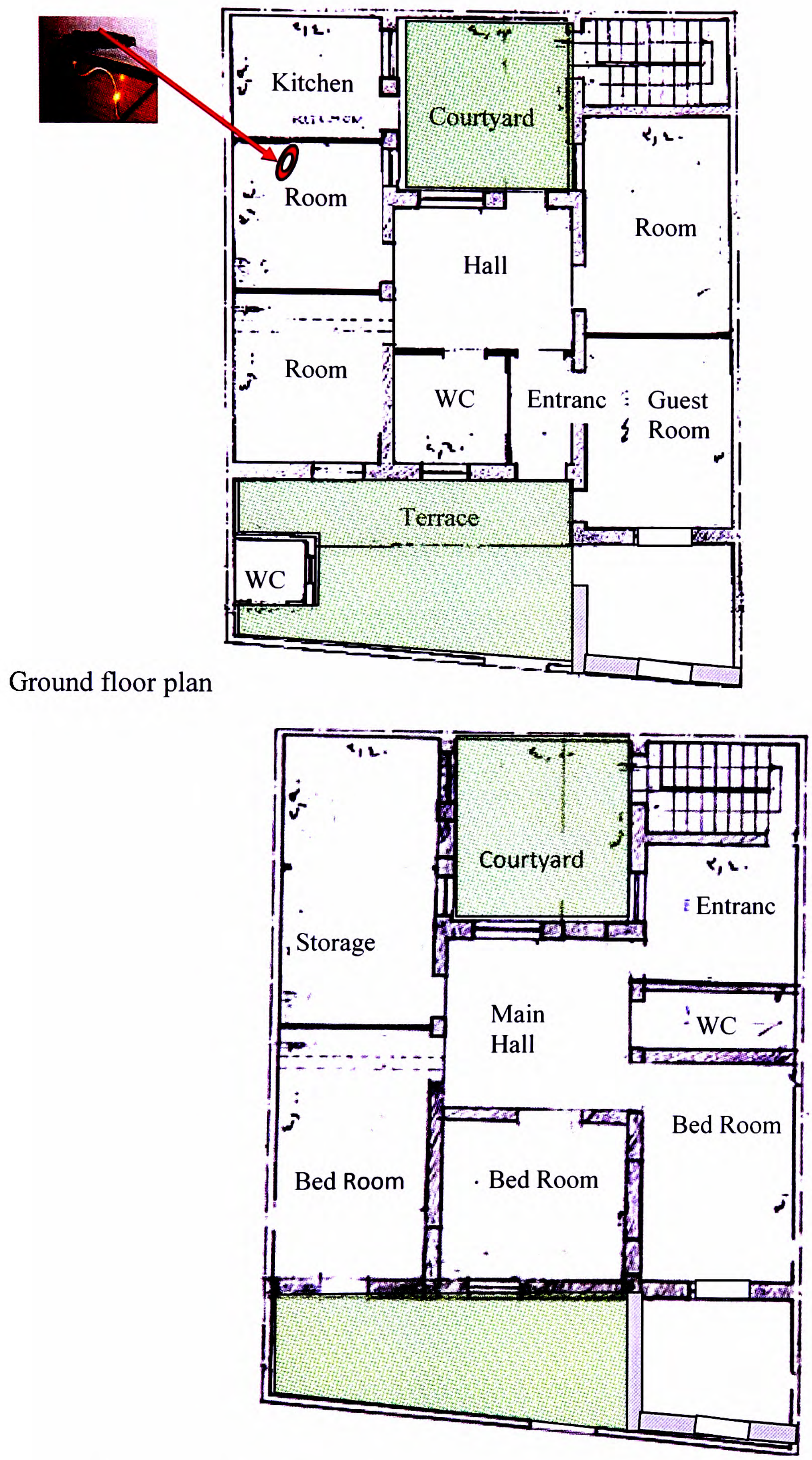


Figure 6. 54: Ground and first floor plans showing the position of the sensors- Data Logger.

Elevations: (Figures 6.55 & 6.56)

External elevation areas = 92m^2

Solid areas = 77 m^2 = 83.7%

Openings = 15 m^2 = 16.3%

(Windows = 10.8 m^2, doors = 4.2 m^2)

Internal elevation areas = 115.2 m^2

Solid areas = 83.2 m^2 = 72.2%

Openings = 32 m^2 = 27.3%

(Windows = 10.5 m^2, doors =21.5 m^2)

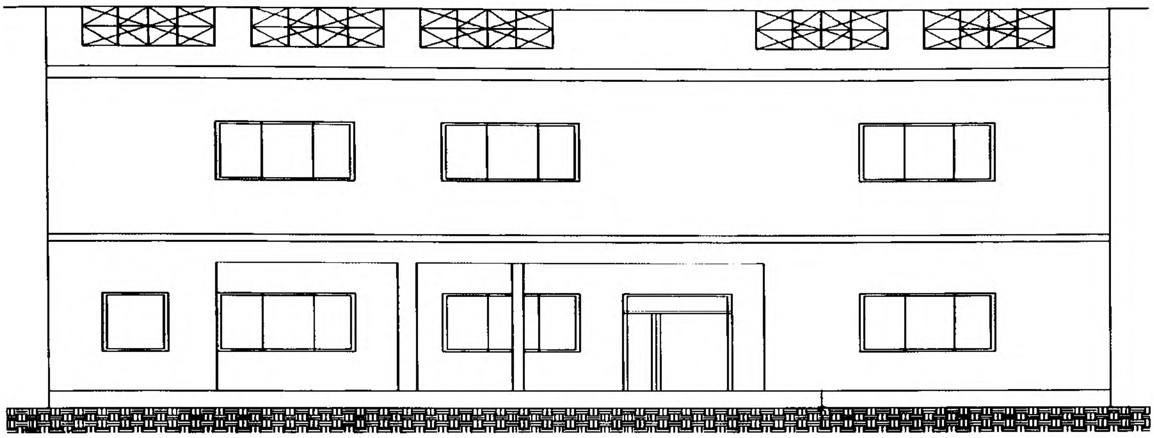


Figure 6. 55: Main elevation.

Figure 6. 56: The openings onto the courtyard, and the front elevation view.

Building materials and method of construction:

The ground floor walls are made of limestone with dimensions of 25cm x 20cm and a concrete roof. The second floor walls are made of cement hollow blocks and the roof is made of concrete ribs and red hollow clay blocks (Figure 6.57).

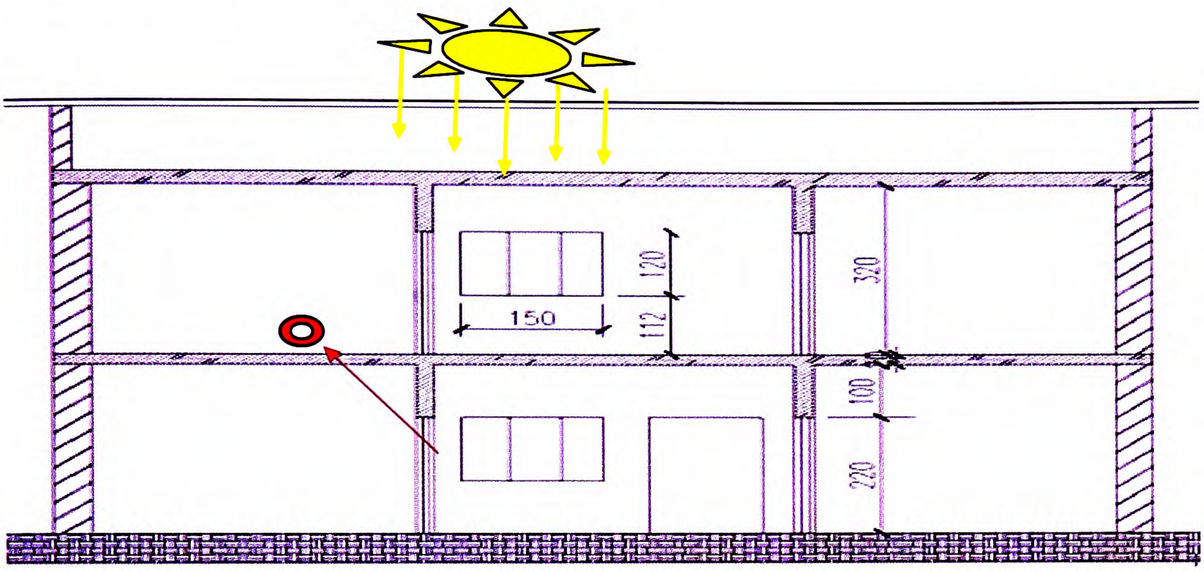


Figure 6. 57: A section showing the location of the sensors - Data Logger.

Comments from the owners:

- The house is generally comfortable because it is a mixture of new and traditional houses style and the number of rooms is good. The things that they do not like about the house are the sizes of the rooms which are not appropriate for modern furniture and the location of the kitchen is very annoying and not good in summer and or in wintertime because they have to cross the courtyard to go to the kitchen.
- Air conditioning is located in the main hall only.

Average indoor temperatures:

According to the measurements presented in (Table 6.42 and Figure 6.58), the measurements recorded a decrease in indoor temperature between the two measurements during the whole year. The highest reduction recorded was in May, June and July of about 5.5°C and the lowest temperature difference (measured in December) was 1.02°C. The differences measured in indoor temperature between day and night showed that most months recorded a decrease in temperature by morning of less than 0.26°C. However, the indoor temperature increased by the morning by less than 2.44°C in the five months from November 2008 to March 2009.

It can be observed that the average indoor temperature in winter at night increased far more than that recorded in case study 1. However, it is still a very small increase in comparison to case study 2.

Table 6. 42: Indoor temperature measured in case study 3.

Dates		08/08	09/08	10/08	11/08	12/08	01/09	02/09	03/09	04/09	05/09	06/09	07/09
Max. Average External Temp.		33.7	32.2	29.2	23.5	18.0	18.3	18.2	21.6	24.9	28.6	32.0	34.0
Min. Average External Temp.		22.2	22.9	19.2	13.5	09.2	10.2	8.9	10.8	13.1	16.7	20.4	22.8
Average Internal Temp.	12.22 pm	29.93	28.45	25.83	21.93	16.98	16.9	16.5	17.62	20.97	22.85	26.33	29.16
	24.22 am	29.12	28.29	25.72	22.38	17.09	17.05	16.57	20.06	20.8	22.67	26.21	29.16
Differences in internal tem. between Pm & am		-0.81	-0.16	-0.11	+0.44	+0.11	+0.15	+0.07	+2.44	-0.17	-0.18	-0.12	0.00
Differences in external tem. between Pm & am		3.77	3.75	3.37	1.57	1.02	1.4	1.7	3.98	3.93	5.75	5.67	4.84

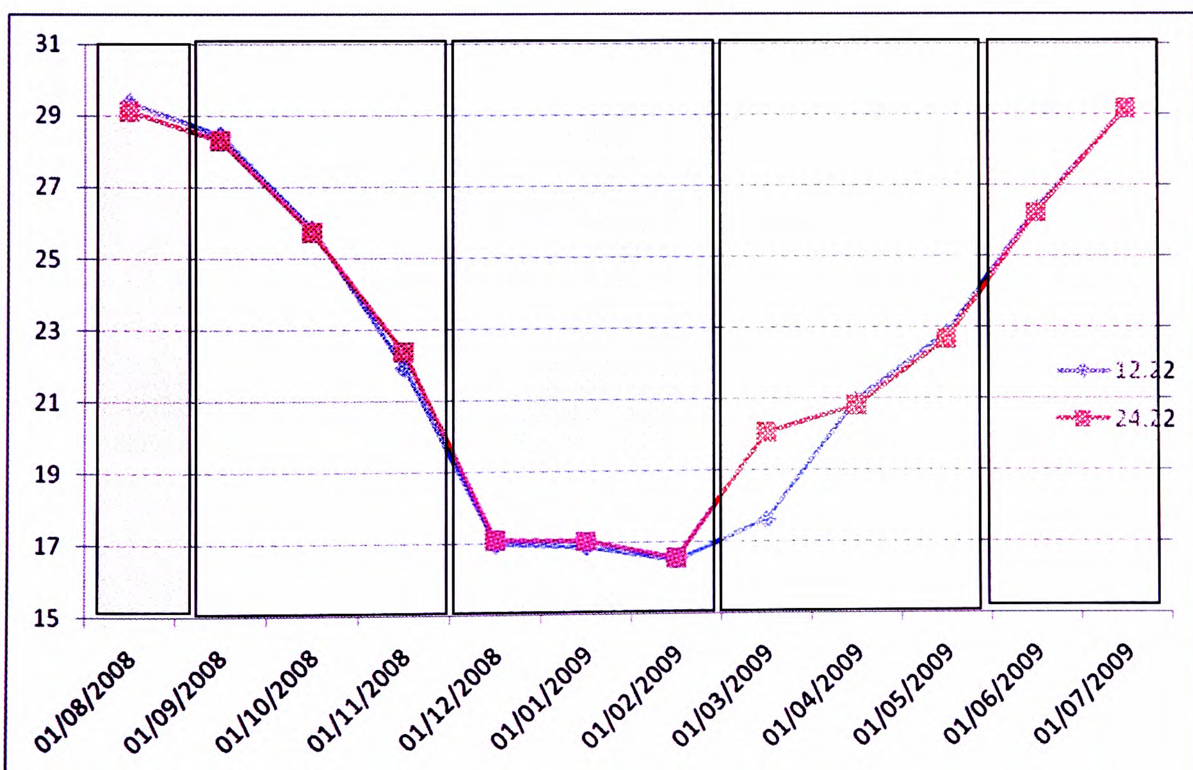


Figure 6.58: Indoor temperatures measured in case study 3.

6.5.4 Case study number 4

The villa type of housing

Location: Located outside Tripoli old city in Alhadba-Hai Demashgk.

Date of construction: built in 1983.

General information: (Figure 6.59)

Land plot area = $800m^2$

Ground floor area = $192m^2$

First floor area = $216m^2$

Number of occupants = 5 persons

Mechanical equipment used:

Television, receiver, cassette, fridge, fan and AC. (Figure 6.60).

Methods used to achieve comfort: Air conditioning, fans, ventilation and covering the courtyard

Figure 6.59: Site plan and south elevation shows the building form.

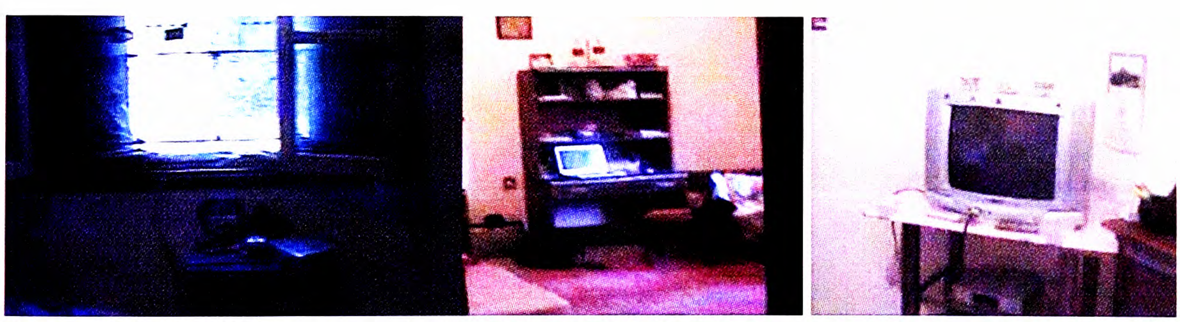


Figure 6.60: The living room, window type and equipment used.

Design concept:

In this house type the courtyard did not exist and had been replaced by the surrounding garden. Accordingly, all the external spaces have direct openings onto the garden (Figures 6.61).

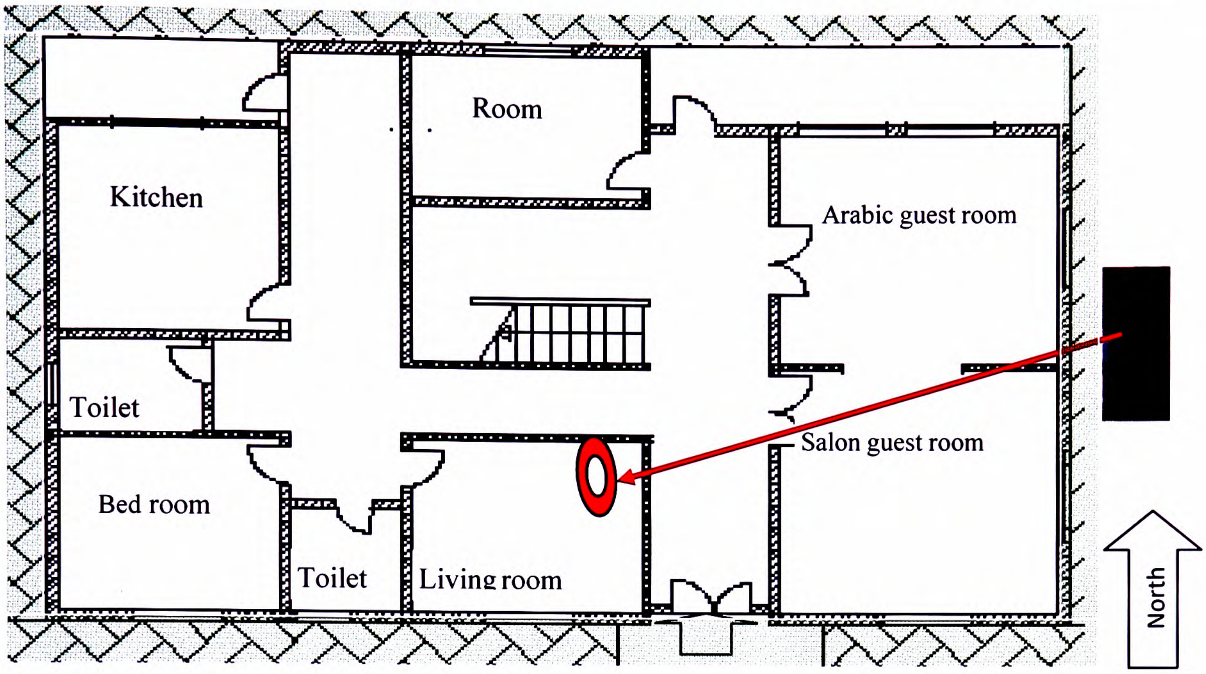


Figure 6. 61: Ground and first floor plan showing the location of the sensors - Data Logger on the ground floor.

Elevations: (Figures 6.5.26 and 6.62)

External elevations area = 747.24 m^2

Solid areas = 689.94 m^2 = 92.3%

Openings = 57.3 m^2 = 7.7%

Windows = 37.2 m^2, Doors = 20 m^2

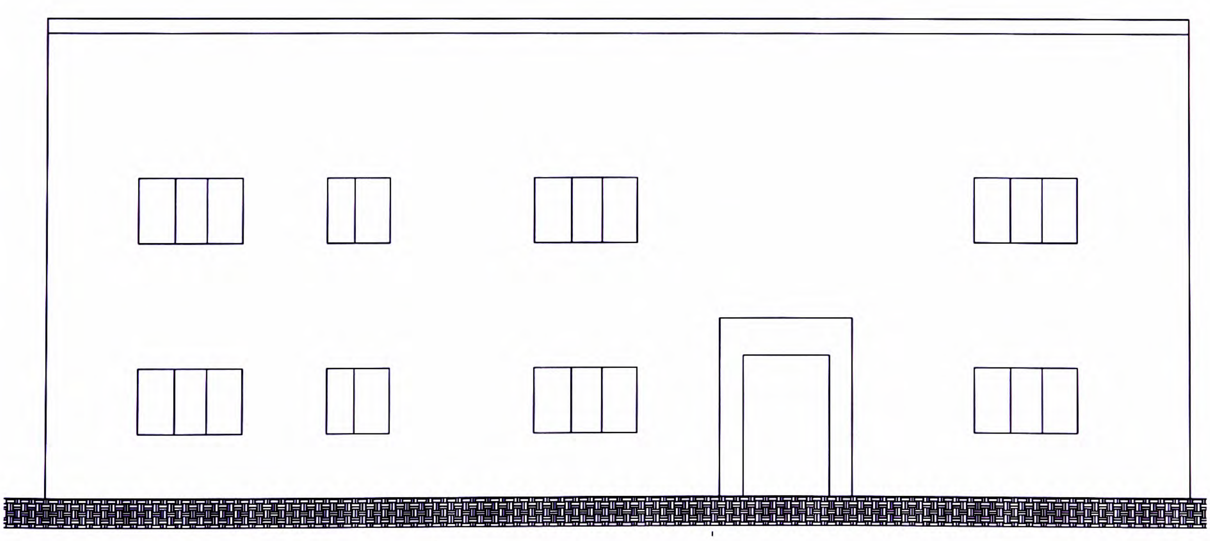


Figure 6. 62: The southern elevation.

Figure 6.63: Main entrance and the house surrounded by the garden.

Building materials and method of construction:

The villa was constructed by using a skeleton frame (reinforcement columns and beams) (Figure 6.64). The walls are made of lime block with the dimensions of 25cm x 20cm with a concrete roof, and single glazed windows with wood shutters.

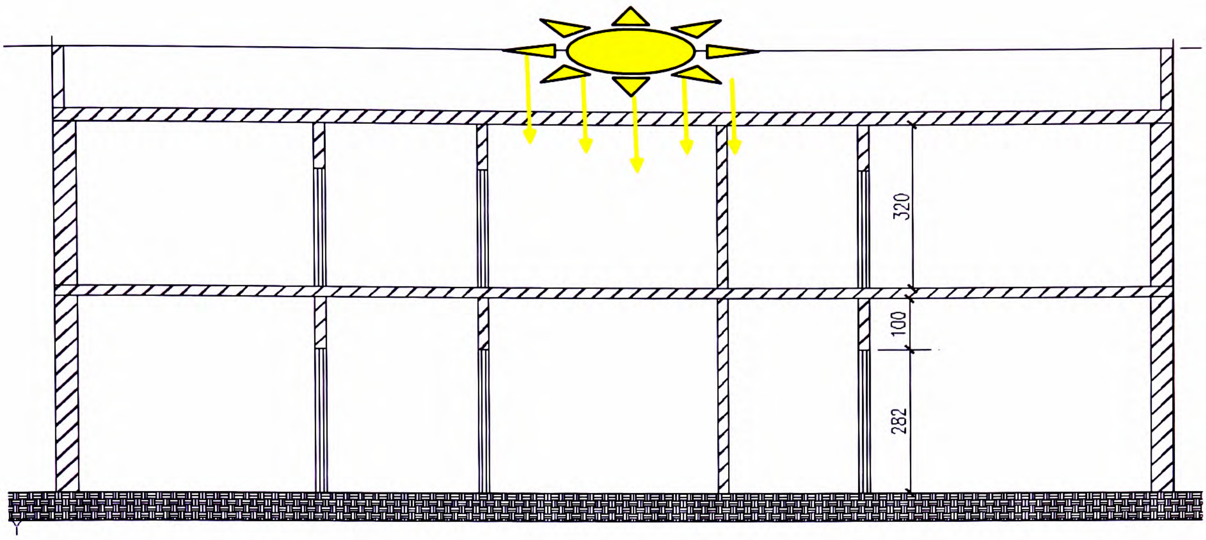


Figure 6. 64: Longitudinal structural section through the house.

Comments from the owners:

- The villa is comfortable from a functional point of view and the area and number of spaces is quite adequate.
- The garden surrounding the house provides privacy, shading and a nice view.
- In summertime it is very warm and they use fans and cross ventilation. However, when it is very warm the family move to the guest room where the air conditioning is located. In winter, they do not use any kind of heating; they cover the openings and wear heavy clothing.

Average indoor temperature:

The average indoor temperature in case study 4 is presented in (Table 6.43 and Figure 6.65). It shows the increase in indoor temperature between the two measurements taken as measured in the three winter months is about 0.6°C. The indoor temperature decreased in the other nine months with the highest decrease (4.58°C) recorded in July.

It is clear that the average indoor temperature increased in most months which is explained by the fact that this case (villa type) faces the sun in all elevations with minimum shading. Accordingly, it is not useful in summer but it is providing warm internal conditions in winter.

Table 6. 43: Indoor temperatures measured in case study 4.

Dates		08/08	09/08	10/08	11/08	12/08	01/09	02/09	03/09	04/09	05/09	06/09	07/09
Max. Average External Temp.		33.7	32.2	29.2	23.5	18.0	18.3	18.2	21.6	24.9	28.6	32.0	34.0
Min. Average External Temp.		22.2	22.9	19.2	13.5	09.2	10.2	8.9	10.8	13.1	16.7	20.4	22.8
Average Internal Temp.	12.22 pm	30.43	28.16	26.53	23.07	18.88	18.82	18.77	20.06	22.62	24.5	27.77	29.42
	24.22 am	29.54	28.79	26.51	23.53	19.29	19.03	18.94	20.16	23.11	24.61	27.83	29.18
Differences in internal tem. between Pm & am		-0.89	+0.63	-0.02	+0.46	+0.41	+0.21	+0.17	+0.10	+0.49	+0.11	+0.06	-0.24
Differences in external tem. between Pm & am		3.27	4.04	2.67	0.43	+0.88	+0.52	+.057	1.54	2.28	4.1	4.23	4.58

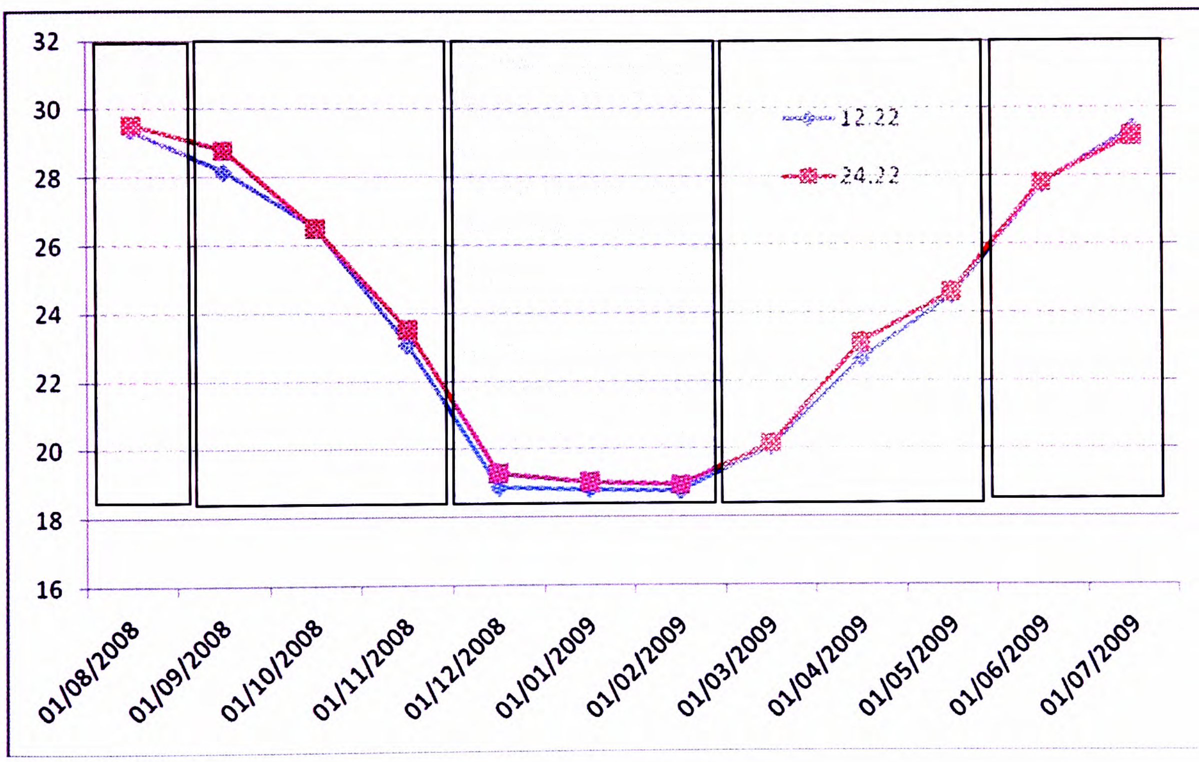
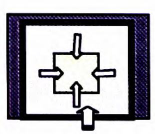
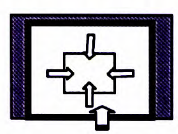
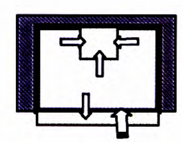
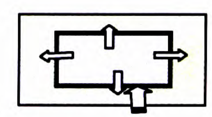


Figure 6.65: Indoor temperatures measured in case study 4.

6.5.5 Summary of the findings of the temperatures measured in selected case studies.

All the information collected about the selected houses (with the results of temperatures measured and the main analysed comments) is presented in (Table 6.44).

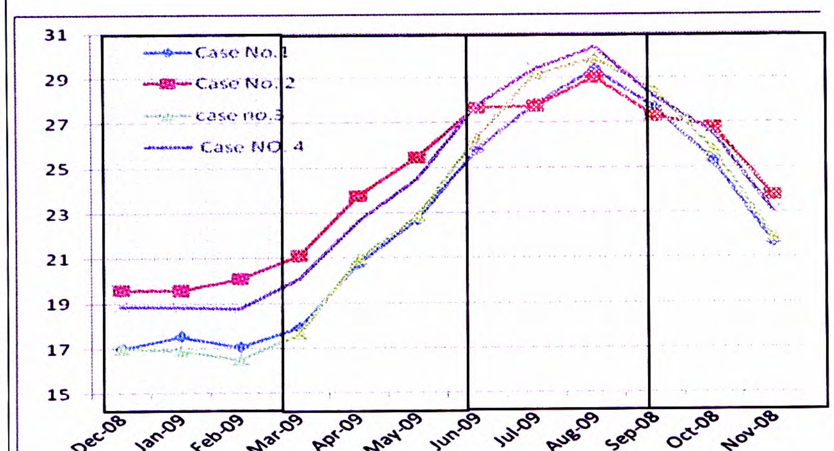
Table 6. 44: The positives and negatives of the case studies.

Factors	Case Study-One	Case Study-Two	Case Study-Three	Case Study-Four	Comments
Location and built	Tripoli old city- built between 1744 & 1832	Tripoli old city built between 1744 & 1832.	Located outside Tripoli old city - built in 1970 and the second floor was built in 1986.	Located outside Tripoli old city built in 1983.	Choosing two different areas and different ages of buildings can help in finding the reasons for changing internal temperature in the four case studies.
General areas	Land plot area = 247 m^2 Ground floor area =237 m^2 First floor area = 241 m^2	Land plot area = 217 m^2 First floor area = 176.m^2 Courtyard area = 41 m2	Land area = 240 m^2 Ground floor plot area =164 m^2 First floor plot area=176 m^2 Court Area =16 m^2	Land plot area = 800 m^2 Ground floor area =192 m^2 First floor area =216 m^2	The plot areas of the first three cases are small and almost the same size; this is why there is a courtyard. The fourth case is more than three times bigger; this is why it does not include a courtyard.
Elevations	External elevations = 104 m^2 Solid areas = 90 m^2 Openings=14 m^2 Internal elevations = 164 m^2 Solid areas = 140 m^2 Openings=23 m^2	External elevations = 20 m^2 Solid areas = 17 m^2 Openings= 3 m^2 Internal elevations = 100 m^2 Solid areas = 86 m^2 Openings= 15 m^2	External elevations = 92m^2 Solid areas = 77 m^2 Openings= 15 m^2 = Internal elevations = 115 m^2 Solid areas = 83 m^2 Openings= 32 m^2	External elevations = 747m^2 Solid areas =690 m^2 Openings = 57m^2	External elevations of case 1 and 3 are nearly the same and the openings in case 3 are more than that in case 1 Case number four recorded good indoor temperature in wintertime whereas, in summertime, it recorded the highest indoor air temperatures.
Design concept:	Two storey central courtyard house, connected with neighbours on three sides 	One storey central courtyard house with one room on the first floor used for men guests; the house connected with neighbours in four sides 	Two storey house. The courtyard is at the back of the house and a small garden is located at the front. 	The courtyard does not exist; instead it has a surrounding garden. Accordingly, all the external spaces have direct openings onto the garden 	It is clear that the need for the courtyard in the first three case studies relates to land area and the attachment to neighbours on three sides in addition to its social and climatic benefits. Accordingly, the position of the courtyard in vernacular architecture was very necessary to provide light and air. However, with contemporary planning and building laws in Tripoli, the land area should be more than 400m^2 and building setback requirements should be more than three metres; accordingly, the courtyard is not necessarily located in the middle.
Building materials	The main method of construction in case one and two: thick load bearing walls with flat roofs. The thickness of the walls is 70cm and made of irregular stone mixed with lime; the spaces between them are filed with small stones and clay mortar and the wall is finished with a plaster coating. The roofs of these houses are usually flat; supporting beams of steel and wood.		The ground floor walls are made of lime block with dimensions of 25cm x 20cm and a concrete roof; the second floor walls are made of cement hollow blocks and the roof is made of concrete reps and red hollow clay blocks.	The villa is constructed by using skeleton type (reinforcement columns and beams) The walls are made of lime block with dimensions of 25cm x 20cm and a concrete roof.	According to the measurements, it is clear that building materials and thickness of walls helps to reduce heat gain. However, the need for improving local building materials and creating thermal insulation is very important.
Tools	Television, satellite receiver, cassette, fridge and roof fan	Television, computer, receiver, cassette, fridge, fan and lately AC.	Television, receiver, cassette, fridge, fan and AC	Television, receiver, cassette, fridge, fan and AC	Usually all Libyan family using the same equipment. Very few families can use air conditioning in all house rooms because it is expensive.

Factors	Case Study-One	Case Study-Two	Case Study-Three	Case Study-Four	Comments
Comments from the residents	They covered the courtyard for many reasons; The roof protects them from winter cold and rain and a very warm days; Provides a suitable area for gathering together family and relatives; They preferred to have a courtyard in the side of the house Covering the courtyard causes dark spaces, a lack of ventilation and increased humidity in the walls, accordingly a need for continuous maintenance	They like the courtyard environment. However, they raised some comments: The courtyard provides a nice atmosphere on nice weather days but on rainy days they cover the courtyard by removable plastic sheets. To achieve comfort in winter time they use the traditional heater and in summer time they usually depend on cross ventilation but lately in late August 2009 they started to occasionally use AC. The space within the rooms are not suitable for the new furniture;	The occupants raised the following: The house generally is comfortable because it mixes new and tradition houses style and the number of rooms are good. The things they do not like about it are the area of the rooms which are not appropriate for modern furniture and also the location of the kitchen is very annoying; it is not ideal in either summer or winter time because they have to cross the courtyard to get to the kitchen. AC. is located in the main hall only.	The occupants' opinions are: The villa is comfortable from the functional point of view where the area and number of spaces are quite enough. The garden surrounding the house provides privacy, shading and a nice view. In summer time it is very warm and they use fans and cross ventilation. In winter they do not use any kind of heating; they cover the openings and wear heavy clothes.	The comments from the occupants can be summarised as follows: A courtyard is a good solution if it can be covered when needed, or if it is located on the side and used as an internal garden. Wintertime does not create big problems and individual comfort can be achieved by using traditional heater and clothes. The contemporary villa provides an acceptable number of comfortable spaces. Also, it provides more privacy and the ability to separate guests and family; boys and girls. An external garden is important if it includes green areas and trees. Using suitable local materials with thermal and humidity insulation is very important. Mixed ideas (vernacular and modern) are preferred in designing new housing.

Average indoor temperature between Aug. 2008 to July. -2009

Time - ^0C	Case No.1	Case No. 2	Case No.3	Case No. 4
Dec-08	17	19.59	16.98	18.88
Jan-09	17.53	19.58	16.9	18.82
Feb-09	17.07	20.09	16.5	18.77
Mar-09	17.9	21.11	17.62	20.06
Apr-09	20.73	23.75	20.97	22.62
May-09	22.69	25.45	22.85	24.5
Jun-09	25.78	27.65	26.33	27.77
Jul-09	27.83	27.73	29.16	29.42
Aug-08	29.43	29.07	29.93	30.43
Sep-08	27.7	27.29	28.45	28.16
Oct-08	25.3	26.8	25.83	26.53
Nov-08	21.66	23.75	21.93	23.07



The table and chart show that case study number 2 recorded the best indoor temperature in both summer and winter times, and case number 4 recorded the worst indoor temperature in summer but a good indoor temperature in winter. The effect of covering the courtyard in case study number 1 is very clear especially in wintertime where the sun cannot penetrate inside the home; the same as case study number 3 which recorded the worst indoor temperature in winter and the second worst indoor temperature in summer.

6.5.6 Field measurements' results and discussion

As stated previously, air temperature measurements were taken between 7th August 2008 and 24th July 2009. Indoor temperatures were taken daily every one hour (see appendix 4). For this study, readings taken at 12.22pm and 24.22am were taken as a reference to measure the indoor temperature inside the case studies. (Table 6.44 and Figure 6.65) illustrate the following results:

The indoor temperatures recorded in summertime shows that case study number 2 recorded the lowest indoor temperature, followed by case number 1 with case number 4 recording the highest temperature.

- In wintertime, case study number 2 recorded the highest indoor temperature followed by case study number 4 with case study number 3 recording the lowest indoor temperature.
- In springtime, when the weather is still cold, case number 2 recorded the best indoor temperature followed by case number 4 with case number 1 and 3 being showing similar readings.
- In autumn, all the case studies recorded only a small difference in readings. However, case studies 1 and 3 recorded the lowest temperatures and case studies 2 and 4 recorded the highest temperatures.

Discussion

The results of the indoor temperature measurements confirmed that case study number 2 (open courtyard type) recorded the most acceptable indoor temperatures almost all the year; this is because of the following:

- The house is surrounded by buildings on four sides; the only one part open to the street is the entrance which reduces the surfaces facing direct sunlight.
- The proportion of the courtyard makes it shaded most of the time.
- The type and thickness of building materials used in the walls and roof helps to protect the indoor spaces.
- The room where the readings were taken is small and is surrounded by other rooms; it has one door and a small window above the door which helps to control the heat gain and heat loss.
- Although most of the building is on one floor which usually helps to increase indoor

temperature, this house is not affected by this factor because suitable building materials were used which have a high thermal mass.

Case study number 1, where the courtyard was covered, recorded the second best reading in summer and the third best in wintertime; this shows that it occupies the middle ground in terms of the four case studies in both summer and winter. This is because of the covering over the courtyard which means no direct or indirect sun can enter the house and there is no cross ventilation to remove hot air from the house; accordingly humidity levels increase within the property which makes the house cooler in winter.

Case number 3 recorded the coldest indoor temperature in wintertime and the third highest indoor temperature in summertime. This is probably because of the following:

- There is no direct sunlight entering the rooms and the height of the courtyard keeps the court shaded all the time. The only elevation facing the street is located in the south aspect where the sun is high and, because there is a canopy, direct solar insulation is prevented from entering.
- The living room where the measurements were collected is located on the ground floor and is surrounded by other spaces and has only one window open to the courtyard.
- Building material mass and wall thickness are less than that used in case study 1 and case study 2, and the house does not receive any solar insulation.

Case study number 4 recorded good indoor temperatures in wintertime whereas, in summertime, it recorded the highest indoor air temperature; this is because of the following:

- The house is surrounded by gardens which means that all the surfaces face direct sunlight and this increases heat gain in summer and winter. In addition to this, there is no shading devices to prevent the sun entering the windows.
- The external colours are not bright enough to help absorb sunlight and the walls are not very thick and do not include any thermal insulation.
- The location of trees is too far away from the house to help to provide shade.

From the above discussion and the results of the field study and the opinions of residents, many reasons have arisen for covering the courtyard (which can be taken into consideration in the suggested guidelines) as follows:

- The position of the courtyard in the middle of the house is not appropriate. Because it is open to sky, it is difficult in both summer and winter time to move from one room in the house to another without crossing the courtyard and therefore being at the mercy of the weather.

- It creating a large additional area.
- It is difficult to use air conditioning when need it.
- Many people wanted to emulate the modern type of housing and saw their own houses as old fashioned.
- People associate the courtyard house with poverty, slum areas, a lack of facilities, outmoded style and inadequacy of services.

By observing some covered courtyard houses, it could be seen that some problems accrued as a result of covering the courtyard; these were as follows:

- A lack in light and air movement.
- An increase in the humidity levels.
- An increase in the temperature levels.
- No connection to the outdoors.
- Loss of the aesthetic and climatic features (such as trees and fountain).

To summarise, the findings of this limited study show that the best indoor temperatures recorded in both summer and winter times were found in the open courtyard house. The maximum summer air temperature was recorded in the villa type of housing (contemporary housing style). However, this type of housing records good indoor temperature in the wintertime. Building orientation, materials, windows' size and shading devices plays a major role in reducing the indoor temperature. Also, the study clarified that covering the courtyard makes the internal environment worse by increasing temperature and humidity and reducing lighting levels. Measuring internal temperature in the selected houses gave an idea about the performance of different building designs, and more studies are needed to optimise these results and provide definitive recommendation.

6.6 DISCUSSION AND CROSS COMPARISON OF THE FINDINGS

This section will compare the understanding and opinions from the literature, professionals and householders and relate them to the temperature measurements in the selected houses in the case studies.

The residents' and professionals' opinions are important, because they live and work in Tripoli and know the culture. The findings show general agreement in almost all non-scientific points such as the advantages of contemporary houses and using new technologies. However, they were not agreed on some points relating to the application of certain vernacular features in future housing. Accordingly, the suggestions provided by the focus group to improve on the collected strategies drawn from the literature have been compared with the opinion of the residents, the professionals' views and with the temperature measurements. The comparisons looked at:

- Local microclimate
- Building design
- Main building components
- Additional building components

6.6.1 Local microclimate:

Many authors confirmed that understanding the local microclimate is a very important factor that can affect building performance, such as the State of Queensland (2008), Mansy (2006), Arias (2005) and the National Renewable Energy Laboratory (NREL, 1995), these have all stated that landscaping may be the best long-term investment for reducing heating and cooling costs, while also bringing other improvements to the community. They clarified that two main elements can affected landscaping design which are:

- Topography - elevation, slopes, hills and valleys, ground surface conditions.
- Vegetation - height, mass, silhouette, texture, location, growth patterns.

El-Menghawi (2004) clarified that because transportation considerations under the urban planning regulations have become more important than the human scale, streets have become wider and straighter. Consequently, the compact urban fabric has been replaced with a grid fabric in order to ease the movement of cars and buses. On the other hand, Edwards and Hyett, (2001) have confirmed that the compact city is the ideal city form. They have suggested further strategies that can be adapted such as suggesting that the best configuration is high density. An ideal city contains green squares and tree-lined streets to bring nature into the heart of the city. Green spaces help to stitch together the urban fabric. As explained in (section 3.6), Edwards and Hyett have suggested many good strategies for hot regions that can be used where appropriate because the main aspect for this region is to maximize shaded areas and walls. Accordingly, the city can be made compact by connecting buildings together as can be seen in vernacular architecture, or by using green areas and trees to provide shading. The designer should make a decision on this aspect according to the project circumstances.

Grafa (2006) stated that before taking action in architecture, engineering and construction in arid and semi-arid countries, it is important to learn lessons in the management of limited national resources.

- Professionals and the focus group confirmed this view and mentioned the lack of water resources in Libya and the importance of choosing the appropriate kind of vegetation.
- They agreed that a compact city could help in reducing the surfaces exposed to solar radiation. However, they mentioned that it is important also to consider the need to use new types of transportation and accordingly, they suggested the need to explore other solutions to reduce the surfaces exposed to the sun such as shading devices, trees or to cover parts of the streets.
- The temperature measurements confirmed the importance of the compact city form to reduce heat gain. However, the compact city form can work positively if the building materials used have the ability to delay heat transfer such as those used in case study 1 and 2. The results of case study 3, where the building materials used were not appropriate, showed that this case study measured the coldest indoor temperature in the cold months and the second warmest indoor temperature in the hot months.
- Householders were not asked about the importance of green areas and vegetation. However, by observing the houses in the case studies and other houses in Tripoli, it was found that houses usually include vegetation outside and inside the houses for shading and beauty purposes.

6.6.2 Building design

Evans (1980) stated that the shape of dwellings can be designed to obtain advantage from the useful aspects of climate and to reduce the impact of adverse aspects. Factors which should be controlled in relation to the needs of the climate zone are: the form, layout, orientation and scale of dwellings and dwelling-groups. Hyde (2000), CLEAR (2004) and the State of Queensland (2008) confirmed these factors and clarified them in much more detail (see chapter 3).

The strategies presented in (Table 6.39) that relate to plan design concept, building heights, building form and room orientation have been confirmed by the professionals and the focus group alike with some comments in terms of the Libyan scenario as follows:

The optimum shape is that which loses the minimum amount of outgoing temperature in winter and accepts the least amount of incoming temperature in the summer. However, in many circumstances, the square house is not the optimum form in any location and all shapes elongated on the north-south axis work well both in winter and in summer.

- The focus group confirmed the point regarding the north-south axis. However, they commented that the square house, even if it is not compact and if there are shaded voids with minimum windows' areas in the east and west direction, can provide better air movement.

Heavyweight walls and roofs can reduce the internal surface temperature swings by 70% (Evans, 2007; Askar et al., 2001; Hyde, 2000, and others). However, the University of Hong Kong (arch.hku.hk) suggests that the whole building should be lightweight to allow rapid cooling down at night.

- Concerning these contradictions, there was an experiment to built prefabricated houses in Tripoli using lightweight construction but people did not accept these kinds of housing because they thought that they were not strong and unsafe (Emhemed, 2005). In addition, using light materials in roofs needs requires a pitched structure which may look strange in the Tripoli context.

  Professionals and the focus group supported the opinion that heavyweight construction is the most appropriate because of the increase of the thermal time lag and because of the available materials. This is confirmed by the feelings of householders who believed that old materials and construction are better than new ones.
- The temperature measurements confirmed the importance of heavyweight construction; case studies 1 and 2 where the wall thickness reached 70cm provided the best readings in summer and winter time.

In his suggestions on the appropriate layout of buildings in hot-humid regions, Givoni (1998) states that when depending on natural ventilation to achieve comfort, a spread-out building (not compact - detached) with large windows can enable more natural cross ventilation.

- Although professionals and the focus group agreed that large windows may provide good ventilation, at the same time they expose interior to more heat gain. To avoid direct heat gain it is very important to provide shade by using trees or shading devices. This opinion is confirmed by the temperature measurements where the case studies used almost the same windows' size; however, those which measured the lowest internal temperature in summer were case studies 1 and 2 because their windows were located inside courts and shaded all time.

- Professionals and the focus group pointed out that in Libya the building laws require detached houses to be built. Detached houses are a good solution if the east and west elevations are shaded.
- Householders prefer to live in detached houses with wide windows. However, they like to use some traditional features in a modern way such as a courtyard and masharbia.

Despite the immense belief of the specialists and professional architects that the courtyard house is the ideal solution for achieving thermal comfort in hot climate regions, some authors argue that the success of the courtyard house depends on the integration of other factors. For instance, The Centre for Desert Architecture and Urban Planning (CDAUP, 2008) stated that the conclusions of a number of studies have indicated that the understanding of the performance of the internal courtyards as thermal modifiers in the built environment of hot regions is not necessarily right. They have suggested that the success of such courtyards in creating a good microclimate depends to a great extent on their detailed design, requiring careful attention to be given to a range of factors including geometry, materials, finish and the use of vegetation.

Muhaisen and Gadi (2005) maintained that special arrangements are required at the design stage to achieve a suitable and satisfying courtyard building. This includes the internal envelope's materials and finishing as well as the proportions of the physical parameters of the courtyard form. Similarly, El-Dars and Said (1972) explained that the courtyard house in Libyan contemporary housing must undertake certain further developments to accommodate social change and the progressive modern requirements of the Libyan family, together with undertaking new advances in building technology. As clarified in section 3.4.1.1 Swan (1991) pointed out the importance of various courtyard features such as ensuring that the walls surrounding the courtyard should be thick and of adobe and that a fountain and plantings all help to provide a better internal environment.

- The literature, professionals and the temperature measurements in the selected case studies, all confirmed the importance of the courtyard house as the ideal social and climatic solution in hot regions because it offers necessary shade to the adjacent rooms in summer (as it is usually surrounded by arcades) while in winter it offers a warm area. Accordingly, it protects the families from the harsh climate, as well as offering daylight and natural ventilation to the surrounding spaces. However, although all householders liked the social advantages of the courtyard those who still lived in a courtyard house did not like to live in it for social and climatic reasons:(1) socially, because they thought that living in a courtyard type is an indication of poverty, and (2) climatically, they did not like the positioning of the courtyard because they has to pass through it during hot summer and wet winter days.

- The focus group felt that the courtyard was the ideal solution when using appropriate building materials and proportions that can provide adequate shading. However, they felt that the position of the courtyard should not be in the middle of the building unless a movable cover was provided to avoid excess summer heat and winter rain. They confirmed that a solarium house was a good solution and a courtyard house can be used as a solarium house when using moveable covered windows and roof. They also stated that balconies are important for providing shading. However, socially they are not often used by occupants unless a big part of the balcony can be covered by *masharbiya.*

The results obtained from the thermal investigation and the interviews with the professionals and householders explored the potential of a courtyard for passive cooling in a warm humid climate. Accordingly, the courtyard house remains an appropriate built form and it could still fulfil the requirements of a contemporary lifestyle if redefined and considered in the light of technological and socio-economic changes. However, these courtyard houses will not work properly unless most or all factors shown in (Figure 6.66) are including in their design, particularly:

- The position of the courtyard in the centre of the house should be changed to avoid crossing it all the time to move between rooms.
- Use new technology to provide a glazed cover to the courtyard which can be opened when necessary.
- The walls surrounding the courtyard need to have good thermal resistance and a long thermal time lag.
- The courtyard should include trees and a fountain to provide shade and evaporation.

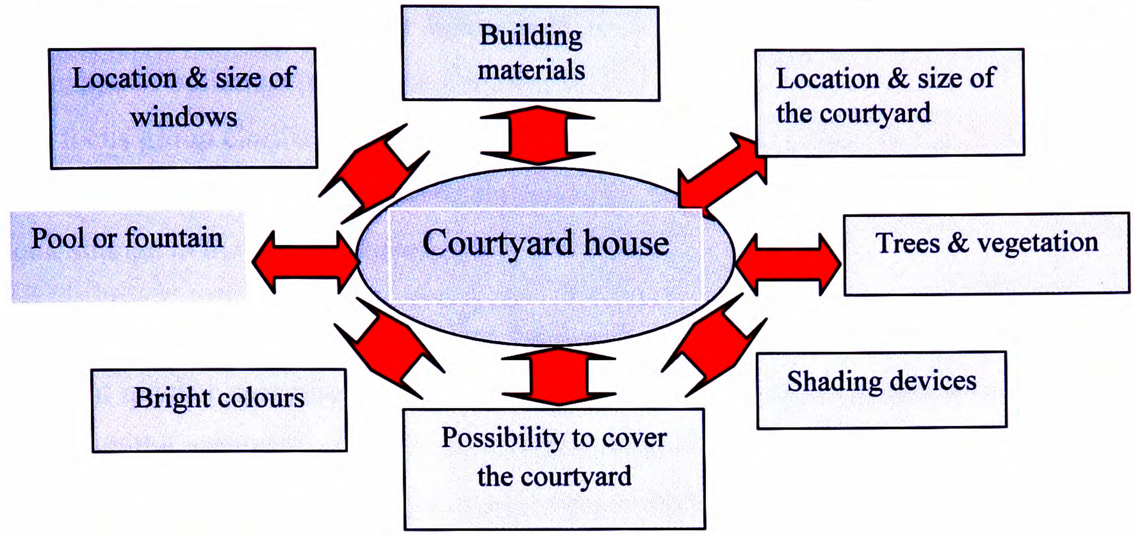


Figure 6.66: Factors affecting the performance of the courtyard house.

The best way to include the courtyard concept in housing in the future can be left to the designer and to the project circumstances. In the future the courtyard could possibly be located in the middle as an internal garden with more attention given to connecting the house rooms in such a way that the inhabitants can access rooms without always having to cross the courtyard. The courtyard could be used as a solarium that includes flexible windows and special kinds of plants that can grow in such environment.

6.6.3 Main building components

The Australian state government (Commonwealth of Australia 2005, Northern Territory Government 2006, Commonwealth of Australia 2007 and The State of Queensland 2008) has suggested using metal roofs because they cool rapidly at night and daytime heat gain can be minimised by using sheeting with a reflective coating on its top. The second comment they made related to the location and shape of openings; they suggested minimising the use of windows on the east and west walls and using vertical wing walls to shade windows and walls from the low west-southwest and east-southeast sun.

- The professional and focus group opinion was that a metal roof is not an ideal solution because it increases heat gain and needs much more shading. With respect to using vertical wings, they clarified that shading the east and west elevation can be by using shading devices, vegetation or by the design of the building.

Meir and Roaf (2007) stated that lightweight roofs have important effects on the thermal performance of buildings (even with extra-heavy walls).

- The focus group clarified that a lightweight roof is not appropriate for the thermal time lag properties and because of the materials available. They also felt that such a structure would look strange in the Tripoli context.

Evans (1980) proposed that a suspended floor with a large well ventilated under-floor cavity will give a quicker response when temperatures drop in the evening than a floor directly in contact with the ground.

- The focus group clarified that a suspended floor can be useful but it is not advised because it needs careful use and maintenance can be difficult.

Givoni (1998) suggested the use of open plan dwellings and stated that privacy can be provided by designing doors made like shutters blocking the view but giving passage to free airflow. He also suggested leaving the upper part of a room-height door open with hinges at the top.

- The focus group clarified that for cultural reasons doors are important in almost all the home. However, the design of the doors could be changed by providing upper or lower openings to allow air movement.

6.6.4 Building materials

Bukamur (1985) suggested that high thermal mass structures with thick walls are required in hot regions. Accordingly, high thermal mass materials such as adobe, masonry, limestone and heavy soil might be used in floors, walls and ceilings.

Professionals and the focus group confirmed the importance of appropriate building materials as the main factor affecting the building performance. They stated that local building materials used in vernacular architecture are much better than those used in contemporary houses because contemporary house materials do not have thermal insulation. They confirmed the strategies advised by the literature as related to building materials and commented that more research is needed in improving local building materials.

The temperature measurements seem to confirm that old traditional materials give better results. As identified previously, case study number 3 was located in a compact area and had a courtyard but was built with current building materials and had the worst indoor temperature in summer and winter time. This indicates that building materials' selection plays a major role in buildings' thermal performance.

6.6.5 Additional Building Components

The importance of using features such as a wind catcher, solarium, fountain, solar panels and balconies are well explored in the literature. Professionals and the focus group confirmed their usefulness and gave some additional suggestions, namely, that the solarium house is a good solution and a courtyard can be used as a solarium when used with moveable covered windows, and that balconies are important for providing shading (although socially they are not often used by occupants unless enclosed by *masharbia).* The householders preferred using these features in a way that ensured privacy and comfort.

CHAPTER SEVEN

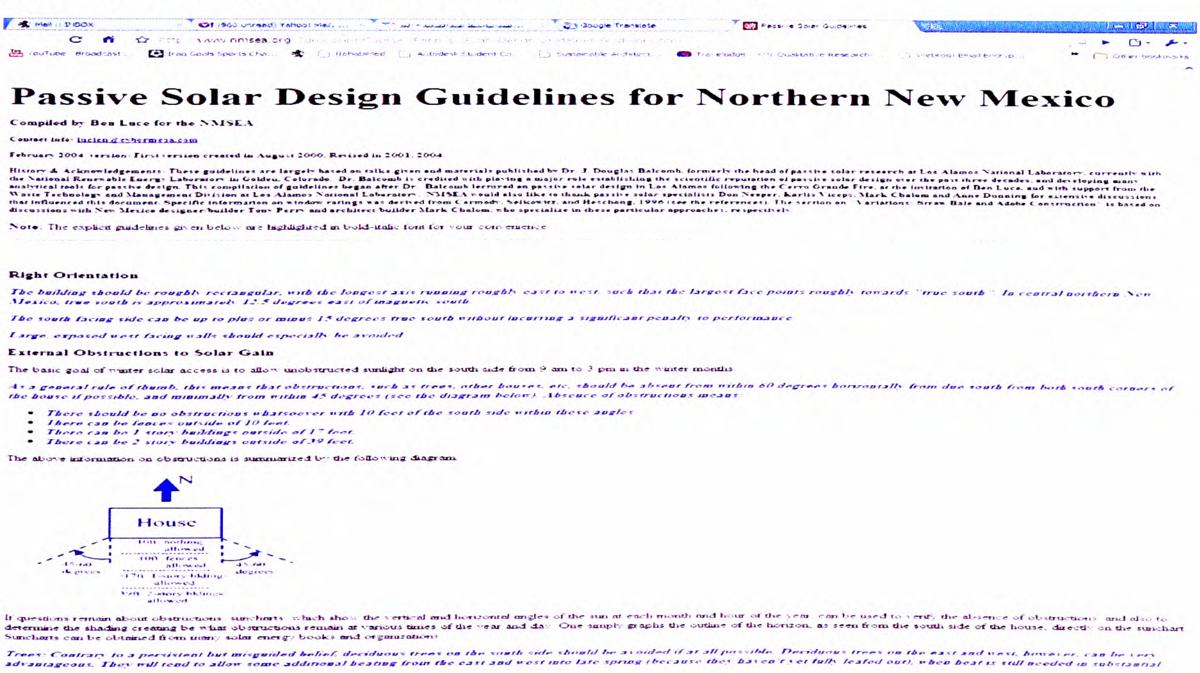
CHAPTER ONE:	INTRODUCTION
CHAPTER TWO:	SUSTAINABLE DEVELOPMENT
CHAPTER THREE:	CLIMATIC DESIGN
CHAPTER FOUR:	LIBY- GENERAL BACKGROUND
CHAPTER FIVE:	RESEARCH METHODOLOGY
CHAPTER SIX:	ANALYSIS OF THE FINDINGS OF THE QUESTIONNAIRE, INTERVIEWS AND TEMPERATURE MEASUREMENTS
CHAPTER SEVEN:	THE FINAL CLIMATIC DESIGN GUIDELINES FOR HOUSING
CHAPTER EIGHT:	CONCLUSION AND RECOMMENDATIONS

CHAPTER SEVEN: THE FINAL CLIMATIC DESIGN GUIDELINES FOR HOUSING

7.1 HOUSING CLIMATIC DESIGN GUIDELINES

This chapter introduces the final climatic design guidelines. In this study, the guidelines are designed to advise architects on how to design more effectively with the climate in hot regions in general and in Tripoli, Libya in particular. Cambridge University Press (2010) defined guidelines as information intended to advise people on what something should be or how something should be done. The most common guidelines cited in the literature regarding climatic design has been collected and discussed with a focus group and improved upon to meet people's climatic and social needs in Tripoli. The professionals consulted strongly confirmed that four factors affect the application of climatic design: users, marketing, government regulations and architects. Clarification on how to improve these four factors in order to implement climatic design guidelines has been presented in section 6.2 (see also Amer 2007).

Many of the best practical guidelines have been reviewed, such as those presented by Luce (2004) who proposed passive solar design guidelines for Northern New Mexico and presented them by setting out the main factors and then explaining the guidance in sentences or bullet points with drawings or diagrams when needed (Figure 7.1).



Passive Solar Design Guidelines for Northern New Mexico

Compiled by Ben Luce for the NMSEA

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February 2004 version: First version created in August 2000. Revised in 2001, 2004

History & Acknowledgements: These guidelines are largely based on talks given and materials published by Dr. J. Douglas Balcomb, formerly the head of passive solar research at Los Alamos National Laboratory, currently with the National Renewable Energy Laboratory in Golden, Colorado. Dr. Balcomb is credited with playing a major role establishing the scientific reputation of passive solar design over the past three decades, and developing many analytical tools for passive design. This compilation of guidelines began after Dr. Balcomb lectured on passive solar design in Los Alamos following the Cerro Grande Fire, at the invitation of Ben Luce, and with support from the Waste Technology and Management Division at Los Alamos National Laboratory. NMSEA would also like to thank passive solar specialists Don Neeper, Karlis Viceps, Mark Chalom and Anne Dunning for extensive discussions that influenced this document. Specific information on window ratings was derived from Carmody, Selkowitz, and Heschong, 1996 (see the references). The section on "Variations: Straw Bale and Adobe Construction" is based on discussions with New Mexico designer/builder Tony Perry and architect builder Mark Chalom, who specialize in these particular approaches, respectively.

Note: The explicit guidelines given below are highlighted in bold-italic font for your convenience

Right Orientation

The building should be roughly rectangular, with the longest axis running roughly east to west, such that the largest face points roughly towards "true south". In central northern New Mexico, true south is approximately 12.5 degrees east of magnetic south.

The south facing side can be up to plus or minus 15 degrees true south without incurring a significant penalty to performance

Large, exposed west facing walls should especially be avoided

External Obstructions to Solar Gain

The basic goal of winter solar access is to allow unobstructed sunlight on the south side from 9 am to 3 pm in the winter months

As a general rule of thumb, this means that obstructions, such as trees, other houses, etc., should be absent from within 60 degrees horizontally from due south from both south corners of the house if possible, and minimally from within 45 degrees (see the diagram below). Absence of obstructions means:

- ***There should be no obstructions whatsoever with 10 feet of the south side within these angles***
- ***There can be fences outside of 10 feet.***
- ***There can be 1 story buildings outside of 17 feet.***
- ***There can be 2 story buildings outside of 39 feet.***

The above information on obstructions is summarized by the following diagram

If questions remain about obstructions, suncharts, which show the vertical and horizontal angles of the sun at each month and hour of the year, can be used to verify the absence of obstructions, and also to determine the shading creating be what obstructions remain at various times of the year and day. One simply graphs the outline of the horizon, as seen from the south side of the house, directly on the sunchart. Suncharts can be obtained from many solar energy books and organizations

Trees: Contrary to a persistent but misguided belief, deciduous trees on the south side should be avoided if at all possible. Deciduous trees on the east and west, however, can be very advantageous. They will tend to allow some additional heating from the east and west into late spring (because they haven't yet fully leafed out), when heat is still needed in substantial

Figure 7.1: Presentation of the passive design guidelines for Northern New Mexico.
Source: Luce (2004)

Similarly, Passive Solar Design (2010) used the same format adding introduction about the main titles and use colours (Figure7.2).

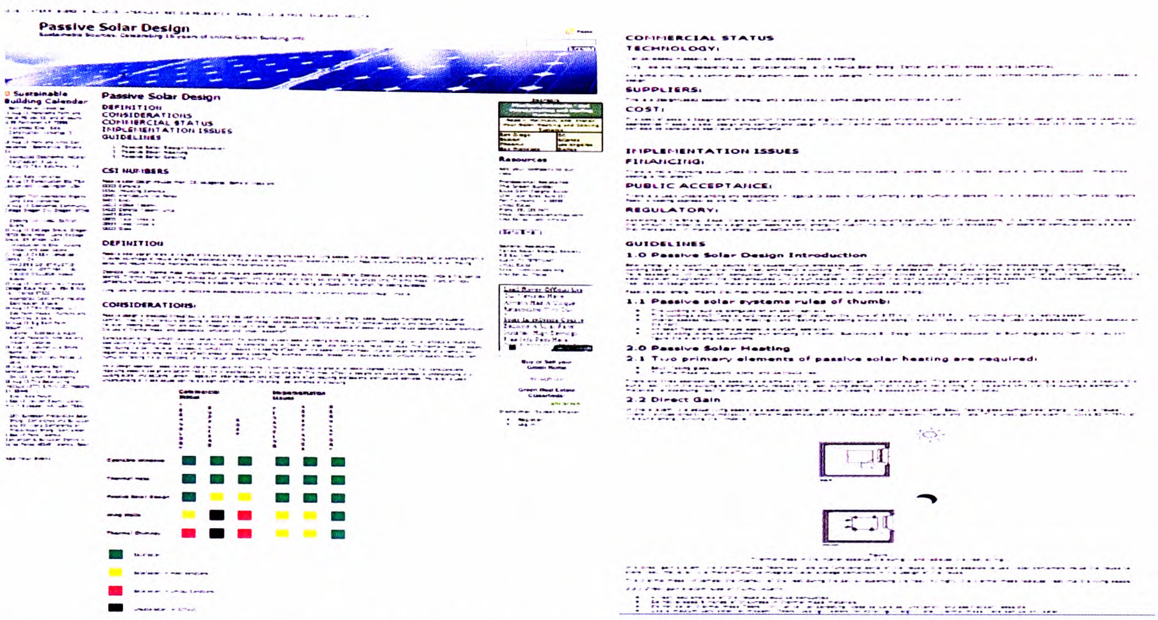


Figure 7.2: Presentation of the passive design guidelines.
Source: Passive Solar Design (2010)

Fosdick (2008) in her guidance about passive solar heating gave general descriptions and set the guidance in many formats; bullets, letters, numbers and figures (Figure7.3).

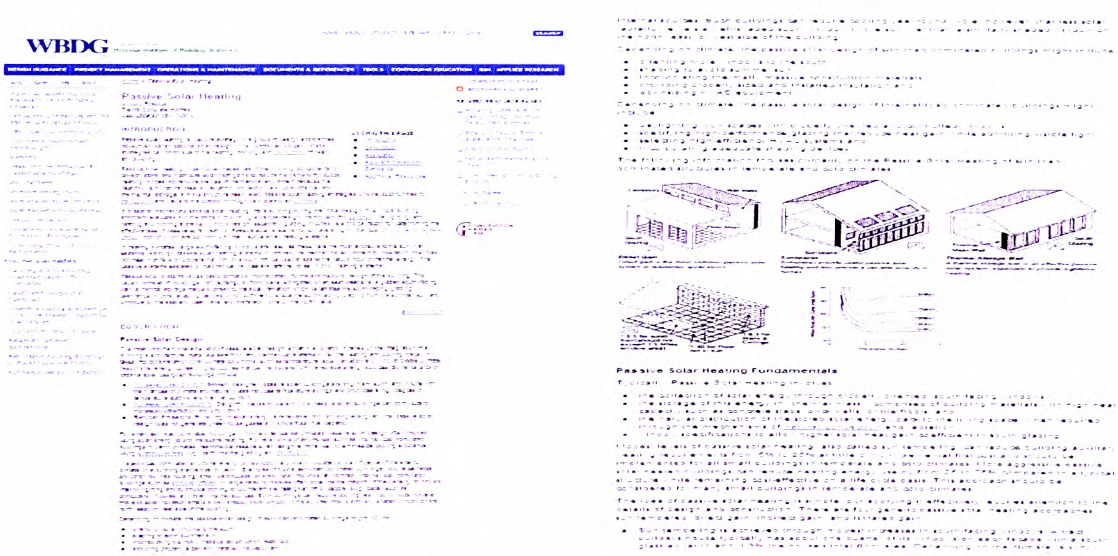


Figure 7.3: Passive solar heating guidelines. Source: Fosdick (2008)

North Carolina Solar Center (2002) presented the checklist of solar home design by giving a description of the main factors and set the guide points in different formats: numbers, bullets and descriptive diagrams (Figure7.4).

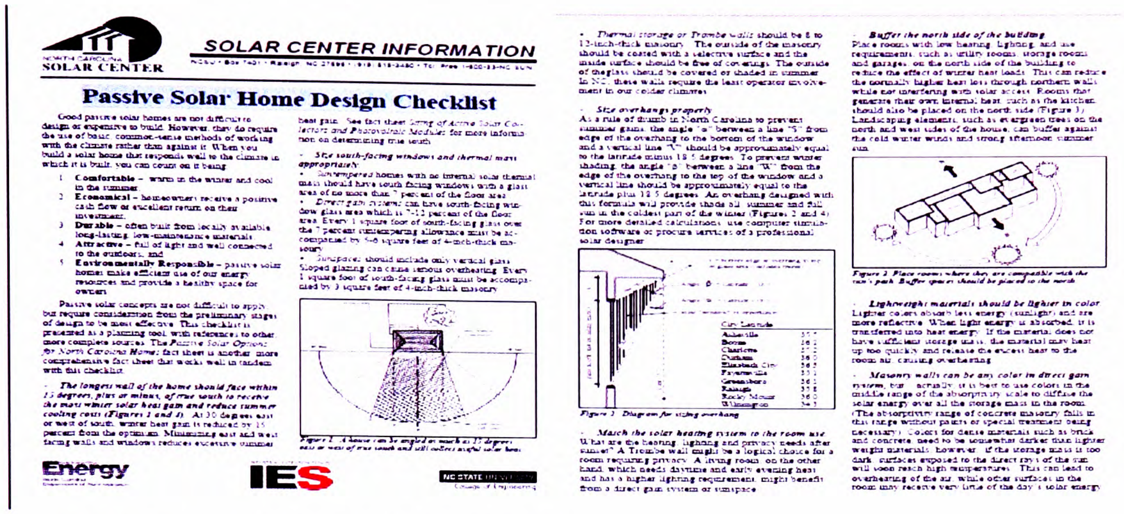
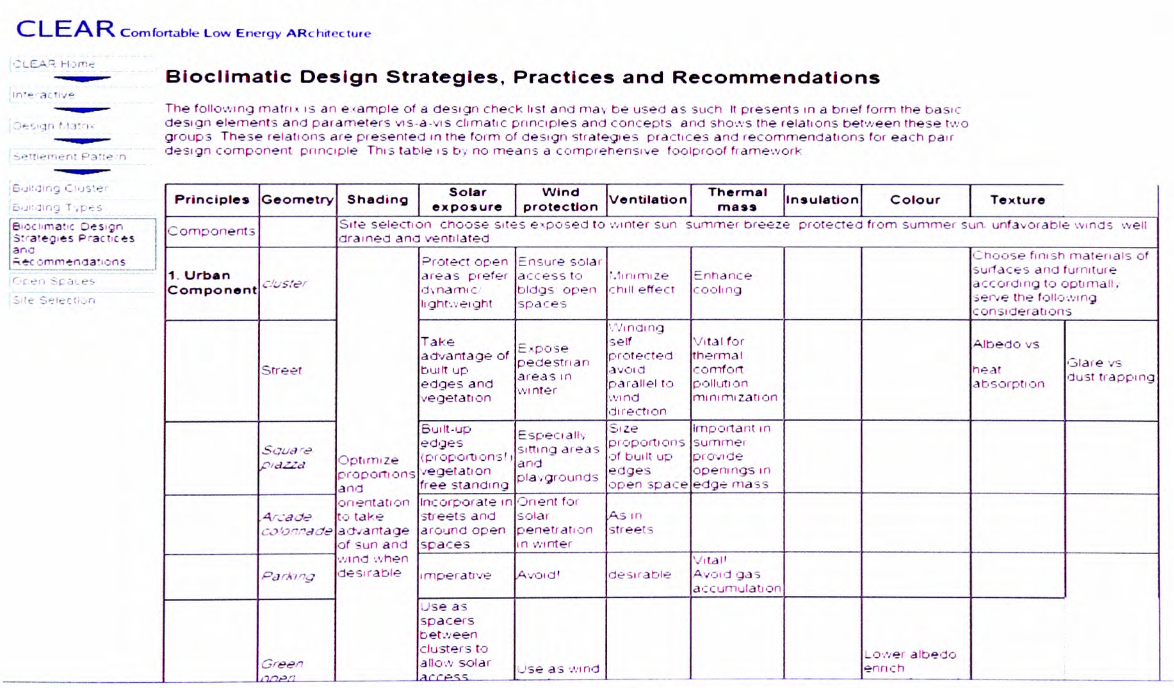


Figure 7.4: Passive solar home design checklist.
Source: The Solar Centre Information NCSC(2002).

CLEAR (2004) gave an example of a design checklist-using matrix, they presents briefly the basic design elements and parameters related to climatic principles and concepts, and show the relations between these groups (Figure 7.5)



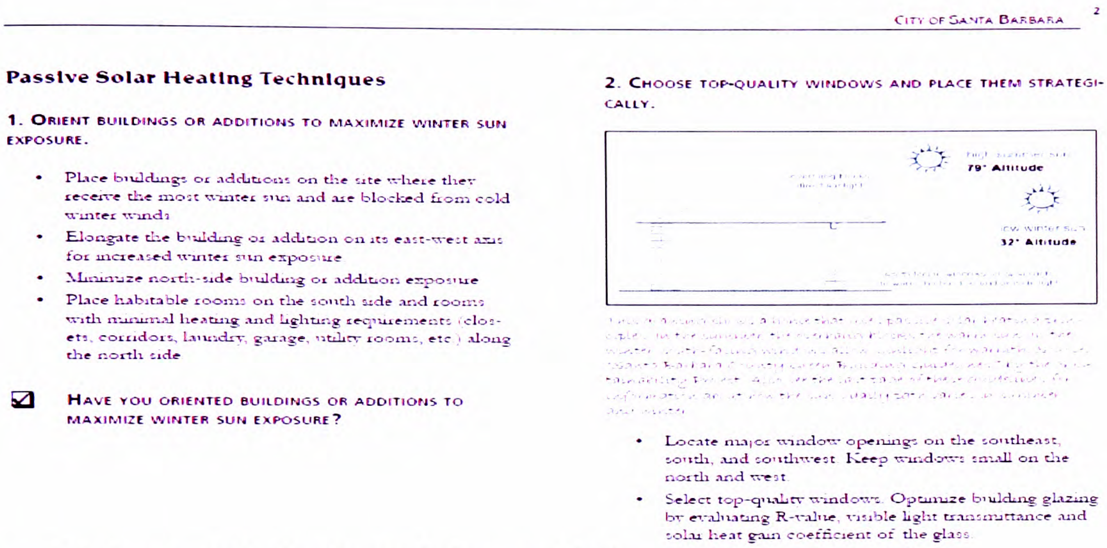
Bioclimatic Design Strategies, Practices and Recommendations

The following matrix is an example of a design check list and may be used as such. It presents in a brief form the basic design elements and parameters vis-a-vis climatic principles and concepts, and shows the relations between these two groups. These relations are presented in the form of design strategies, practices and recommendations for each pair design component principle. This table is by no means a comprehensive, foolproof framework.

Principles	Geometry	Shading	Solar exposure	Wind protection	Ventilation	Thermal mass	Insulation	Colour	Texture	
Components		Site selection: choose sites exposed to winter sun, summer breeze, protected from summer sun, unfavorable winds, well drained and ventilated								
1. Urban Component	*cluster*		Protect open areas, prefer dynamic/ lightweight	Ensure solar access to bldgs' open spaces	Minimize chill effect	Enhance cooling			Choose finish materials of surfaces and furniture according to optimally serve the following considerations	
	Street		Take advantage of built up edges and vegetation	Expose pedestrian areas in winter	Winding self protected avoid parallel to wind direction	Vital for thermal comfort pollution minimization			Albedo vs heat absorption	Glare vs dust trapping
	Square piazza	Optimize proportions and orientation to take advantage of sun and wind when desirable	Built-up edges (proportions!) vegetation free standing	Especially sitting areas and playgrounds	Size proportions of built up edges open space	important in summer provide openings in edge mass				
	Arcade colonnade		Incorporate in streets and around open spaces	Orient for solar penetration in winter	As in streets					
	Parking		imperative	Avoid!	desirable	Vital! Avoid gas accumulation				
	Green open		Use as spacers between clusters to allow solar access	Use as wind				Lower albedo enrich		

Figure 7. 5: Design checklist-using matrix. Source: CLEAR (2004)

City of Santa Barbara Community Development Department (2006) provided guidelines that offer guidance to property owners, architects, contractors and others who may be interested in creating a passive solar building to save energy and create a more comfortable home environment. The guidelines include techniques for designing passive solar buildings that use solar energy. They presented their guidelines by identifying the main factors, using numbers and bullets and giving description and drawings when explanation need. Also they used check list for users to check if they follow the right strategy or not (Figure 7.6).


CITY OF SANTA BARBARA 2

Passive Solar Heating Techniques

1. ORIENT BUILDINGS OR ADDITIONS TO MAXIMIZE WINTER SUN EXPOSURE.

- Place buildings or additions on the site where they receive the most winter sun and are blocked from cold winter winds
- Elongate the building or addition on its east-west axis for increased winter sun exposure
- Minimize north-side building or addition exposure
- Place habitable rooms on the south side and rooms with minimal heating and lighting requirements (closets, corridors, laundry, garage, utility rooms, etc.) along the north side

☑ HAVE YOU ORIENTED BUILDINGS OR ADDITIONS TO MAXIMIZE WINTER SUN EXPOSURE?

2. CHOOSE TOP-QUALITY WINDOWS AND PLACE THEM STRATEGICALLY.

- Locate major window openings on the southeast, south, and southwest. Keep windows small on the north and west
- Select top-quality windows. Optimize building glazing by evaluating R-value, visible light transmittance and solar heat gain coefficient of the glass

Figure 7.6: Passive solar heating techniques guidelines.
Source: The City of Santa Barbara (2006)

Zimmerman (2003) in his sustainable architecture guidelines arranged guidance in categories and divided into two groups within each category: guidance that should be applied to all renovation and construction projects should marked as 'Required Minimum Standards' ; and guidance that might be considered and applied if possible marked as "Optional Items". In addition to that, he used drawings to explain the concept (Figure 7.7).

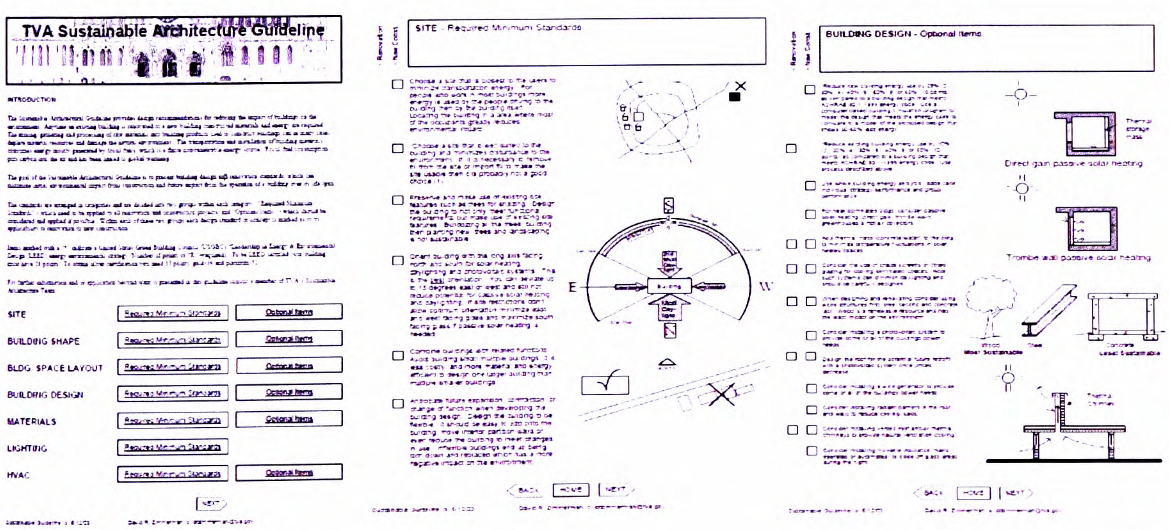


Figure 7. 7: sustainable architecture guidelines. Source: Zimmerman (2003)

From this view of the different types of guidelines, it was found that all the strategies can be useful. However, Luce (2004) and Zimmerman (2003) provide a more suitable strategy for this study because they classified the main factors into categories and each category has a subdirectory with brief descriptions. Accordingly, the guidelines design for this thesis will include the main factors divided into categories with a brief description and without drawings because the guidelines are designed to be used by architects who already know the meanings of the guidance. Also, the professionals who validated the guidelines stated that there was no need to provide extra explanations or figures. In addition to that the above, all the items presented in the guidelines have already been defined in chapter 3.

As illustrated in Figure 7.8, the guidelines are divided into four main principles related to building design and planning. The guidelines start by understanding the main factors that might help improve building performance in the local microclimate stage and understanding the relation between buildings and the surroundings. Then looking at the main building concept design, followed by more detailed strategies for the main building components such as walls, roofs and windows etc, finally looking at additional building components that might be included in the building or might not depending on the project's circumstances, (these additional components should be taken into consideration in the design concept stage).

Each principle has subtitles clarifying the main components which are included the main guidance. The priority of the points listed in the guidance are presented according to the point's importance, availability, cost and the opinion of professionals and householders. The final guidelines that were sent to the professionals to validate are summarised and presented in (Table 7.1) using bullet points style. A copy of the responses can be found in (appendix 3)

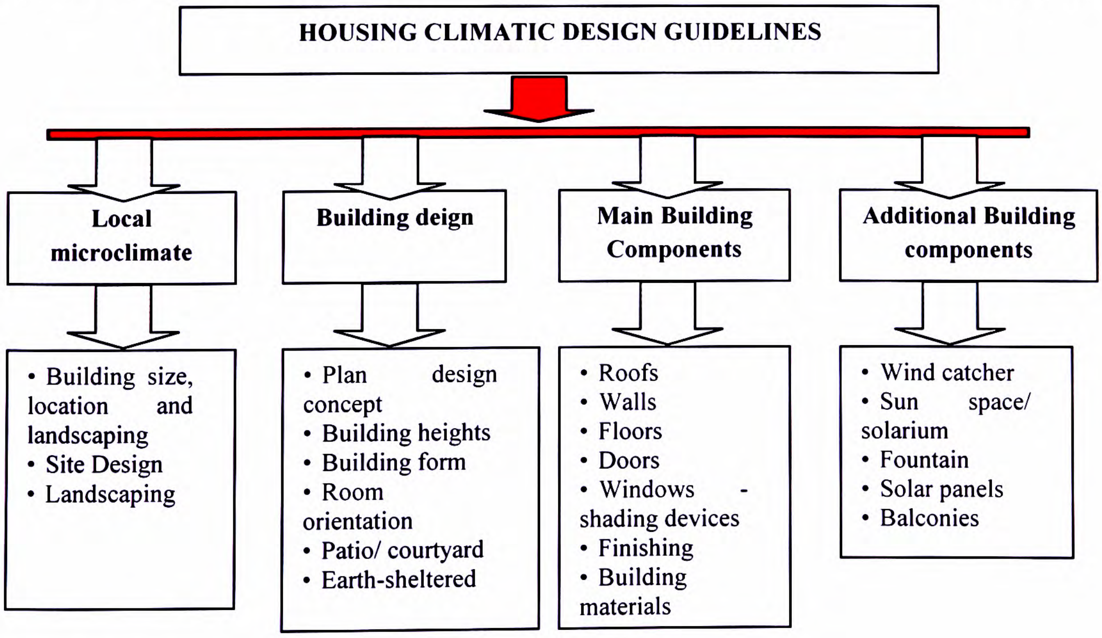


Figure 7. 8: The guidelines design.

7.1.1 The first Principle: Local microclimate:

Tripoli the location for the case studies, is located in a hot-humid region which is characterised by excessive heat and an unusually large day – night temperature variation. There is continuous moderate to high humidity which is also an issue that has to be addressed. The main components that can be affected by the local microclimate are related to the site plan design such as building size, location and landscape. The climatic design strategies related to this point are as follows:

- **Building size, location and landscaping**

While planning stage, it is important to consider the followings:

- Orient streets to run east-west and then accordingly, buildings will be oriented correctly.
- The spacing of the buildings should be carefully considered to avoid obstructing the wind flow around those buildings.
- In order to reduce the surfaces exposed to solar radiation and to increase shaded areas, the compact city form is the ideal city form. However, it is important to consider the need to use different kinds of transportation and accordingly, shading devices, trees or covering parts of streets and providing green spaces can help to stitch together the urban fabric.
- Because of the lack of water resources in Libya, choose the appropriate kind of vegetation.
- Maximize green areas and keep existing trees. Green squares and tree-lined streets get nature into the heart of the city.
- Maximise shading areas.
- The lower the ratio between the building volume and the width of open spaces, the lower the temperature in buildings and outdoor spaces.
- Minimize the street width and the car parking size. Narrower streets can behave as cooling ducts by venting away hot air.
- Consider sharing parking facilities with neighbouring buildings.
- Minimize heat island effect at paved areas, i.e., provide 40% shade coverage by mature tree or provide alternate paving such as light colour or grass-covered pavement

- **Site Design**

While designing the site plan, it is important to consider the followings:

- Minimize the building area to preserve as much site as possible for open landscaped space.
- To minimize heat gain, heat loss and material usage, it is recommended that the house shape should be a rectangular one with the long side facing north and south.
- A two-storey house can help in reducing plot land area and reduce direct heat gain from the roof to the first floor.
- Consider the use of green roofs (landscaped) to reduce energy consumption.
- Recycle grey water (rainwater collection or bath water recapture) and re-use it in landscaping or in toilet flushing.
- Avoid designing square and "L" shaped buildings which can result in half the windows facing east and west

- **Landscaping**

- Shading by natural means (e.g. via trees) reduces the radiation entering adjacent buildings and the effects of wind.
- Provide open spaces such as streets, squares and courtyards.
- Plant deciduous trees to shade windows in summer and allow solar heat gain in winter.
- Choose appropriate plants that thrive in the local climate with minimal irrigation.
- The pergola system lowers the rate of heat gain and reduces diffuse reflection to the surrounding dwellings.
- Trees create different airflow patterns and can be used to direct or divert the wind advantageously by causing a pressure difference.
- The shade created by trees and the effect of grass and shrubs reduce air temperatures adjoining the building and provide evaporative cooling.
- Trees and other plants represent a natural protective element against solar radiation as well as wind control.
- Vegetation may be used like a sunshade, for example palm trees whose leaves are able to block solar radiation and their tall trunks will easily allow unimpeded ventilation.

- The most appropriate plants for landscaping in hot-humid climates are a mixture of grasses, low flower beds, and shade trees with high trunks.

7.1.2 The second Principle: Building deign

- **Plan design concept**

- Open-plan living areas with high ceilings can help in maximising air movement and reduce radiant heat to occupants.
- Building laws in Libya require detached buildings. The east and west elevations should be shaded.
- A flexile courtyard can help in regulating internal thermal comfort and increase cross ventilation.
- Divide the building into multiple thermal zones. Therefore, unused areas can be closed down.
- The design should ensure flexibility in use.

Courtyard house

- A courtyard house is an ideal solution in hot climate regions in that it can serve as a reservoir of coolness.
- The position of the courtyard in the centre of the house should be altered to avoid inhabitants having to cross them all the time and new technology should be used to provide the possibility of covering the courtyard and opening it again when necessary.
- The walls surrounding the courtyard should have a good thermal resistance and a long thermal time lag.
- The courtyard should include trees and a fountain to provide a shaded area and evaporation.

Earth-sheltered

- Earth-sheltered and underground housing are ideally suited to this climate.

- **Building heights**

- Enlarge room heights up to 4m.

- Use high openings near the ceiling to allow warm air to exit.
- Utilize up to two to three floors maximum Building form.

- **Building form**

- The building should be elongated on an east-west axis; it can be diverged up to 15 degrees east or west.
- The whole building should be of a high thermal mass that can increase the thermal time lag of the building envelope.
- The square house is not the optimum form in any location.
- Curved surfaces work much better than flat surfaces in reflecting direct sunlight.
- A two story building is effective in reducing the roof area.
- Raising the building off the ground can improve the ventilation potential
- To reduce the size of any air conditioning equipment, the building should be made compact to minimise the surface area of its envelope and thus to reduce heat gain.
- For improved natural ventilation, a spread-out building (not a compact building which includes courtyards) with adequate windows enables more natural cross ventilation. Shading devices can help in preventing direct heat gain.

- **Room orientation**

- It is recommended that the living room and the guest room be located in the south or north because there is no direct sun from the north and the sun is located very high in the south and a small liner canopy can prevent the sun's rays.
- Bedrooms can be located in the east. The sun rises in the east in the morning and usually people use bedrooms at night.
- Service rooms such as the kitchen and the toilets can be located in the west.

7.1.3 The third Principle: Main Building Components

- **Roofs**

- Use light colours to reflect the heat of the sun.
- Use heavy-weight materials that can delay heat gain such as double layer roofs of hollow blocks.
- Shade the roof with suspended mats or timber boards or by vegetation up above the roof.

- Using an insulation layer on the outside of a concrete slab can increase the thermal time lag to eight hours.
- Consider the outer surface of the roof and the thermal resistivity of its materials.
- To avoid overheating, vaults and domes are climatically superior to flat roofs because flat roofs consume a large amount of the sun's heat as it falls on the roof of a building whereas vaults and domes reflect sunlight and increase the speed of air flowing over their curved surface.
- Properly designed roof gardens help to reduce heat loads in a building.
- Design the roof for the potential future retrofit with a photovoltaic system.
- Design the roof to collect rainwater & provide storage tanks to use the water for landscaping & toilets.

- **Walls**

- The external envelope should have a high thermal mass, for example, using cavity walls or double walls with thermal insulation, and small openings should be placed in the top and bottom of the walls to allow warm air to escape.
- The walls should be well insulated by using wall materials with good insulation properties.
- Use light colours to reflect the heat of the sun.
- Use shading devices to shade windows and walls.
- The location of the internal walls should not prevent cross-ventilation.
- Incorporate walls with cavities that act as air ducts for heat-exchange purposes.
- Light internal walls can should? be used in rooms which are used in the day such as the living room and the kitchen.
- Provide some openings or holes in the parapet walls around the roof to avoid hot air remaining there.

- **Floors**

- Use kind of materials that can resist heat.
- A suspended floor with a large well ventilated under-floor cavity will give a quicker response when temperatures drop slightly in the evening than a floor directly in contact with the ground.

- **Doors**

- For privacy reasons, doors are important in almost all the house. However, the design of the doors can be improved by providing upper or lower openings in them to allow air movements.

- **Windows - shading devices**

- Small windows can help minimize heat gain. However, they lessen natural cross ventilation. Therefore, adequate window sizes with appropriate shading devices can provide an adequate solution.
- Provide fixed horizontal overhangs for south windows, vertical overhangs for east windows and combine vertical and horizontal overhangs for west windows.
- Use mashrabiya which has five functions: (1) controlling the passage of light, (2) controlling the air flow, (3) reducing the temperature of the existing air, (4) increasing the humidity of the existing air, and (5) ensuring privacy.
- To ensure the circulation of air within a building (to ensure cross ventilation) openings should be located on two opposite walls.
- Specify energy-efficient windows by using double glazed glass with thermal break frames.
- Provide daylight lighting with windows and skylights. Minimize glazing on the east and especially on the west exposures in order to reduce heat gain.
- Consider installing movable insulation (hand operated or automated) to close off glazed areas during the night.

- **Finishing**

- To reduce the effects of the sun on buildings the outside walls should be reflective with respect to insulation by painting them white or utilising light coloured glazed brick-facings.

- **Building materials**

- Adobe buildings are better suited to hot regions.
- Heavy masonry with an extreme thermal mass (typical of stone and mud) can have an important positive effect on the thermal performance of buildings particularly in those walls located on the western and southern sides.
- In order to provide a well-insulated building that minimizes heat gain and loss roofs and walls should include high insulating properties (U-values).

- Use locally available materials for construction to minimize transportation.
- Use durable, easily maintained materials inside and out to minimize future replacement.
- Develop the technology for using local materials for new housing construction.

7.1.4 The fourth Principle : Additional Building components

- **Wind catcher**

- Wind catchers can help in increasing the flow of air in houses. They can be incorporated into modern buildings aesthetically.
- Staircases can be designed to catch a pleasant wind.

- **Sun space/ solarium**

- A solarium employs a combination of direct heat gain and indirect heat gain system features.
- A courtyard house can be used as a solarium house if moveable covered windows are used.

- **Fountain**

- A fountain discharges its water and mixes it with the surrounding air to increase humidity and to cool the air by evaporation.

- **Solar panels**

- Solar panels can be used for hot water and for heating spaces.
- A photovoltaic system can help produce energy consumption.

Balconies

- Balconies provide protection to walls and windows from the sun and the rain. However, socially they are not often used by occupants unless a large part of them can be covered by masharbiya.
- Rooms should have direct access to open balconies or verandas on one or two sides

7.2 VALIDATION OF THE PENULTIMATE FINAL CLIMATIC DESIGN GUIDELINES FOR HOUSING

As clarified in chapter 5, the proposed guidelines were sent to 6 Libyan architects and planning experts (the same experts who were used in the focus group discussions) who have experience in housing design and construction and they were invited to validate the guidelines.

After discussion (face-to-face or by e-mail) between the researcher and the experts and some explanatory guidance on matters that were not clear in the proposed guidelines, they all agreed on the information provided in the guidelines (taking their comments in considerations). They gave different priorities to the points in the guides.

The main comments made by the architects and planners relating to the local microclimate were as follows:

- Narrow streets can help reduce the paved area which is good from a climatic point of view, but narrow streets can cause traffic problems and needs to change urban planning regulations. Accordingly, this area needs more studies relating to locational circumstances.
- Big open areas in hot regions need extensive care in order not to become a source of concern and not to create problems in the built environment.
- Orienting streets to run east-west is good for the orientation of buildings. However, it is important to break rows of houses by vertical streets facing north in order to provide breezes to houses.
- An open green area is a good solution as long as it does not minimise the building area too much because Libyans prefer large houses., There should be a balance between the two.

The main comments related by the planners and architects on building design were as follows:

- Heavy weight materials with a thermal mass can increase thermal time lag. However, if there are materials that can provide the same thermal time lag with a light weight construction this can solve the problem of the wall and roof thickness.
- Avoid west facing openings even for services (kitchen and toilets) or more arrangement needed to avoid bad smells.
- Bear in mind the courtyard and the earth shelter concepts from the beginning of the house design.

The main comments made by the architects and planners on main building components were as follows:

- The kitchen is another source of heat. Therefore, special arrangements are needed to allow for this, such as separation by an internal thick wall.
- A suspended floor can be a good solution in public buildings. However, in private housing it needs more attention and that may not be practical.
- Using locally available materials to minimize transport is a factor related mainly to sustainability and not to climatic design.
- Using new techniques with old methods can provide good solutions.

The main comments from the architects and planners relating to additional building components were as follows:

- It is not necessary for rooms to have direct access to open balconies or verandas, one access outwards with a window can be enough.
- Solar panels are not affordable for private housing because they are expensive and need monitoring and maintenance. Therefore they can be put in as a last priority.

The experts were asked to answer three questions about how to present the guidelines, the importance of setting priorities and the necessity to link to some sources to clarify some points.

The answers obtained from the experts were very helpful for improving the final guidelines. The main comments from the experts that were taken into consideration in the final guidelines were as follows;

- Avoid repetition in the information.
- Re-order the main points.
- Avoid long sentences.
- Reduce any explanations in the guidance that are well known.
- Prioritising the factors is not easy because many other factors may affect the choices. Therefore, all points should have high priority.
- Linking to sources to clarify some points can help those who want more information about the subject but will not serve the purpose of the guidelines.

The final guidelines will be presented in the next part.

7.3 FINAL CLIMATIC DESIGN GUIDELINES FOR HOUSING IN TRIPOLI

This section presents the climatic design guidelines provided for architects to improve the quality of design when considering climatic conditions when designing for hot regions in general and for Tripoli, Libya in particular. The guidelines presented in the next Table including the final findings from the householders' opinions; the professionals' and focus group opinions and the building case studies results. These were all validated by the same focus group and professionals who had already reviewed the guidelines that were collected from the literature. The guidelines are divided into four main principles relating to building design and planning. Each principle has subtitles clarifying the main components included in the guidance. The prioritization of the factors in the guidance is according to their importance, availability, cost and to the opinion of the professionals and householders. Table 7.1 provides the final guidelines.

Table 7.1: Final climatic design guidelines for housing in Tripoli

Urban design and Landscaping - The first principle: consider and protect the Local Microclimate:

Strategies for building size, location and landscaping. While planning stage, it is important to consider the followings:
• **Urban Design** • In order to reduce the surfaces exposed to solar radiation and increase shaded areas, the compact city is the ideal city form. However, it is important to consider the need to use different kind of transportation which may require wider streets and therefore, shading devices, trees, covering parts of streets and green spaces can help to stitch together the urban fabric. • Consider the lack of water resources in Libya and choose the appropriate kind of vegetation. • Maximize green areas and preserve existing trees. Green squares and tree-lined streets get nature into the heart of the city. • Maximise shading areas. • The spacing of buildings should be carefully considered to avoid the obstruction of wind flow around those buildings. • Provide open spaces such as streets, squares and courtyards. • Minimize the heat island effect of paved areas by minimizing the street width and the car parking size (this could be done by sharing car parking facilities with neighbouring buildings). • Orient streets to run east-west, so that buildings will be oriented correctly and cross these streets with vertical streets facing north to provide breezes to houses. • The lower the ratio between the building volume and the width of spaces, the lower the temperature in buildings and outdoor spaces. • Narrow streets can behave as cooling ducts by venting away hot air. However, it is important to consider traffic considerations.
• **Site Design** While designing the site plan, it is important to consider the followings: • A two-storey house can help in reducing plot land area and also reduce direct heat gain from the roof to the first floor. • Consider the use of green roofs (landscaped) to reduce energy consumption. • Recycle gray water (rainwater collection or recaptured bath water) and re-use it in landscaping or in toilet flushing. • To minimize heat gain, heat loss and material usage, the house shape can be rectangular with the long side facing north and south. • Avoid designing square and "L" shaped buildings which can result in half the windows facing east and west unless the windows is well shaded. • The building area/surrounding building area ratio should be balanced to preserve as much site as possible for open landscaped space.

- **Landscaping**

- Use shading by natural means, such as trees and other plants which will provide a natural protective element against solar radiation as well as providing some wind control.
- Plant deciduous trees to shade windows in the summer and allow solar heat gain in the winter.
- Choose appropriate plants that thrive in the local climate with minimal irrigation.
- Trees create different airflow patterns and can be used to direct or divert the wind advantageously by causing a pressure difference.
- The shade created by trees and the effect of grass and shrubs reduce air temperatures adjoining the building and provide evaporative cooling.
- Vegetation can be used as a sunshade, for example, palm trees whose leaves are able to block solar radiation and their tall trunks will easily allow unimpeded ventilation.
- The most appropriate plants for landscaping in hot-humid climates are a mixture of grasses, low flowerbeds and shade trees with high trunks.
- The pergola system lowers the rate of heat gain and reduces diffuse reflection to the surrounding dwellings.

Building design - The Second principle: use appropriate Building Form:

- **Floor Plan Design**

- The design should ensure flexibility in use.
- In designing detached buildings, the east and west elevations should be well shaded.
- Divide the building into multiple thermal zones, so that unused areas can be closed down.
- Including a flexible courtyard concept can help in regulating internal thermal comfort and increase cross ventilation.
- Open-plan living areas with high ceilings can help in maximising air movement and reduce radiant heat to the occupants.
- Earth- shelters and underground housing are ideally suited to this climate.

➢ **Patio/ courtyard**

- The position of the courtyard in the centre of the house should be changed to avoid crossing it all the time to move between rooms. Technology could be used to offer the possibility of covering the courtyard and opening it again when necessary.
- The walls surrounding the courtyard should have a good thermal resistance and a long thermal time lag.
- A courtyard house is an ideal solution in hot climate regions as it serves as a reservoir of coolness.
- The courtyard should include trees and a fountain to provide a shaded area and evaporation.

• **Interior Space Height** • Enlarge room heights to more than 3m. • Use high openings near the ceiling to allow warm air to exit. • Utilize a maximum of two to three storeys.
• **Building Form and Envelop** • A two storey building is effective in reducing the roof area. • Curved surfaces work much better than flat surfaces in reflecting direct sunlight. • The building should be elongated along an east-west axis, it can be diverged by up to 15 degrees south-east or south-west. • To improve natural ventilation, a spread-out building (not compact and including a courtyard) with adequate windows enables more natural cross ventilation. Shading devices can help in preventing direct heat gain. • The whole building should be of heavy weight material with a high thermal mass that can increase the thermal time lag of the building envelope, or otherwise use materials that can provide the same U value. • A square house is not the optimum form in any location. However, it can be adopted if good shading and ventilation are ensured. • Raising the building off the ground can improve the ventilation potential. • To reduce the use of air conditioning the building should be compact to minimise the surface areas of its envelope and thus to reduce the heat gain.
• **Room Orientation** • It is recommended that the living room and the guest room be located in the south or the north. It is preferable to locate the living room in the south because it is used for a large proportion of the day. • Bedrooms can be located in the east. • Avoid west facing openings even for services (kitchen and toilets).

Detailed Design -The Third Principle: Select Appropriate Building Components and Materials
• **Roofs** • Using an insulation layer on the outside of a concrete slab can increase the thermal time lag to eight hours. • Consider the outer surface of the roof and the thermal resistivity of its materials. • Design the roof to collect rainwater & provide storage tanks to use the water for landscaping & toilets. • Vaults and domes are climatically superior to flat roofs. They reflect the sunlight and increase the speed of air flowing over their curved surfaces. • Use heavy weight materials that can delay heat gain such as double layer roofs composed of hollow blocks. • Shade the roof with suspended mats or timber boards or by vegetation. • Use light colours to reflect the heat of the sun. • Properly designed roof gardens can help to reduce heat loads in a building. • Design the roof for the potential future retrofit (such as solar panels and a photovoltaic system).
• **Walls** • Walls should be well insulated by using good insulation properties. • Use shading devices to shade windows and walls. • Provide some openings or holes in the parapet walls around the roof to avoid hot air remaining there. • To reduce the effects of sun on buildings the outside walls should be made reflective by painting them in light colours. • The external envelope should have a high thermal mass (for example, using double walls with thermal insulation or cavity walls with small openings in the top and bottom to allow warm air to escape. • The location of the internal walls should not prevent cross-ventilation. They can include cavities for heat-exchange purposes. • Light internal walls can be used in rooms which are used by day such as the living room and the kitchen.
• **Floors** • Use the kind of materials that can resist heat. • A suspended floor with a large well-ventilated under-floor cavity will give responses better than a floor directly in contact with the ground. However, it is harder to give this facility the proper attention in private houses.

- **Doors**
- For privacy reasons, doors are important in almost all the house. However, the design of the doors can be improved by providing upper or lower openings in them to allow air movement.

- **Windows - Shading Devices**
- Careful selection of windows and their positioning can help enhance the natural ventilation possibilities.
- Using double glazing with appropriate thickness.
- Small windows can help minimize heat gain. However, they lessen natural cross ventilation. Therefore, adequate window sizes with appropriate shading devoices can provide a reasonable solution.
- Provide fixed horizontal overhangs for south windows, vertical overhangs for east windows and combine vertical and horizontal overhangs for west windows.
- Using *mashrabiya* can help in controlling the passage of light and air flow, reducing the temperature of the existing air, increasing the humidity of the existing air and ensuring privacy.
- Exterior shutters and shades, either hinged or the rolling blind type, are another option for shading.
- Using interior shading such as draperies and curtains that are most effective when made of tightly-woven, thick material of a light or reflective colour.
- Ensure the circulation of air within a building. To achieve this, openings should be located in the two opposite walls.
- Specify energy-efficient windows by using double glazed glass with thermal break frames.
- Provide daylight lighting with windows and skylights. To reduce heat gain, minimize glazing on the east and the west.
- Consider installing movable insulation (hand operated or automated) to close off glassed areas during the night.

- **Building Materials**

- Provide a well-insulated building that minimizes heat gain and loss. Therefore, roofs and walls should include high insulating properties (U-values)
- Develop the technology for using local materials for new housing construction. Adobe buildings are better suited to hot regions.
- Using new techniques with old methods can provide good solutions.
- Heavy weight masonry with extreme thermal mass (typical of stone and mud) can have an important positive effect on the thermal performance of buildings particularly in those walls located on the western and southern sides.
- Use durable, easily maintained materials inside and out to minimize future replacement.

Additional Building Components - The Fourth Principle: Using Extra Passive Solutions
• **Fountain** • A fountain discharges its water and mixes it with the surrounding air to increase humidity and to cool the air by evaporation. • **Wind catcher** • Wind catchers can help in increasing the flow of air in houses. It can be incorporated into modern buildings aesthetically. • Staircases can be designed to catch a pleasant wind. • **Balconies** • Balconies provide protection to walls and windows from sun and rain. However, socially they are not often used by the occupants unless a large part of them can be covered by *masharbiya.* • Rooms should have direct access to open balconies or verandas. • **Sun space/solarium** • The solarium employs a combination of direct heat gain and indirect heat gain system features. • A courtyard can be used as a solarium when it uses moveable covered windows. • **Solar panels** • Solar panels can be used for hot water and heating spaces. • A photovoltaic system can help illuminate a house and thus reduce fossil energy consumption.

In the following chapter, the key conclusions, recommendations and further work are presented.

CHAPTER EIGHT

CHAPTER ONE:	INTRODUCTION
CHAPTER TWO:	SUSTAINABLE DEVELOPMENT
CHAPTER THREE:	CLIMATIC DESIGN
CHAPTER FOUR:	LIBYA- GENERAL BACKGROUND
CHAPTER FIVE:	RESEARCH METHODOLOGY
CHAPTER SIX:	ANALYSIS OF THE FINDINGS OF THE QUESTIONNAIRE, INTERVIEWS AND TEMPERATURE MEASUREMENTS
CHAPTER SEVEN:	TOWARDS THE FINAL CLIMATIC DESIGN GUIDELINES FOR HOUSING
CHAPTER EIGHT:	CONCLUSION AND RECOMMENDATIONS

CHAPTER EIGHT: CONCLUSION AND RECOMMENDATIONS

8.1 INTRODUCTION

The previous chapters have discussed the main findings of this study and provided the final guidelines. This chapter provides the main conclusions of the research and makes the link to the theoretical issues and questions raised in the context. Also this chapter provides the outcome of the research aim and objectives, a summary of the main findings, some recommendations and suggestions for future research.

8.2 CONCLUSIONS:

In order to achieve the research aim and objectives, an exploratory case study was adopted in this study and this is justified in chapter five. According to the research nature, the interpretivism paradigm was adopted as the main research philosophy and a qualitative approach was used to analyse the questionnaire designed to explore the opinion of the householders. Semi-structured interviews were conducted to explore the professionals' opinions on housing performance in Tripoli and also their suggestions as to future housing. However, by working with building performance and sampling temperature measurements that provided real data a quantitative approach was also used to justify the knowledge collected from the literature and from the professionals' opinions as well as the householders' opinions about the usefulness of the courtyard house.

To capture a more complete, holistic and contextual picture of the case studies and their findings, triangulation methods were used for data collection and data analysis. Each of the different methods (questionnaire, semi-structured interviews and a focus group as well as direct observation, sampling and the collection of supporting documentation) were used to find out the best way to conduct passive climatic design in future housing.

The data collected for this study was analysed using a non-quantified method by using Excel and Nvivo software. Sampling temperatures in the selected case studies (quantitative data) was analysed by using the software Easy-Log USB sensors version 4 (section 5.8).

This research thesis comprises eight chapters. Following the introductory chapter, the literature review is presented in two chapters. Chapter 2 covers the literature relevant to the research problem of this study and provides an overview of sustainable development as an important approach, which deals with the natural environment generally, and the built environment in particular. Chapter 3 reviews and assesses climatic design and its effects on architecture and on the urban morphology of the traditional built environment. The chapter provides a traditional and contemporary passive design solution.

In chapter 4 general background information on the Libyan context is given together with a review of the vernacular architecture from the climatic point of view with more detailed information about Tripoli as a case study.

Chapter 5 considers the methodology and the procedures adopted to conduct the study. It deals with the research philosophy, approach, strategy and the methods used for data collection and data analysis.

Chapter 6 provides the results of the data analysis and identifies the main factors that can be used in the climatic design guidelines. It also provides factors that affect the implementation of this guidance in Libya, presents a cross discussion of the findings in relation to the theory and considers the implication of the findings.

Chapter 7 validates the proposed guidelines and provides the final climatic design guidelines.

Chapter 8 provides a review of the thesis and gives general recommendations. Further research areas are suggested and the final conclusion is given. The outcome of the research is mainly to assist architects. However, it is expected to help planners and authorities when considering climatic design strategies in future housing projects.

8.3 ACHIEVING THE AIM AND OBJECTIVES OF THE RESEARCH

Throughout the discussion and analysis in this thesis, the key aim has been to *provide guidelines for architects to consider how to practice climatic design in creating architecture related to the local environment that can provide more sustainable solutions in hot climate regions with a particular focus on Tripoli.*

Eight objectives have been created to achieve the aim.

This research contains four issues: the first is establishing the knowledge available on climatic design and its relationship with sustainability; the second is understanding the attitudes towards existing housing in Tripoli; the third, to undertake experiments on the housing performance of vernacular and contemporary houses in Tripoli. Finally, the research aimed to establish climatic design guidelines for hot regions, particularly for Tripoli.

The first issue was established through two objectives (1-2, section 1.5):

Objective 1: *To investigate the role of climatic design in providing a proper stable comfortable internal microclimate in a natural way.* To achieve this objective, a critical literature review on the discussion of climatic design in the built environment was conducted. The literature covers issues relating to sustainable development, to sustainable architecture and environment and its relation to global warming and climate change, to architecture and clarifying the role of architects in protecting the environments. Additionally, a more detailed review of climate and its components and classifications and the main factors affecting internal thermal comfort in buildings has been reviewed.

Objective 2: *To identify the characteristics of passive systems and natural energy in designing buildings and to analyse solutions stemming from vernacular architecture, housing and passive design systems in the hot climate region.* To achieve this objective, a critical literature review relating to climatic design has been undertaken. It includes many sections; climatic design in architecture; factors affecting climatic design; climatic design and vernacular architecture, passive climatic design and contemporary architecture and examples of passive climatic design techniques in vernacular and contemporary architecture. And finally, climatic design strategies for hot regions have been collected and discussed with the focus group (presented in section 6.4)

The second issue (the attitude towards the existing housing in Tripoli) is established through two objectives (3-4):

Objective 3: *To examine the degree of householder satisfaction with both traditional and contemporary housing in terms of the internal microclimate.* In order to gain wider and in-depth understanding of current houses, data collected from two areas in Tripoli, from people living in the old city and people living in contemporary area but they used to live in courtyard house. The findings presented in chapter 6, shows that people like the advantages of contemporary houses and find difficulties in living in courtyard houses for social and climatic reasons cited in the same chapter. Overall however, they would prefer to live in houses that combine the best features of modern, vernacular and traditional characteristics.

Objective 4: To explore the opinions of design and construction professionals in terms of climatic design on modern housing for Tripoli society. In order to satisfy this objective, 11 interviews were conducted with architects and urban planners and with 1 civil engineer and 2 specialists in the properties of materials. They provided a deep understanding of the research problem and confirmed the need for climatic design as one of the solutions to current global problems. They also clarified that four main factors affecting the implementation of climatic design strategies in Libya are: Architects, Government, Users and Marketing. More information can be found in (section 6.3).

The third issue to undertake experiments on the housing performance of vernacular and contemporary houses in Tripoli) is established through two objectives (5-6):

Objective 5: *To investigate the traditional and contemporary housing characteristics in Tripoli in order to understand how these houses perform in the context of current life style needs and requirements.* To achieve this objective, a review of traditional and contemporary houses was conducted and is presented in chapter 4. Examples of vernacular houses were chosen from three geographical areas: Tripoli in the coastal area, Garian in the mountainous area and Gadames in the desert area. The objective was to investigate the main vernacular architectural features established in Libya and how they can be developed and implemented in housing in the future.

Objective 6: *To make sample measurements the temperature inside selected vernacular and contemporary houses to clarify actual internal and external conditions.* In order to achieve this objective, four houses as case studies were selected from two areas in Tripoli. Two houses chosen in the old city were examples of vernacular types, one of the houses is an open central courtyard house and the second is a covered central courtyard house. The other two houses from the contemporary area represents two types of contemporary houses built in different periods of time, the third is an attached house with an open courtyard located in the back of the house and the fourth house represents the villa type. the findings show that the best indoor temperatures recorded in both summer and winter times were found in the open courtyard house (section 6.5).

The last issue (establish climatic design guidelines for Tripoli) has been achieved through two objectives;

Objective 7: *To compare the opinions of householders and experts on the comfort conditions with the sample measurements taken in the houses in order to understand and challenge the perceptions and expectations of comfort.* To achieve this objective, the findings derived from the previous objectives were discussed in order to gain more understanding of the case studies and of the opinions of householders and professionals and connect all this information with the knowledge gathered from the literature to help establishing climatic design strategy guidelines that can be applied in Tripoli (section 6.6)

Objective 8: *To establish a set of guidelines for designing new urban housing projects which use a combination of climatic design principles and contemporary technology to provide more environmentally friendly housing solutions that meet social needs and functional expectations.* To achieve this objective, the findings of the seven objectives were collected, presented in a table and sent to the experts to validate and amend and then according to the recommendations of the experts to establish the final guidelines presented in (section 7.4).

8.4 SUMMARY OF THE MAIN FINDINGS

From the findings presented in chapter 6, the main points raised can be summarised as follows:

8.4.1 Main findings from the residents' survey

- Occupants moved from traditional houses because they were not satisfied with the style, space, the courtyard location and also because it is difficult to use new technology. They saw their own courtyard houses as old fashioned and think that living in such houses give a sign of poverty. However, some occupants thought that they could live in a courtyard type house if some changes were made to meet current life needs.
- Respondents from old city often covered the courtyard because they think the position of the courtyard in the middle of the house is not appropriate, because it is difficult in both summer and winter time to move from one room in the house to another without crossing the courtyard and therefore being at the mercy of the weather.
- Majority of the respondents from the both areas thought that courtyard houses are more comfortable in summer, however, they believe that contemporary houses provides more comfort, safety and beauty that should be taken in consideration in future hoses. Accordingly, most of respondents preferred to live in houses that consisted of a combined house style (that is, a style containing both traditional and modern features and including modern technology).
- The majority of the respondents had no knowledge of sustainable houses. Most of the respondents thought that current building materials are not suitable for the local climate, which can help increasing environmental problems.

- Almost all the contemporary area respondents use air-conditioning all the year. This raises the problem of depending on AC. to achieve comfort.
- Majority of the respondents from both areas chose open windows to get cross air currents as a solution to escape high temperatures when there is no air-conditioning.

8.4.2 Main findings of the professionals' opinions

The general findings of professionals' views are summarised by the following points:

- Interviewees confirmed that western architecture has influenced the style of modern architecture in Tripoli both negatively and positively. They confirmed that contemporary architecture, urban planning and streets' design are not appropriate to the local climate.
- They agreed that vernacular architecture proved their suitability to the local climate. Accordingly, vernacular houses are more environmentally friendly than the contemporary ones. However, they confirmed that the numbers of advantages provided by contemporary houses are greater than the number of disadvantages.
- All the interviewees confirmed the importance of building materials as one of the main factors to achieve climatic design. They clarified that, in Libya, there is an improvement in the production of building materials such as steel, cement and hollow concrete bricks. However, more studies are needed to look to improving local materials. They thought that, the development of building materials and the implementation of sustainable housing concepts are the responsibility of all; specialist, people and the government.
- The majority of the interviewees stated that architects should be creative and free minded. They suggested that instead of designing a fixed model, it would be more useful to provide general strategic guidelines (that include scientific facts) which can be used as references to help architects when designing and wishing to take on board climatic considerations.
- The interviewees indicated that, in order to reduce environmental impacts and apply sustainable future housing, four factors that can contribute in developing current houses are designers, users, marketing and government.

8.4.3 Main findings of the focus group's opinions

The focus group confirmed most of the design strategies collected from the literature (section 6.4) and gave comments for some of them as follows:

- **Local microclimate:**
- The focus group confirmed the importance of landscaping in providing shading areas and reducing heat gains. They also mentioned the lack of water resources in Libya and thus the need to choose the appropriate kind of vegetation is very important.
- They agreed that a compact city could help in reducing the surfaces exposed to solar radiation. However, considering new forms of transportation is very important and architects should find other solutions to reduce the surfaces exposed to solar radiation such as shading devices, trees or even to cover parts of streets.

- **Building design**

The focus group confirmed all the strategies related to building design concepts with some comments:

- The courtyard is the ideal solution in the case of using appropriate building materials and proportions that can provide adequate shading. However, the courtyard's position should not be in the middle of the house unless a movable or openable cover is provided to avoid excessive summer heat and winter rain.
- Detached buildings are good if the east and west elevations are shaded. And a square house can be appropriate if it is not compact and there are some shaded openings with using minimum number of small windows facing east and west that can provide air movement.
- Heavyweight construction (ie, thicker walls etc) is most appropriate because of the increase in the thermal time lag.
- Large windows may provide good ventilation but at the same time can allow more exposure to heat gain.

- **Main Building Components**

The focus group confirmed most of the strategies related to main building components (ie, walls, roofs,...etc) presented in (Table 6.4.1) with some further comments as listed below:

- A lightweight roof is not appropriate because of its short thermal time lag properties. And metal roof is not the ideal solution because it increases heat gain and needs much more shading.
- Shading east and west elevations can be undertaken by using shading devices, vegetation

or by the design of the building.

- A suspended floor is not advised because it needs careful use and maintenance.
- The design of the doors can be improved by providing upper or lower openings to allow air movement.
- All the strategies related to building materials have been confirmed by the focus group, they commented that more research in improving local building materials is needed.
- The solarium house is a good solution and a courtyard can be used as a solarium when using moveable covered windows.
- Balconies are important for providing shading. However, socially they are not often used by occupants unless a big part can be enclosed by musharabia.

8.4.4 Main findings of the field measurements

The main findings of this limited study show that the best indoor temperatures recorded in both summer and winter times were found in the open courtyard house. The highest summer air temperature was recorded in the villa type of housing (contemporary housing style). However, this type of housing records good indoor temperature in the wintertime. Building orientation, materials, windows' size and shading devices plays a major role in reducing the indoor temperature. Also, the study clarified that covering the courtyard makes the internal environment worse by increasing temperature and humidity and reducing lighting levels. Measuring internal temperature in the selected houses gave an idea about the performance of different building designs, and more studies are needed to optimise these results and provide definitive recommendations for future building projects in Libya.

8.5 SUMMARY OF THE FINAL HOUSING CLIMATIC DESIGN GUIDELINES IN TRIPOLI

The final guidelines presented in chapter 7 are divided into four main categories related to building design and planning are, local microclimate: building design: the main building components and additional building components. These guidelines are summarized and presented as follows:

Urban design and Landscaping - The first principle: consider and protect the Local Microclimate:

- **Site Layout**

- The compact city is the ideal city form. However, it is important to consider the need to use different kind of transportation;
- Consider the lack of water resources in Libya, and choose the appropriate kind of vegetation.
- Maximize shading areas, green areas and reserve the existing trees;
- consider the spacing of buildings to avoid obstructing of wind flow around those buildings;
- Provide open spaces such as streets, squares and courtyards;
- Minimize heat island effect at paved areas by minimizing the street width and parking lot size;
- Orient streets to run east-west, accordingly, and cross them by vertical streets facing north to provide breeze to houses.
- Reduce the ratio between the building volume and the width of spaces;

- **Site Design**

While designing the site plan, it is important to consider the followings:

- Two-story house can help in reducing direct heat gain from the roof to the first floor;
- Consider the use of green roofs (landscaped) to reduce energy consumption;
- Recycle gray water and re use it in landscaping or in toilet flushing;
- The house shape can be rectangle with the long side facing north and south;
- Avoid designing square and "L" shaped buildings which can result in half the glass facing east and west unless it is well shaded; and
- The building area should be balanced to preserve open landscaped space.

- **Landscaping**

- Shading by natural means, such as trees and other plants. Use vegetation as a sunshade, as palm trees whose leaves are able to block solar radiation and tall trunks will easily allow unimpeded ventilation. Also, use trees to direct or divert the wind;
- Plant deciduous trees to shade glass in summer and allow solar heat gain in winter;
- Choose appropriate plants that thrive in local climate with minimal irrigation;
- The most appropriate plants for landscaping in hot-humid climates are a mixture of grasses, low flowerbed, and shade trees with high trunks.
- Use the pergola as a system restrains the rate of heat gain and reduces diffuse reflection to surrounding dwellings.

Building design - The Second principle: use appropriate Building Form:

- **Floor Plan Design**

- The design should ensure flexibility in use.
- In designing detached building, the east and west elevations should be well shaded;
- Divide the building into multiple thermal zones, therefore, unused areas can be switched off or allowed to float;
- Including flexible courtyard concept; and
- Open-plan living areas with high ceilings can help in maximising air movement and reduce radiant heat to occupants;
- Earth-sheltered and underground housing are ideally suited to this climate.

➢ **Patio/ courtyard**

- A courtyard house is an ideal solution to hot climate regions that serves as a reservoir of coolness;
- Avoid positioning of the courtyard in the centre of the house, unless, offering the possibility to cover the courtyard and open it when necessary;
- The walls surrounding the courtyard should have a good thermal resistance and a long time lag;
- The courtyard should include trees and a fountain to provide shade area and evaporation.

- **Interior Space Height**

- Enlarge ceiling heights more than 3m;
- Use high openings near the ceiling to exit worm air :and
- Utilize Two to three floors maximum.

- **Building Form and Envelop**

- Two story building is effective in reducing the roof area;
- Curved surfaces works much better than flat surfaces in reflecting direct sunrises;
- Elongate the buildings along on east-west axis; it can be diverged up to 15 degrees south-east or south-west.
- A spread-out building with adequate windows can provide natural cross ventilation, and compact building can minimise the surface areas of the envelop and thus to reduce the heat gain;
- Use high-weight structure with high thermal mass that can increase the time lag of the building envelope, or use materials that can provide the same U value;
- The square house is not the optimum form in any location, however, it can be adapted if insuring good shading and ventilation;
- Raise the building off the ground to improve the potential of ventilation;

- **Room Orientation**

- Locate living- room and guest- room in the south or north. it is preferred to locate living room in the south because it is used almost all the day;
- Locate bed- rooms in the east; and
- Avoid west openings even for services (kitchen and toilets) or more arrangement needed to avoid bad smells.

Detailed Design -The Third Principle: Select Appropriate Building Components and Materials

- **Roofs**

- Using insulation layer on the outside of a concrete to increase the time lag;
- Consider the outer surface of the roof and the thermal resistivity of its materials;
- Design the roof to collect rainwater & provide storage tanks to use the water for landscaping & toilets.
- Vaults and domes are climatically superior to flat roofs;
- Use high-weight materials that can delay heat gain;
- Shade the roof with suspended mat or timber boards or by vegetation;
- Use light colours to reflect the heat of the sun;
- Properly designed roof gardens help to reduce heat loads in a building; and
- Design the roof for the potential future retrofit with a solar panels and photovoltaic system;

- **Walls**

- Walls should be well insulated by using good insulation properties;
- Use shading devices to shade windows and walls;
- Provide some openings or holes in the parapet walls around the roof;
- The outside walls should be reflective by painting it by light colours;
- External envelope should have a high thermal mass;
- Location of internal walls should not prevent cross-ventilation; and
- Light internal walls can be used to separate rooms.

- **Floors**

- Use kind of materials that can resist heat;
- Use suspended floor with a large well-ventilated under-floor cavity; however, in private housing it needs more attention.

- **Doors**

- The design of the doors can be improved by providing upper or lower openings to allow air movements.

- **Windows - Shading Devices**

- careful selection of windows and their positioning can help enhance the natural ventilation;
- Using double glazing with appropriate thickness;
- Small windows can help minimize heat gain, however, it disable natural cross ventilation, therefore, adequate windows size with appropriate shading devoices can provide adequate solution;
- Provide fixed horizontal overhangs for south windows, vertical overhangs for east windows and combined vertical and horizontal overhangs for west windows;
- Using *mashrabia* to help in controlling the passage of light, the air flow, reducing the temperature of the air existing, increasing the humidity of the air existing, and ensuring privacy;
- Use exterior shutters and shades, either hinged or rolling blind type, to provide extra shading;
- Use interior shading such as draperies and curtains that are most effective when made of tightly-woven, thick material of a light or reflective colour.
- Ensure the circulation of air within a building by locate openings in two opposite walls.
- Provide day lighting with windows and skylights.
- Minimize glazing on east and west;
- Consider installing movable insulation to close off glass areas during the night.

- **Building Materials**

- Provide a well-insulated building, accordingly, roofs and walls should included high insulating properties (U-values)
- Develop the technology of using local materials for new housing construction;
- Using new techniques with old methods can provide good solutions;
- Heavy masonry with extreme thermal mass (typical of stone and mud) can have an important positive effect on the thermal performance of buildings;
- Use durable, easily maintained materials inside and out to minimize future replacement.

Additional Building Components - The Fourth Principle: Using Extra Passive Solutions

- **Fountain**

- The fountain discharges its water and mixes it with surrounding air to increase humidity and to cool the air by evaporation.

- **Wind catcher**

- Wind catchers can help in increasing the flow of air in houses, It can be incorporated into modern buildings aesthetically;
- Staircases can be designed to catch a pleasant wind.

- **Balconies**

- The balconies provide protection to walls and windows from sun and rain, however, socially they are not often used by occupants unless a big part of it can be covered by *mashrabia*.
- The rooms should have direct access to open balconies or verandas.

- **Sun space/ solarium**

- It employs a combination of direct gain and indirect gain system features.
- Courtyard can be used as a solarium house when using moveable covered windows.

- **Solar panels**

- Solar panels can be used for hot water and heating the spaces and heating the spaces;
- Photovoltaic system can help illuminate to reduce fossil energy consumption.

8.6 RECOMMENDATIONS

The research findings suggest some important recommendations that could be useful in achieving climatic design in present and future developments. A variety of points, suggestions and recommendations are highlighted in this section. The objective is not to produce a definite policy but to recommend some general principles that will assist in improving the housing design in Tripoli.

As stated previously, many factors have an important role in the implementation of climatic design in Tripoli where the interviewees believed in the importance of architects' and users' understanding of how to use these elements in addition to the importance of available building materials and government support. The suggestions to improve these factors are summarised as follows:

- **Recommendations to architectural and planning design:** To improve the design concepts, architects and planners should consider the following strategies:

For climate reasons:

- Apply sustainable architecture and climatic design principles at the design stage;
- Consider the house and its surroundings by understanding the land use, landscape, buildings' locations and building design.
- Reuse the courtyard concept in a modern way and improve traditional concepts such as using staircases as wind catchers.
- The city design plan should consider the need for cars.
- The compact city format reduces the surface area available for solar radiation but narrow streets are not necessarily useful for cars and other forms of transport. Therefore, if streets are built wider it is recommended that trees and other shading devices are used within them.
- Using national and international vernacular architectural features such as the courtyard concept with some modifications; also other features such as curved roofs; malgaf and masharabia in Libyan houses in the future in a careful way.

The form of buildings should be designed in such a way to meet climatic needs by considering the following:

- Curved surfaces are better than flat surfaces particularly with attention to roof design;
- Provide good orientation;

- ➢ Study openings' sizes and position;
- ➢ Reduce the amount of surface facing direct sun by shading (by the building itself and by shading devices such as trees and vegetation);
- ➢ The longest elevation should face north and south;
- ➢ Ensure there is internal cross ventilation;
- ➢ Consider the need for thermal resistance;
- ➢ Use technology and developed building materials with more attention to using thermal insulation;

For other sustainable reasons:

- ➢ Respect people's behaviour, changes in lifestyle and the needs of persons and their families for comfort (including thermal, visual, functional and safety factors;
- ➢ Reduce energy consumption by using renewable energy and passive design techniques such as solar panels, double walls and solarium house. Also by increasing the internal walls' height with upper openings to allow hot air to exit;
- ➢ Reduce the cost by gathering together the services (kitchen and toilets etc) to reduce the number of water supply pipes and sewerage pipes.

- **End users:** To improve current housing, users should consider the following:
  - ➢ Reduce dependency on air conditioning to achieve internal thermal comfort;
  - ➢ Be aware of the concepts and benefits of sustainable design;
  - ➢ Understand and respect the building laws;
  - ➢ Be convinced of the importance of climatic design; and
  - ➢ Understand that the extra costs of climatic solutions do not exceed 5% of the total cost of normal buildings and its future impact is great.

- **Market and procurement:** To improve current housing the following should be considered:
  - ➢ Provide suitable building materials at appropriate cost;
  - ➢ Provide experienced labour;
  - ➢ Examine current building materials and improve upon them;
  - ➢ Reduce energy consumption when producing building materials;
  - ➢ Reuse building waste.

- **Government:** To improve current housing the government should consider the following:
  - Implement housing projects with sustainable concepts and encourage people to use them, experiment with them and convince people of the benefits. These projects should be developed continually. Use the media to convince people to accept sustainable concepts;
  - Provide construction schools for training skills;
  - Offer competitions to select the best projects and test these projects by people who are able to measure the advantages and disadvantages;
  - Building laws should be changed and should include strict rules that designers and users should follow and thus reduce the number of unsuitable procedures;
  - Provide codes related to building materials;
  - Ensure architects are included in the design process and organize practicing the profession ;
  - Encourage groups that will undertake the protection of Libyan heritage;
  - Encourage scientific researchers to develop local building materials;
  - Produce building materials at an appropriate cost.

8.7 EXPECTED CONTRIBUTION TO KNOWLEDGE

It is believed that the findings and conclusions from the different phases of this research have great value and make a significant contribution to the knowledge of climatic design particularly in Libya and in Arabic hot regions in general. Generally, the research has made the following contributions:

1 As mentioned in chapter 1 there is a shortage of empirical studies regarding the effective use of climatic design principles in Arabic countries and particularly in Libya. This research will begin to fill the gap in the literature on Arabic countries;

2 Climatic design has been applied in a number of western countries. The study explores how these principles need to be developed and adapted for the Arab world beyond the work already undertaken by Hassan Fathy and his disciples;

3 This study provides real data (temperature measurements taken over a year in different kind of houses) that can be used in future research related to climatic design and energy efficiency.

4 The findings and recommendations of this study provide important factors that affect the application of climatic design in Libya and the study also provides suggestions on how to improve these factors;

5 This study provides a set of guidelines based on climatic design principles for use in designing new urban housing projects which may help a designer to find better solutions to the new buildings in the Mediterranean climatic regions;

6 The guidelines will provide useful support to the eco-region vision.

7 The guidelines have been designed for architects working in academia or industry. However, they can be used as a reference to improve building laws in Tripoli.

8 It can be seen that most of the guidance presented in the final guidelines are strategies adapted from similar regions' conditions. However, this study discussed some issues that related to implementing these international strategies in the case studies in Tripoli, and this study also discussed improved strategies relating to the implementation of vernacular architectural features in housing in the future.

9 The guidelines have been designed for Tripoli. However, most of the guidance can be useful for similar cultural and climatic regions.

8.8 SUGGESTION FOR FUTURE RESEARCH

The subject of climatic design is very wide and this thesis covers a significant part. However, throughout the discussion and analysis in this study, various issues and topics have emerged which can be suggested as subjects for future research. Seven main future research areas can be recommended as follows:

- For fully sustainable housing, it is important to study the economic effects of implementing the given climatic design guidelines.
- Many studies are needed to improve building materials and to find appropriate materials for the Libyan environment.
- Examine the findings of this research by designing a model and testing it using the 'ECOTECT' dynamic thermal simulation software.
- Repeat the methodology used in this research to study climatic design in different Libyan regions (mountain and desert);
- More studies are needed to investigate the effects of the climatic design guidelines in solving three main problems; reducing pollution, reducing energy consumption and providing local or special identity.
- More detailed studies can be done to improve the guidelines by providing specific details on each guidance.

- To fully evaluate thermal comfort and energy consumption in Libyan housing, additional detailed measurements would be needed for public houses (high-rise buildings).

8.9 LIMITATIONS OF THE STUDY

Research in climatic design is not an easy task. As was reported in section 5.6.8 this study has suffered from several limitations and all possible efforts were made to overcome them and to avoid their influence on the processes, findings, conclusions and recommendations of this study. What follows provides a brief outline of these major limitations.

8.9.1 Limitation of the respondents

- For cultural reasons and because of the nature of the study which needed selective case studies (householders who were living or had experienced living in the courtyard type of house) the author could not ask anyone to participate in the empirical study. Accordingly, the researcher used work, social and family relationships to encourage individuals to participate in the study. Therefore, it can be argued that this reduced the sample used for this study.
- In the old city area, the author would have been seen as a stranger and distrusted. Accordingly, for security and social reasons, the strategy used in distributing the questionnaire was to visit with an officer who has been working in the area (for an institute responsible for the conservation of the old city). Because the number of Libyan families living in the old city is small and it is difficult to find the address of each family, the officer helped in collecting the questionnaire and persuading householders to accept keeping the sensors in their houses. This took extra time and money.

8.9.2 Limitation of the case studies

- It was not easy to find cases where the occupiers agreed to put unknown instruments in their buildings;
- It was difficult to find cases that had similar characteristics such as orientation, floor area, the kind of service equipment used and the number of people living in the cases.
- The size of study was limited by the time available for the analysis. Accordingly, a considerable amount of information emerging from this study can be used for future research.

8.10 FINAL CONCLUSION

The design of housing is one of the most important tasks and it should meet people's functional, social and spiritual needs. This thesis emerged from the necessity of developing an approach to using climatic design for houses in order to meet the aims and objectives of the study. It does not claim that it can solve all climatic housing problems. It is one of the steps that can help improve future Libyan housing.

Identifying, understanding and controlling the climatic influences on a building are one of the most critical aspects of building design. The main aims of climatic design can be clarified by these three objectives; reducing the energy costs of a building, using natural energy instead of mechanical systems and power, and providing a comfortable and healthy environment for people. To achieve this aim more studies in vernacular architecture, available technology, building materials and methods of construction (in addition to understanding the local climate and its influences on life) are needed for the design of a lower energy, and therefore lower carbon and more sustainable future.

Despite limited use in modern design, the findings of this study show that the open courtyard house is a good design concept for hot regions. Also that contemporary houses perform well in winter. These results suggest using the advantages of both vernacular and contemporary houses to design housing in the future. Measuring the internal temperature in the selected houses gave an indication of the performance of different building designs, and more studies are needed to optimise these results and provide definitive recommendations for future building projects in Libya.

The research has identified the important aspects that can be used to improve the quality of housing performance. These aspects are the main components of the climatic design guidelines that are considered as being the core contribution of this study. The outcome is expected to help designers, planners and authorities to be more aware of the needs of climatic design in future housing in Libya.

It is hoped that this research will become a source of useful information and provide a platform for future research into Libyan climatic design. It is also hoped that this study provides a contribution towards the study of housing climatic design generally.

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APPENDICES

Appendix 1: Copy of the questionnaire and interviews

Survey questionnaire

Dear Sir / Madam

Re: Theses – PhD – Built environment, the University of Salford.

I am Aisha A. Almansuri. Currently, I am a post graduate student at the University of Salford in the United Kingdom. I am doing a research project on Libya. This research involved measuring the indoor and outdoor weather of local and contemporary Libyan houses in one of the three regions of the country. The region selected is the coastal region to allow getting an actual reading of thermal comfort inside buildings. The instruments that will be used in measurement is the "EasyLog model EL-USB series products", it measure temperature and humidity. Also, understanding the level of peoples' satisfaction and housing preferences, of existing housing, both traditional and contemporary. This survey conducted will be help with future planning and design of residential buildings in Libya.
This can be by distributing a questionnaire to selected amount of householders who lived in the courtyard house and currently living in contemporary houses , also chose people still living in the courtyard house in the region selected, specifically in Tripoli. Interview some professionals in four specialists (architects and urban planning, property of materials, electrical and mechanical engineers). We will choose samples from each subject. And these samples will be chosen from different places (universities, general offices, and private offices....etc).

I would greatly appreciate it if you could complete the following questionnaire and write any further comments in the spaces provided or on a separate sheet.

If you have any queries please contact me using A.A.Almansuri@pgr.salford.ac.uk . Needless to say, all the information provided will be treated with complete confidentiality and will not be passed or used for any other purpose.

Survey questionnaire with residents living inside the old city

Part one: Personal Information:
Please note that you are asked about age and sex because these are both related to people's requirements so that follow up can be made on any matters that may happen. You can leave it blank if you don't want to.

Date................................ Address ....
Nationality ....

Sex: - - Male ☐ Female ☐
Age less than 20 ☐ 20-30 ☐ 31-40 ☐ 41-50 ☐ over 50 ☐
Marital Status- Single ☐ Married ☐ Divorced ☐ Widow ☐
Occupation - Professional - (please specify)....................................
Employee ☐ Retired ☐ others ....
Academic Education level - primary stage☐ Intermediate stage ☐ University stage ☐ post Graduate ☐
Others (please specify) ....
Number of the family- 2 ☐ 3-4 ☐ 5-8 ☐ more than 9☐

Part two: Housing situation –

1-A- What kind of dwelling are you living in?
Villa ☐ House ☐ Attached house ☐ Flat ☐ Courtyard house ☐

1- B- How long have you been living in this property?
Less than 2 years ☐ 2- 6 years ☐ 7-11 years ☐ more than 11years ☐

1-C- How old do you think your current house is?
Less than2 years ☐ 3-6 years ☐ 7-10 years ☐ 11-15 years ☐ more than 15 years☐

2-If you have a chance to change your house to the new modern one, would you like to change?
Yes ☐ no ☐
Please specify why ---

3- Did you cover the courtyard in your houses? Please give reasons?
Yes ☐ no ☐
Please explain your answer below
....
....

4-Do you think that the building materials used in your houses are suitable for the climate?
Yes ☐ no ☐ I do not know ☐
Please explain your answer below
....
....

5- Have you got any idea about what a sustainable house is?
Yes ☐ no ☐

6- What kind of houses do you prefer to live in?
Old Traditional houses☐ modern houses☐ modern houses with tradition style ☐
new houses which combined (Tradition+ Modern+ technology) ☐

Part three: The relationship between houses and climate

7- Do you think that some of the environmental problems are due to building construction?
Yes ☐ no☐
If yes, please explain why and how?
....

8- Form a climatic point of view, which is more comfortable in winter and summer times?
Old house ☐ contemporary house ☐
Others (please specify) ---

9-A- Are you using air conditioning?
Yes ☐ No ☐

9-B- If yes, in which rooms?
Guest room ☐ living room ☐ bed rooms ☐ the whole building ☐

9-C- How often do you use the air conditioning?
All the year☐ all summer time ☐
When the temperature is very high☐ when the temperature is very low ☐

10- Which degree of temperature do you feel is very high?
Above 30^0c☐ 25 ^{0}c - 30 ^{0}c ☐ 18 ^{0}c - 24 ^{0}c ☐

11- If electricity is off what will you do to escape a high temperature?
Open windows to get cross air ☐ visit a family that have an air conditioner ☐
Sit in the garden☐ go to the sea ☐
Others (please specify) ....

12-Do you think that the kind of building could affect people's health?
Yes ☐ no ☐ I do not know ☐

Any Comments about health (please specify)
....
13- What are your wishes that new buildings must achieve? You may select more than one
Comfort☐ beauty ☐ economic☐ safety ☐
Sustainability ☐ all of these reasons ☐
Others (please specify) ....
14- If you have anything to add about any weather problems in your home, please state them in separate sheet?
....

Survey questionnaire with residents living outside the old city

Part one: Personal Information:

Please note that you are asked about age and sex because these are both related to people's requirements so that follow up can be made on any matters that may happen. You can leave it blank if you don't want to.

Date................................ Address ....
Nationality ....

Sex: - - Male ☐ Female ☐
Age less than 20 ☐ 20-30 ☐ 31-40 ☐ 41-50 ☐ over 50 ☐
Marital Status- Single ☐ Married ☐ Divorced ☐ Widow ☐
Occupation - Professional - (please specify)....................................
Employee ☐ Retired ☐ others ....
Academic Education level - primary stage☐ Intermediate stage ☐ University stage ☐ post Graduate ☐
Others (please specify) ....
Number of the family- 2 ☐ 3-4 ☐ 5-8 ☐ more than 9☐

Part two: Housing situation –

1-A- What kind of dwelling are you living in?
Villa ☐ House ☐ Attached house ☐ Flat ☐ Courtyard house ☐

1- B- How long have you been living in this property?
Less than 2 years ☐ 2-6 years ☐ 7-11 years ☐ more than 11years ☐

1-C- How old do you think your current house is?
Less than2 years ☐ 3-6 years ☐ 7-10 years ☐ 11-15 years ☐ more than 15 years☐

2-A- Before you moved to your present house, what kind of dwelling did you live-in?
House ☐ Attached house ☐ Flat ☐ Courtyard house ☐
Others (please specify) ....

2-B- How long did you live in the previous house?
Less than 2 years ☐ 2-6 years ☐ 7-11 years ☐ more than 11 years ☐

2-C- How old do you think your previews property is?
Less than15 years ☐ 16-20 years ☐ 21-30 years☐ 31 - 40 years ☐
41-50 years ☐ more than 50 years ☐

3-Why did you move from your previous house?
Style ☐ design ☐ size ☐ technology ☐ construction ☐
building materials ☐ all of the pervious reasons ☐
Others (please specify) ---

4-Is it still possible to live in your old houses?
Yes ☐ no ☐
Please explain your answer below
....

5- Do you think that the building materials used in modern houses are suitable for the climate?
Yes ☐ no ☐ I do not know ☐
Please explain your answer below
....

6-A- Have you got any idea about what a sustainable house is?
Yes ☐ no ☐

6-B- If your answer is yes, do you think that these kinds of houses are more expensive than the contemporary buildings?
More expensive ☐ less expensive ☐
Please explain your answer below
....

7- What kind of houses do you prefer to live in?
Old Traditional houses☐ modern houses☐ modern houses with tradition style ☐ new houses which combined (Tradition+ Modern+ technology) ☐

Part three: The relationship between houses and climate

8- Do you think that some of the environmental problems are due to building construction?
Yes ☐ no☐
If yes, please explain why and how?
....

9- A- Form a climatic point of view, which is more comfortable in winter?
Old house ☐ contemporary house ☐

9-B- If you have chosen the old house, which of the following best? Explain why? You may select more than one?
Good cross ventilation ☐ Good thermal resistance ☐
Good lighting ☐ more healthy ☐ all of these reasons ☐
Others (please specify) ---

9-C- If you have chosen the contemporary house, which of the following best? Explain why? You may select more than one
Air conditioning ☐ more resistance to weather ☐ technology ☐ provided good lighting ☐ All of these reasons ☐
Others (please specify) ....

10-A- Are you using air conditioning?
Yes ☐ No ☐

10-B- If yes, in which rooms?
Guest room ☐ living room ☐ bed rooms ☐ the whole building ☐

10-C- How often do you use the air conditioning?
All the year☐ all summer time ☐
When the temperature is very high☐ when the temperature is very low ☐

11-Which degree of temperature do you feel is very high?
Above 30^0c ☐ 25^0c - 30^0c ☐ 18^0c - 24^0c ☐

12- If electricity is off what will you do to escape a high temperature?
Open windows to get cross air ☐ visit a family that have an air conditioner ☐
Sit in the garden☐ go to the sea ☐
Others (please specify) ....

13-Do you think that the kind of building could affect people's health?
Yes ☐ no ☐ I do not know ☐

Any Comments about health (please specify)
....

14- What are your wishes that new buildings must achieve? You may select more than one
Comfort☐ beauty ☐ economic☐ safety ☐
Sustainability ☐ all of these reasons ☐
Others (please specify) ....

15- If you have anything to add about any weather problems in your home, please state them in separate sheet?

INTERVIEW FOR PROFESSIONAL- Architects and urban planning -

1- What do you think of contemporary housing in terms of Appropriateness to the environment?
....
....

2 -Do you think that the old traditional housing are more environmentally friendly than contemporary housing?
....
....

3 – Can the old traditional housing be amended to conform to the requirements of the current era? Explain your answer?
....

4- In your opinion what are the advantages of contemporary houses?
....
....

5- How can we develop the contemporary housing to achieve the needs of citizens, and do not damage the environment?
....
....

6 - To what extent does the cost of the building affect its shape and methods of construction?
....

7- Do you think that the construction materials used in contemporary housing are suitable for the climate of the region?
....

8- Is it possible for the ordinary inhabitant to implement housing that carry concepts of sustainable design?
....

9-Do you think that modern Libyan architecture was influenced by western architecture? And to what extent do these influences contributed to a blurring of development of Libyan architecture?

10- From climatic point of view, what are the suitable building forms for Tripoli climate, and what are the reasons that flat roofs are commonly used instead of curved or pitched one?
....
....

11- Do you think that borrowing elements from local vernacular architecture such as courtyard, local materials and openings could improve the future housing projects?
....

12- Do you think that borrowing elements from international vernacular architecture such as *malgaf*, *mashrabia* and curved roofs could improve the future housing projects or create a new architecture?
....
....

13 –In your view, what is the best model of house?
....

14- Can we design a special architectural model with special specifications of the particular region and climate, to become a particular model requires can help when design in the same circumstances?

1- What do you think of contemporary housing in terms of suitability for climate?

....

....

2-Do you think that the old traditional housing are more environmentally friendly than contemporary housing?

....

....

3- In your opinion what are the advantages and disadvantage of contemporary houses?

....

....

4- Do you think that the construction materials used in contemporary housing are suitable for the climate of the region?

....

....

5- To what extent the local building materials contribute in reducing burdens of air-conditions in the contemporary housing?

....

....

....

6- How can we develop local building materials to achieve the needs of housing and don not harm the environment?

....

....

....

7- To what extent, building materials industry has developed in Libya? Do this development contributed in the preservation of the environment?

....

....

....

8- Is there any new studies about developing the local building materials? If so, did these materials experiment in buildings?

....

....

9- Who is responsible of developing the local building materials, person, government or both?

....

....

10 –In your view, what is the best model of house ?

....

....

11- To achieve good results, what is your advice on this study?

....

....

Appendix 2: Copy of the interviewee's responses.

Form of Consent

Name: Interviewee 3

Position: Professor

Organisation/Company: AlFateh University- Architecture department

Experience in academy and industry: 35 years

Address: AlFateh University- faculty of engineering- Architecture department Tripoli, Libya

Date: July 2008

Anonymity - Requested / **not requested** (Please select as appropriate)

I am the above named interviewee. I would like to confirm that I give my full consent and understand that the information I provide can be used as data for research and may be used by other researchers, published and put into public domains such as the British Library, Universities' Libraries, Internet, etc. If I request anonymity I understand that the information I provide will be edited so that it cannot be linked to me.

I understand that the subject of the interview is to provide guidelines for architects to consider how to practice climatic design in creating architecture related to the local environment that should provide more sustainable solutions in hot climate regions with a particular focus on Tripoli.

I accept that there are no hazards or risks responding to this interview associated with this work.

I understand that my participation is entirely voluntary and that may withdraw at any time and without providing any reasons for such withdrawal.

I understand that I may elect to provide the information anonymously and will indicate so above; in which case the researcher will allocate a random reference to me and only the researcher will know the name of the original source.

Signature: ....

Date: ....8/ 2008...

.

Survey (Interviews)

INTERVIEW FOR PROFESSIONAL- Architects and urban Planners -

What do you think of contemporary housing in terms of appropriateness to the environment?

Generally, contemporary houses are inappropriate to the environment because they are using the same building materials in different geographical locations (coastal, mountain and desert). Priority is given to functional solutions and personal comfort rather than to climatic solutions.

Do you think that the old traditional housing is more environmentally friendly than contemporary housing?
Old traditional housing can be considered as being more appropriate than the current ones. Traditional solutions were used in a specific time and they were very appropriate to the time. New solutions (and freedom from using old building materials and old construction methods serve functional needs and ignore the environment and climate specifically.
In respect of climate, it is necessary to consider the house and its surrounding. Old houses with their courtyards respected social and climatic aspects and provided internal gardens with trees and fountains. These reflected the microclimate inside the house and separated from outside climate.

Can the old traditional housing be amended to conform to the requirements of the current era? Explain your answer.

Old traditional housing was not designed by architects but came about as a result of experiments and continuous experiences. The main advantages of the old city are compact planning, courtyards, small windows and thick walls. Nowadays, we cannot design or build cities like the traditional ones because of changes in lifestyle and the appearance of technology.
Old traditional housing can be amended to match the requirements of the current era, not to copy it but to amend it to meet today's needs.
For this, we should understand the concepts of the old traditional houses and specify the advantages and disadvantages and the re-apply the positive features in a modern way, i.e., vaults and domes.

In your opinion what are the advantages of contemporary houses?

Contemporary houses that existed in the industrial revolution era were the first contemporary houses put up after the second world war and the second type of contemporary housing were put up after the 1970s and after that came the modern and post modern types. The main advantages of Libyan contemporary housing is that it provides all persons' needs, comfort and privacy (the ability to separate men and women). Before, a householder and his children are living in the same house; now we can find groups of family houses separated and near each other. In my opinion, the advantages of contemporary house are greater than its disadvantages.

How can we develop contemporary housing to achieve the needs of citizens (residents), and not cause damage to the environment?

We should acknowledge that technology improvements contribute to making things easier. However, they also contribute to rising environmental pollution and increasing energy consumption. In contemporary architecture, interior spaces are bigger than that which people need. i.e., in a living room, a person needs ½ m^2 x 4 persons = 8 m^2; usually we find in contemporary houses living rooms of 20 m^2, whereas in traditional buildings space areas are related to functional needs.

Economic factors contribute to people's desire to get away from the old thinking and look for comfortable spaces that reflect their wealth.

Developing current houses to reduce environmental impacts is not an easy request, because of our needs from our houses. In addition our general culture keeps our needs above environmental needs. 20 years ago it was difficult to find someone using AC but at the current time it is difficult to find any house, mosque or car without AC.

It is possible to reach a compromise between traditional and current housing if some studied changes are made.

These include:

Avoiding the negative aspects of current houses such as: having no identity, weak relative relationship, less safety and, to create internal thermal comfort, current houses have ignored the external environment.

Improving current houses can be undertaken by using some features such as: reusing the courtyard concept but with a change its position, good orientation, shading devices and the use of vegetation.

To what extent does the cost of the building affect its shape and methods of construction?

The cost of building and its effect on shape depends on the architects' understanding of their tools and available materials. Designing for one person is easier than designing housing projects for different needs.

People want buildings to be special, for example, people bring about changes in housing projects in order to give their houses special styles. The economic situation of people affects to a great extent the shape of building.

Do you think that the construction materials used in contemporary housing are suitable for the climate of the region?

One of the difficulties facing us is suitable building materials, this is controlled by economic and social factors. We have had previous experiences with prefabricated buildings where people did not use them because they thought that they were not strong enough. Also they do not like living in flats, they consider flats as temporary housing. Libyan people prefer houses because of the relationship to the earth.

Is it possible for the ordinary inhabitants to implement housing that includes concepts of sustainable design?

Sustainable architecture is an economic expression that means protect current energy for the next generations. This topic is bigger than a person's possibilities because of its cost and techniques. The government can start implementing these concepts in projects and can let people experiment with it and convince them of its benefits. These projects should be developed continually.

Do you think that modern Libyan architecture was influenced by western architecture? And to what extent do these influences contribute to a blurring of the development of Libyan architecture?

Libyan architecture is influenced by western architecture, which contributes by ignoring vernacular architecture and its identity. However, it can contribute in improving internal spaces.

From a climatic point of view, what are the suitable building forms for Tripoli's climate and what are the reasons that flat roofs are commonly used instead of a curved or pitched one?

I think there is no a specific form for a climate because any form can be designed in such a way to meet climatic needs, but we can say that the main points are: it is recommended that the longest elevation face north and south; using shading devices; ensuring internal cross ventilation, vegetation and shading roofs. Flat roofs are commonly used in vernacular architecture because of available materials and they provide an extra area which can be used for social needs and in the summertime. However, domes and vaults are used when large areas are required internally. Flat roofs in contemporary houses can be used be social reasons (i.e., weddings) and for possible future extensions.

Do you think that borrowing elements from local vernacular architecture such as courtyards, local materials and openings could improve future housing projects?

Yes, these features can improve future houses (for both climate and identity).
Do you think that borrowing elements from international vernacular architecture such as malgaf, mashrabiya and curved roofs could improve future housing projects or create a new architecture?

Well, as I stated previously, it is all about the architect and his understanding of these elements, how to use them in an appropriate way and how to develop them so they do not look strange.

In your view, what is the best model for a house?

The best model is that which achieves full interaction between man and environment. Comfort (socially, climatically).

Can we design a special architectural model, with special specifications appropriate to the particular region and climate, as a particular model that can help when designing in the same circumstances?

It is impossible to reach a complete model, but it is possible to provide wide guidelines and classifications which can be given as references. It should not be a complete design but it can be a zoning concept which describes all relations and then the design can be left to each architect to put on his figure print. This model should be a fantasy model and can be developed according to needs.

For me, to achieve good results, what is your advice on this study?

I want you to consider that any architecture is the reflection of specific historical life, so it is not wise to build in 2008 such a building as those that that have existed more than four centuries. However, we can protect traditional identity with new ideology. And changes in climate between regions can help in providing a special identity for each region.
Getting back to the past because it is better, is an escape from reality. We talk about the past emotionally; that it is always better, but if we experienced living there currently, we would face problems that could change our opinion. In that time, life was difficult and poor, nothing of these difficulties remain in our mind and the only things that have stayed are some features (such as courtyards, fountains, shadows and vegetation).

Appendix 3: Sample copy of the interviewee's comments on the final guidelines

Form of Consent

Name: [redacted]
Position: PhD Student
Organisation/Company: New Jersey Institute of Technology
Experience in academy and industry: 16 Yrs / 10 Yrs Academic / profession
Address: 270 Elm St. Kearny, NJ USA 07032
Date: 08/07/2010

Anonymity - Requested / not requested (Please select as appropriate)

I am the above named interviewee. I would like to confirm that I give my full consent and understand that the information I provide can be used as data for research and may be used by other researchers, published and put into public domains such as the British Library, Universities' Libraries, Internet, etc. If I request anonymity I understand that the information I provide will be edited so that it cannot be linked to me.

I understand that the subject of the interview is to provide guidelines for architects to consider how to practice climatic design in creating architecture related to the local environment that should provide more sustainable solutions in hot climate regions with a particular focus on Tripoli.

I accept that there are no hazards or risks responding to this interview associated with this work.
I understand that my participation is entirely voluntary and that may withdraw at any time and without providing any reasons for such withdrawal.
I understand that I may elect to provide the information anonymously and will indicate so above; in which case the researcher will allocate a random reference to me and only the researcher will know the name of the original source.

Signature: ....

Date: ......08/07/2010........

HOUSING CLIMATIC DESIGN GUIDELINES in TRIPOLI

Key : opinions	✓ Agreed	x Not Agreed

Rating Priority: 1 compulsory, 2 Important, 3 Optional

The first Principle: Local microclimate:

Strategies for building size, location and landscaping While planning stage, it is important to consider the followings:	Opinions	Priority
• Orient streets to run east-west, accordingly, buildings will be oriented correctly.	✓	3
• The spacing of buildings should be carefully considered to avoid obstructing of wind flow around those buildings;	✓	2
• To reduce the surfaces exposed to solar radiation and increase shaded areas, the compact city is the ideal city form. However, it is important to consider the need to use different kind of transportation, accordingly, shading devices, trees or cover parts of streets and green spaces can help to stitch together the urban fabric;	✓	1
• Provide open spaces such as streets, squares and courtyards;	✓	2
• Consider the lack of water resources in Libya, and choose the appropriate kind of vegetation.	✓	1
• Maximize green areas and reserve the existing trees. Green squares and tree-lined streets get nature into the heart of the city;	✓	1
• Maximise shading areas.	✓	1
✢ The lower the ratio between the building volume and the width of spaces, the lower temperature in buildings and outdoor spaces;	✓	3 ?
✢ Minimize heat island effect at paved areas by minimizing the street width and parking lot size. Narrow streets can behave as cooling ducts by venting away hot air;	✓	2
✢ Consider sharing parking facilities with neighbouring buildings;	?	3
• **Site Design** While designing the site plan, it is important to consider the followings:		
✢ Minimize the building area to preserve as much site as possible for open landscaped space.	X	3
✢ To minimize heat gain, heat loss and material usage, the house shape can be rectangle with the long side facing north and south.	✓	2
✢ Two-story house can help in reducing plot land area and reduce direct heat gain from the roof to the first floor.	✓	1
✢ Consider the use of green roofs (landscaped) to reduce energy consumption.	✓	1
✢ Recycle gray water (rainwater collection or bath water recapture) and re use it in landscaping or in toilet flushing.	✓	1
✢ Avoid designing square and "L" shaped buildings which can result in half the glass facing east and west unless it is well shaded.	✓	3

3

• **Landscaping**		
• Shading by natural means (e.g. via trees) reduces the isolation entering adjacent buildings and the effects of wind. Trees and other plants represent a natural protective element against solar radiation as well as wind control;	✓	2
• Plant deciduous trees to shade glass in summer and allow solar heat gain in winter.	✓	1
• Choose appropriate plants that thrive in local climate with minimal irrigation.	✓	1
♣ The pergola system restrains the rate of heat gain and reduces diffuse reflection to surrounding dwellings.	✓	3
♣ Trees create different airflow patterns and can be used to direct or divert the wind advantageously by causing a pressure difference;	✓	2
♣ The shade created by trees and the effect of grass and shrubs reduce air temperatures adjoining the building and provide evaporative cooling;	✓	2
♣ Vegetation can be used as a sunshade; like palm trees whose leaves are able to block solar radiation and tall trunks will easily allow unimpeded ventilation.	✓	2
♣ The most appropriate plants for landscaping in hot-humid climates are a mixture of grasses, low flowerbed, and shade trees with high trunks.	✓	2
For more detailed landscaping design see NCSU (2001) available on line in; http://www.ncsc.ncsu.edu/include/_upload/media/pubs/Energy_Landscape.pdf		

Comments:

- I agree with having open & [illegible] areas, but not to minimizing the building areas to much. I mean there should be a balance. Moreover, open areas in hot-humid regions need extensive care and maintain other wise these areas will become a source of concern and problems in the built environment.

The Second Principle: building design:	Opinions	Priority
• **Plan design concept**		
• Open-plan living areas with high ceilings can help in maximising air movement and reduce radiant heat to occupants;	✓	3
• Building lows in Libya insists to design detached building, accordingly, the east and west elevations should be well shaded;	?	?
✤ Including flexile courtyard concept can help in regulating internal thermal comfort and increase cross ventilation;	✓	3
✤ Divide the building into multiple thermal zones, therefore, unused areas can be switched off or allowed to float;(and)	✓	2
✤ The design should ensure flexibility in use.	✓	1
• **Building heights**		
• Enlarge ceiling heights up to 4m;	✓	3
✤ Use high openings near the ceiling to exit worm air :and	✓	3
✤ Utilize Two to three floors maximum	✓	3
• **Building form**		
• The building should be elongated on east-west axis; it can be diverged up to 15 degrees south-east or south-west.	✓	3
• The whole building should be high weight with high thermal mass that can increase the time lag of the building envelope;	✗	
✤ The square house is not the optimum form in any location, however, it can be adapted if insuring good shading and ventilation;	✓	3
✤ Curved surfaces works much better than flat surfaces in reflecting direct sunrises;	✓	3
✤ To reduce the roof area, two story building can solve the problem;		
✤ Raising the building off the ground can improve the potential of ventilation;		
✤ To reduce the size of any AC. equipment, the building should be compact to minimise the surface areas of its envelop and thus to reduce the heat gain;		
✤ For depending on natural ventilation, a spread-out building (not compact and includes courtyards) with adequate windows enables more natural cross ventilation, (shading devices can help in preventing direct heat gain;) ?	✓	3
✤		
• **Room orientation**		
✤ Living- room and Guest- room can be located in the south or north. Depends on the site characteristics, it is preferred to locate living room in the south because it is used almost all the day and sun located very high in the south and small liner canopy can prevent sun raise;		
✤ Bed- rooms can be located in the east. Sun in the east raises in the morning, and usually occupants using bed rooms at night.	✓	2
✤ Services such as kitchen and toilets can be located in the west.	✓	3
Comments:		

5

The Third Principle: The Main Building Components	Opinions	Priority
• **Roofs**		
• To avoid overheating ,vaults and domes are climatically superior to flat roofs because flat roofs consumes large amount of sun's heat falls on the roof of a building, whereas, vaults and domes reflects sunrise and increases the speed of air flowing over their curved surface;	✓	3
• Use high-weight materials that can delay heat gain such as double layer roofs of hollow blocks.		2
• Shade the roof with suspended mat or timber boards or by vegetation;	✓	2
• Using insulation layer on the outside of a concrete slab can increase the time lag to eight hours;	✓	1
• Consider the outer surface of the roof and the thermal resistivity of its materials;		1
• Use light colours to reflect the heat of the sun;	✓	2
✤ Properly designed roof gardens help to reduce heat loads in a building;	✓	3
✤ Design the roof for the potential future retrofit with a solar panels and photovoltaic system;	✓	2
✤ Design the roof to collect rainwater & provide storage tanks to use the water for landscaping & toilets.		1
• **Walls**		
• External envelope should have a high thermal mass such as using double walls with thermal insulation or cavity walls with small openings in the top and bottom to escape the raised worm air;	✓	2
• Walls should be well insulated by using good insulation properties;	✓	1
• Use shading devices to shade windows and walls;	✓	2
• Location of internal walls should not prevent cross-ventilation; it can include cavities for heat-exchange purposes.	✓	2
✤ Light internal walls can be used in rooms which are used by day such as living room and kitchen;	✓	3
✤ Provide some openings or holes in the parapet walls around the roof to avoid lasting hot air.	✓	2
• **Finishing**		
✤ To reduce the effects of the sun on buildings the outside walls should be reflective with respect to insulation by painting it white or utilising glazed brick-facings.		
• **Floors**		
• Use kind of materials that can resist heat;		
✤ A suspended floor with a large well-ventilated under-floor cavity will give a quicker response when temperatures drop slightly in the evening than a floor directly in contact with the ground.		

• **Doors** • For privacy reason, doors are important in almost all the house, however, the design of the doors can be improved by providing upper or lower openings to allow air movements;	✓	2 or 3
• **Windows - shading devices** • Small windows can help minimize heat gain, however, it disable natural cross ventilation, accordingly, adequate windows size with appropriate shading devoices can provide adequate solution;	✓	2
• Provide fixed horizontal overhangs for south windows, vertical overhangs for east windows and combined vertical and horizontal overhangs for west windows;	✓	2
• Using double glazing with appropriate thickness;	✓	1
• Using mashrabiy can help in serving five functions: 1- controlling the passage of light, 2- controlling the air flow, 3- reducing the temperature of the air existing, 4- increasing the humidity of the air existing, and 5- ensuring privacy.	✓	2
• Exterior shutters and shades, either hinged or rolling blind type, are another option for shading.		
• Using interior shading such as draperies and curtains that are most effective when made of tightly-woven, thick material of a light or reflective colour.	✓	2
• Ensure the circulation of air within a building, to achieve this, openings should be located in two opposite walls.	✓	2
• careful selection of windows and their positioning can help enhance the natural ventilation possibilities of the house;	✓	1
• Specify energy-efficient windows by using double glazed glass with thermal break frames;	✓	2
• Provide day lighting with windows and skylights. To reduce heat gain, minimize glazing on east and west;	?	2
• Consider installing movable insulation (hand operated or automated) to close off glass areas during the night. For more detailed windows design see NCSU (2001) available on line in; http://www.ncsc.ncsu.edu/include/_upload/media/pubs/03shadng.pdf	✓	2

• **Building materials**		
• Provide a well-insulated building that minimizes heat gain and loss, accordingly, roofs and walls should included high insulating properties (U-values)	✓	1
♣ Adobe buildings are better suited for hot regions;		
♣ Heavy masonry with extreme thermal mass (typical of stone and mud) can have an important positive effect on the thermal performance of buildings particularly those located in western and southern sides.	✓	3
← ♣ Use locally available materials for construction to minimize transportation.	✓	2
♣ Use durable, easily maintained materials inside and out to minimize future replacement;	✓	1
♣ Develop the technology of using local materials for new housing construction,	✓	1
Comments: I'm with using some new techniques with the old methods and not to rely only on the latter.		

The Fourth Principle: additional building components:	**Opinions**	**Priority**
• **Earth-sheltered**		
♣ Earth-sheltered and underground housing are ideally suited to this climate.	✗	3
• **Patio/ courtyard**		
• A courtyard house is an ideal solution to hot climate regions that serves as a reservoir of coolness;	✓	2
• The position of the courtyard in the centre of the house should be changed to avoid crossing them all the time, or using technology to offer the possibility to cover the courtyard and open it when necessary;	✓	1
• The walls surrounding the courtyard should have a good thermal resistance and a long time lag;	✓	1
• The courtyard should include trees and a fountain to provide shade area and evaporation.	✓	2
• **Fountain**		
• The fountain discharges its water and mixes it with surrounding air to increase humidity and to cool the air by evaporation.	✓	3

• **Wind catcher**		
✚ Wind catchers can help in increasing the flow of air in houses, It can be incorporated into modern buildings aesthetically;	✓	2
✚ Staircases can be designed to catch a pleasant wind.	✓	2
For more vernacular solutions see Fathy (1986) available on line in; http://www.4shared.com/get/3AgOeAzE/Natural_Energy_and_Vernacular_.html		
• **Balconies**		
• The balconies provide protection to walls and windows from sun and rain, however, socially they are not often used by occupants unless a big part of it can be covered by musharbia.	✓	2
• The rooms should have direct access to open balconies or verandas on one or two sides;	X	3
Alternatives of bacons design can be found in: http://www.scribd.com/doc/30955006/Architectural-design-guidelines-for-Balconies		
• **Sun space/ solarium**		
✚ It employs a combination of direct gain and indirect gain system features.	?	?
✚ Courtyard can be used as a solarium house when using moveable covered windows.	✓	3
For more detailed sun space design see NCSU (1998) available on line in; http://www.ncsc.ncsu.edu/include/_upload/media/pubs/21sunspc.pdf		
• **Solar panels**		
• Solar panels can be used for hot water and heating the spaces;	✓	3
✚ Photovoltaic system can help illuminate energy consumption.	✓	2
For more details about passive and active solar domestic hot water systems see NCSU (2002) available on line in; http://www.ncsc.ncsu.edu/include/_upload/media/pubs/SolarDHW.pdf		

Comments:

Solar devices are not affordable for private housing. In addition, using them in public housing needs monitoring and maintenance.

9

By the end of your answers, may I ask you to tell me your opinion about the folwings;

1- **The guidelines design (for example; the structure, the way the informations presented; is it easy to follow and so on?)**

In general, the guidelines are well structured and presented in a coherent way. However, there is some repetition in the information. Some points are detailed very much and I think you don't need to state some general and very well known facts.

2- **Is it nessesarly to link to the sorces to clarify some points?**

Yes, it's a good Idea.

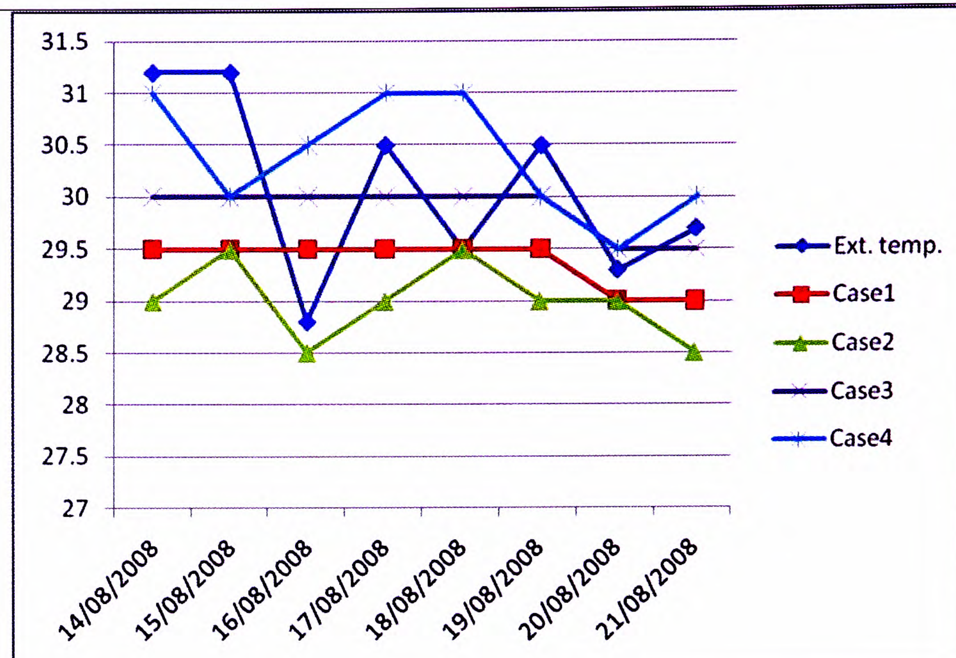
3- **Is it nessesarly to set the proiorites of the guidance?**

I guess so, but some guidelines are difficult to set priorities for them as either they are facts or they are written as statements.
(I put ?? for these guidelines)

10

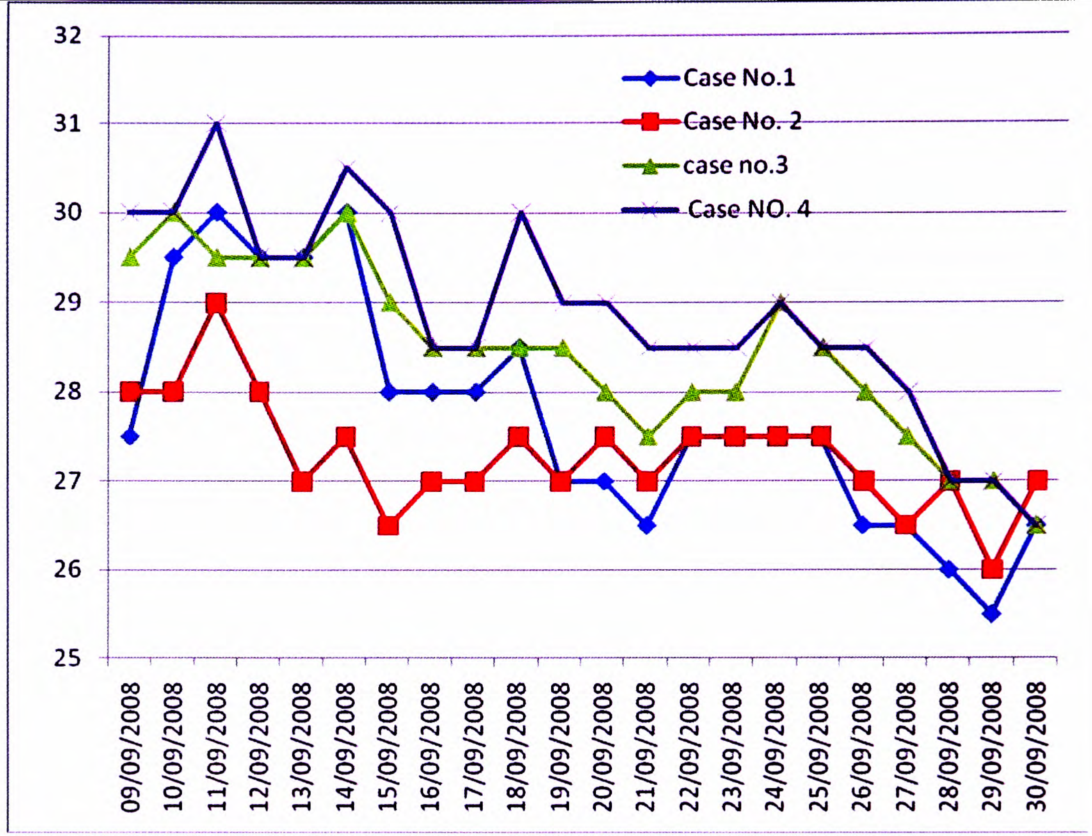
Appendix 4: Average monthly internal temperatures in the 4 case study houses at 13.22hours

August indoor temperature inside the 4 case studies				
	Case1	Case2	Case3	Case4
14/8/08	29.5	29.0	30.0	31.0
15/8/08	29.5	29.5	30.0	30.0
16/8/08	29.5	28.5	30.0	30.5
17/8/08	29.5	29.0	30.0	31.0
18/8/08	29.5	29.5	30.0	31.0
19/8/08	29.5	29.0	30.0	30
20/8/08	29.0	29.0	29.5	29.5
21/8/08	29.0	28.5	29.5	30

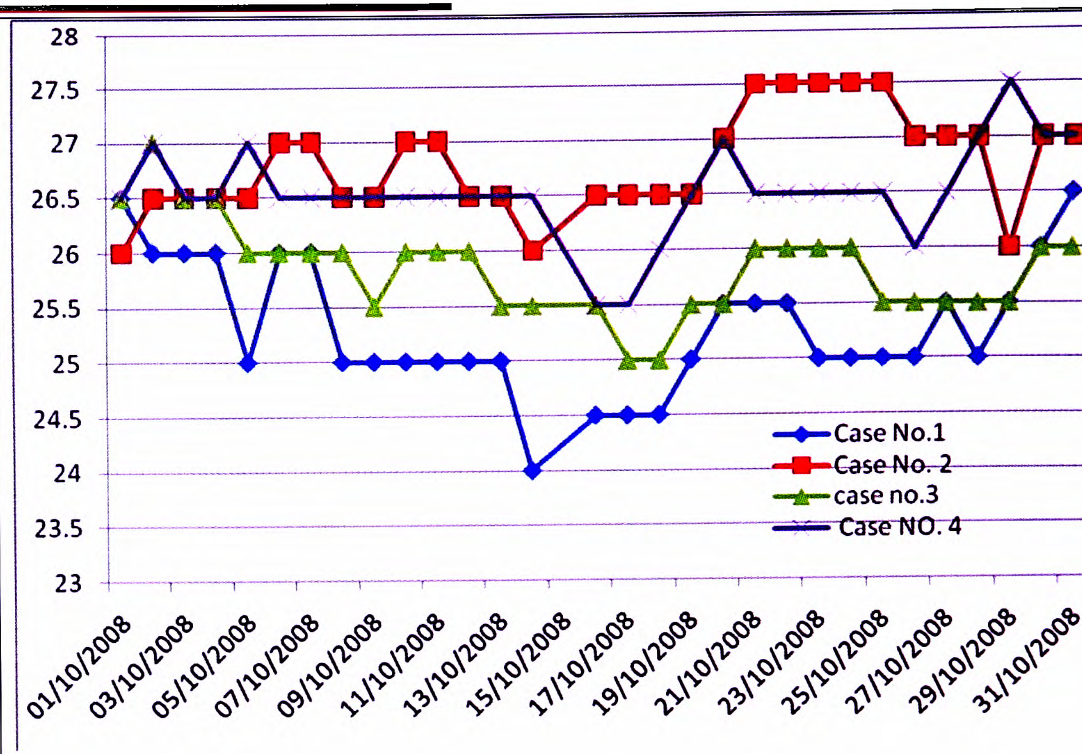


September indoor temperature inside the 4 case studies

Time - 13:22- °C	Case No.1	Case No. 2	Case no.3	Case NO. 4
09/09/2008	27.5	28	29.5	30
10/09/2008	29.5	28	30	30
11/09/2008	30	29	29.5	31
12/09/2008	29.5	28	29.5	29.5
13/09/2008	29.5	27	29.5	29.5
14/09/2008	30	27.5	30	30.5
15/09/2008	28	26.5	29	30
16/09/2008	28	27	28.5	28.5
17/09/2008	28	27	28.5	28.5
18/09/2008	28.5	27.5	28.5	30
19/09/2008	27	27	28.5	29
20/09/2008	27	27.5	28	29
21/09/2008	26.5	27	27.5	28.5
22/09/2008	27.5	27.5	28	28.5
23/09/2008	27.5	27.5	28	28.5
24/09/2008	27.5	27.5	29	29
25/09/2008	27.5	27.5	28.5	28.5
26/09/2008	26.5	27	28	28.5
27/09/2008	26.5	26.5	27.5	28
28/09/2008	26	27	27	27
29/09/2008	25.5	26	27	27
30/09/2008	26.5	27	26.5	26.5

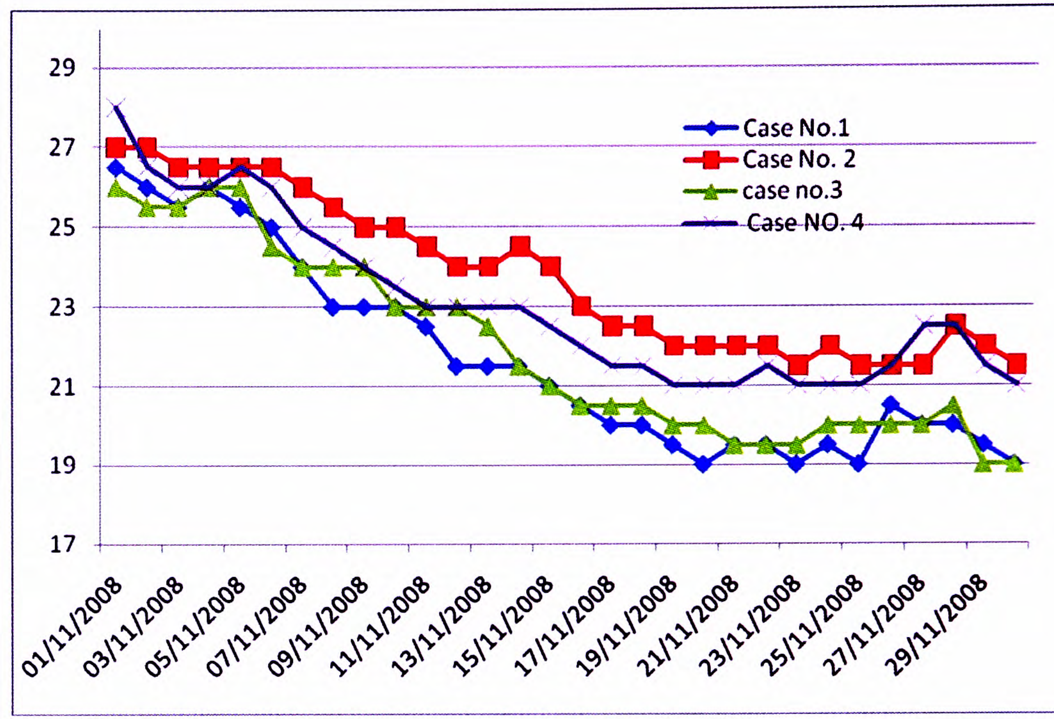


October indoor temperature inside the 4 case studies				
Time - 13:22- °C	Case No.1	Case No. 2	case no.3	Case NO. 4
01/10/2008	26.5	26	26.5	26.5
02/10/2008	26	26.5	27	27
03/10/2008	26	26.5	26.5	26.5
04/10/2008	26	26.5	26.5	26.5
05/10/2008	25	26.5	26	27
06/10/2008	26	27	26	26.5
07/10/2008	26	27	26	26.5
08/10/2008	25	26.5	26	26.5
09/10/2008	25	26.5	25.5	26.5
10/10/2008	25	27	26	26.5
11/10/2008	25	27	26	26.5
12/10/2008	25	26.5	26	26.5
13/10/2008	25	26.5	25.5	26.5
14/10/2008	24	26	25.5	26.5
16/10/2008	24.5	26.5	25.5	25.5
17/10/2008	24.5	26.5	25	25.5
18/10/2008	24.5	26.5	25	26
19/10/2008	25	26.5	25.5	26.5
20/10/2008	25.5	27	25.5	27
21/10/2008	25.5	27.5	26	26.5
22/10/2008	25.5	27.5	26	26.5
23/10/2008	25	27.5	26	26.5
24/10/2008	25	27.5	26	26.5
25/10/2008	25	27.5	25.5	26.5
26/10/2008	25	27	25.5	26
27/10/2008	25.5	27	25.5	26.5
28/10/2008	25	27	25.5	27
29/10/2008	25.5	26	25.5	27.5
30/10/2008	26	27	26	27
31/10/2008	26.5	27	26	27

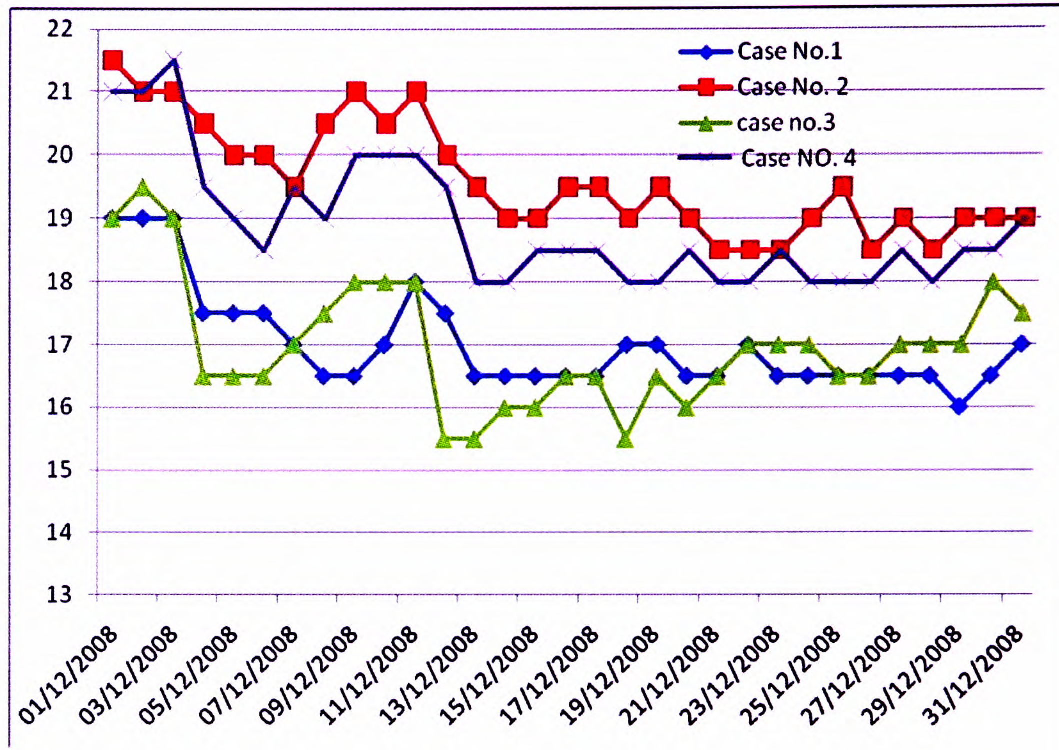


November indoor temperature inside the 4 case studies

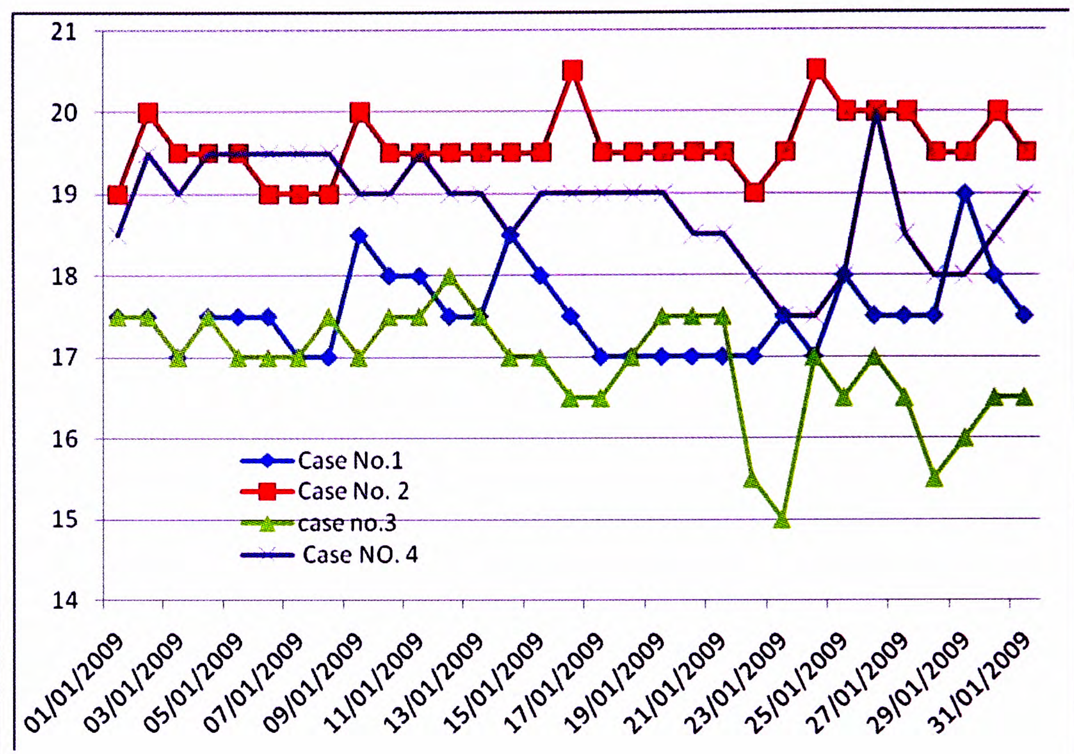
Time - 13:22- °C	Case No.1	Case No. 2	case no.3	Case NO. 4
01/11/2008	26.5	27	26	28
02/11/2008	26	27	25.5	26.5
03/11/2008	25.5	26.5	25.5	26
04/11/2008	26	26.5	26	26
05/11/2008	25.5	26.5	26	26.5
06/11/2008	25	26.5	24.5	26
07/11/2008	24	26	24	25
08/11/2008	23	25.5	24	24.5
09/11/2008	23	25	24	24
10/11/2008	23	25	23	23.5
11/11/2008	22.5	24.5	23	23
12/11/2008	21.5	24	23	23
13/11/2008	21.5	24	22.5	23
14/11/2008	21.5	24.5	21.5	23
15/11/2008	21	24	21	22.5
16/11/2008	20.5	23	20.5	22
17/11/2008	20	22.5	20.5	21.5
18/11/2008	20	22.5	20.5	21.5
19/11/2008	19.5	22	20	21
20/11/2008	19	22	20	21
21/11/2008	19.5	22	19.5	21
22/11/2008	19.5	22	19.5	21.5
23/11/2008	19	21.5	19.5	21
24/11/2008	19.5	22	20	21
25/11/2008	19	21.5	20	21
26/11/2008	20.5	21.5	20	21.5
27/11/2008	20	21.5	20	22.5
28/11/2008	20	22.5	20.5	22.5
29/11/2008	19.5	22	19	21.5
30/11/2008	19	21.5	19	21



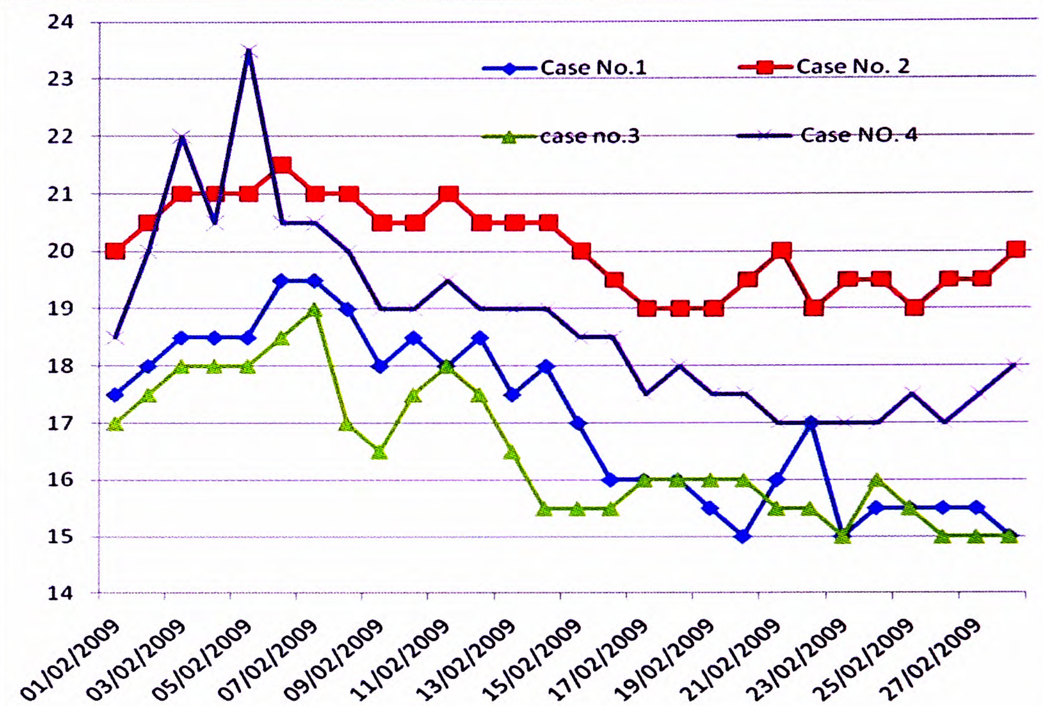
December indoor temperature inside the 4 case studies				
Time 13:22- °C	Case No.1	Case No. 2	case no.3	Case NO. 4
01/12/2008	19	21.5	19	21
02/12/2008	19	21	19.5	21
03/12/2008	19	21	19	21.5
04/12/2008	17.5	20.5	16.5	19.5
05/12/2008	17.5	20	16.5	19
06/12/2008	17.5	20	16.5	18.5
07/12/2008	17	19.5	17	19.5
08/12/2008	16.5	20.5	17.5	19
09/12/2008	16.5	21	18	20
10/12/2008	17	20.5	18	20
11/12/2008	18	21	18	20
12/12/2008	17.5	20	15.5	19.5
13/12/2008	16.5	19.5	15.5	18
14/12/2008	16.5	19	16	18
15/12/2008	16.5	19	16	18.5
16/12/2008	16.5	19.5	16.5	18.5
17/12/2008	16.5	19.5	16.5	18.5
18/12/2008	17	19	15.5	18
19/12/2008	17	19.5	16.5	18
20/12/2008	16.5	19	16	18.5
21/12/2008	16.5	18.5	16.5	18
22/12/2008	17	18.5	17	18
23/12/2008	16.5	18.5	17	18.5
24/12/2008	16.5	19	17	18
25/12/2008	16.5	19.5	16.5	18
26/12/2008	16.5	18.5	16.5	18
27/12/2008	16.5	19	17	18.5
28/12/2008	16.5	18.5	17	18
29/12/2008	16	19	17	18.5
30/12/2008	16.5	19	18	18.5
31/12/2008	17	19	17.5	19



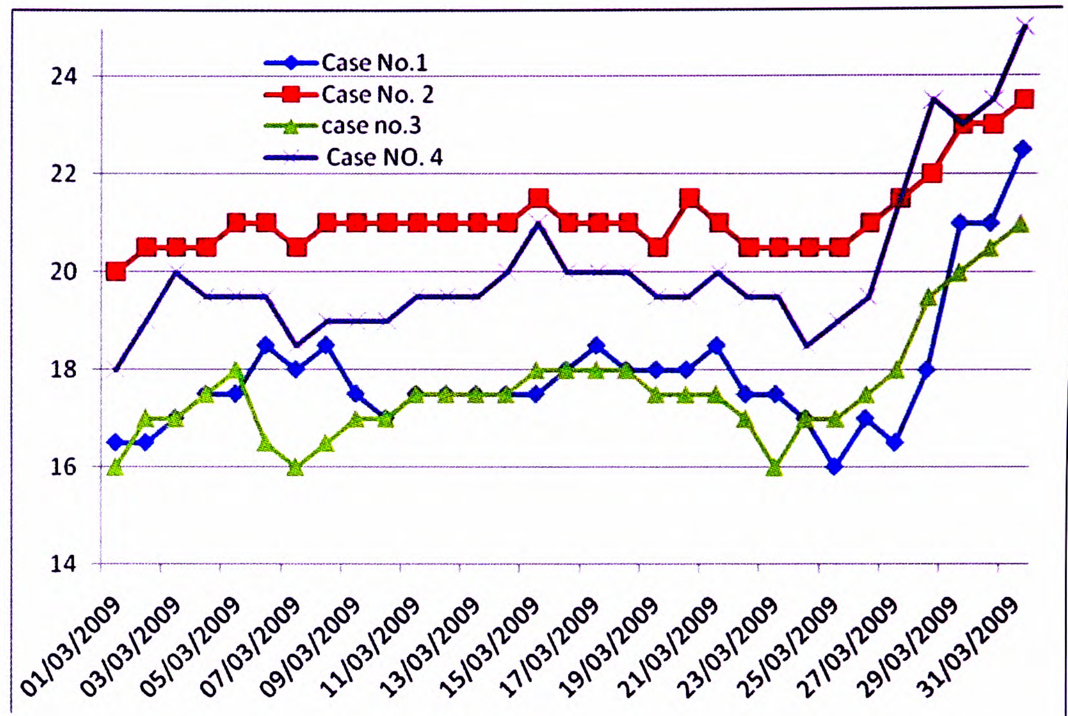
January indoor temperature inside the 4 case studies				
Time-13:22- °C	Case No.1	Case No. 2	case no.3	Case NO. 4
01/01/2009	17.5	19	17.5	18.5
02/01/2009	17.5	20	17.5	19.5
03/01/2009	17	19.5	17	19
04/01/2009	17.5	19.5	17.5	19.5
05/01/2009	17.5	19.5	17	19.5
06/01/2009	17.5	19	17	19.5
07/01/2009	17	19	17	19.5
08/01/2009	17	19	17.5	19.5
09/01/2009	18.5	20	17	19
10/01/2009	18	19.5	17.5	19
11/01/2009	18	19.5	17.5	19.5
12/01/2009	17.5	19.5	18	19
13/01/2009	17.5	19.5	17.5	19
14/01/2009	18.5	19.5	17	18.5
15/01/2009	18	19.5	17	19
16/01/2009	17.5	20.5	16.5	19
17/01/2009	17	19.5	16.5	19
18/01/2009	17	19.5	17	19
19/01/2009	17	19.5	17.5	19
20/01/2009	17	19.5	17.5	18.5
21/01/2009	17	19.5	17.5	18.5
22/01/2009	17	19	15.5	18
23/01/2009	17.5	19.5	15	17.5
24/01/2009	17	20.5	17	17.5
25/01/2009	18	20	16.5	18
26/01/2009	17.5	20	17	20
27/01/2009	17.5	20	16.5	18.5
28/01/2009	17.5	19.5	15.5	18
29/01/2009	19	19.5	16	18
30/01/2009	18	20	16.5	18.5
31/01/2009	17.5	19.5	16.5	19



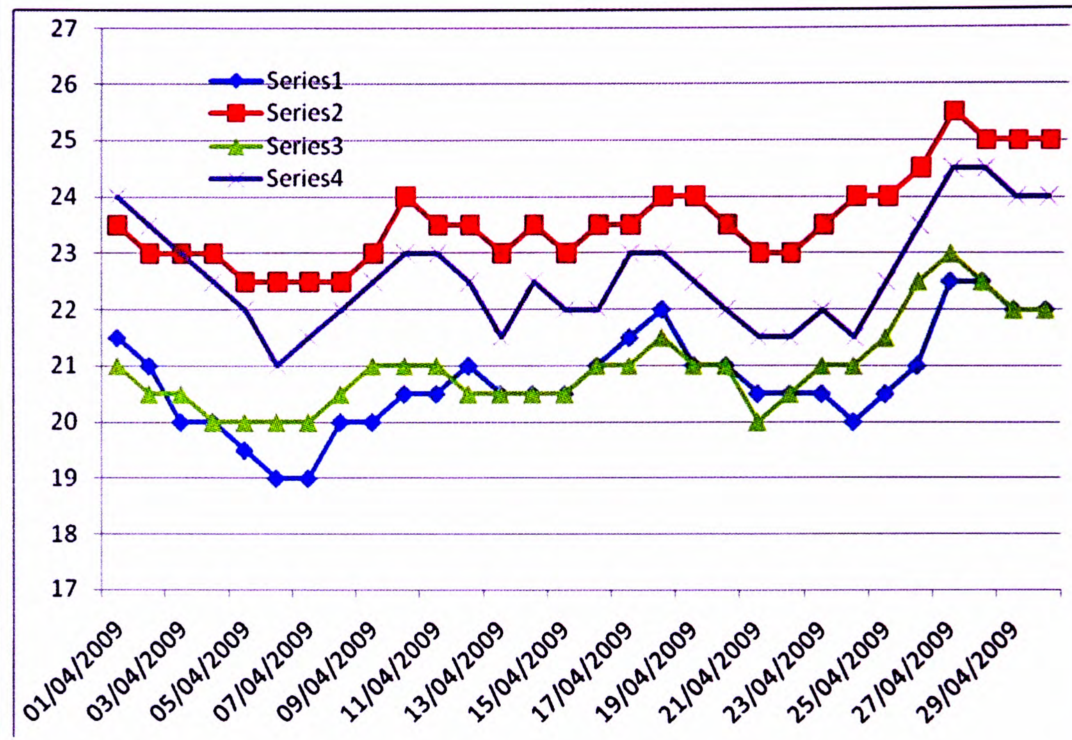
February indoor temperature inside the 4 case studies				
Time 13:22- °C	Case No.1	Case No. 2	case no.3	Case NO. 4
01/02/2009	17.5	20	17	18.5
02/02/2009	18	20.5	17.5	20
03/02/2009	18.5	21	18	22
04/02/2009	18.5	21	18	20.5
05/02/2009	18.5	21	18	23.5
06/02/2009	19.5	21.5	18.5	20.5
07/02/2009	19.5	21	19	20.5
08/02/2009	19	21	17	20
09/02/2009	18	20.5	16.5	19
10/02/2009	18.5	20.5	17.5	19
11/02/2009	18	21	18	19.5
12/02/2009	18.5	20.5	17.5	19
13/02/2009	17.5	20.5	16.5	19
14/02/2009	18	20.5	15.5	19
15/02/2009	17	20	15.5	18.5
16/02/2009	16	19.5	15.5	18.5
17/02/2009	16	19	16	17.5
18/02/2009	16	19	16	18
19/02/2009	15.5	19	16	17.5
20/02/2009	15	19.5	16	17.5
21/02/2009	16	20	15.5	17
22/02/2009	17	19	15.5	17
23/02/2009	15	19.5	15	17
24/02/2009	15.5	19.5	16	17
25/02/2009	15.5	19	15.5	17.5
26/02/2009	15.5	19.5	15	17
27/02/2009	15.5	19.5	15	17.5
28/02/2009	15	20	15	18



March indoor temperature inside the 4 case studies				
Time-13:22- °C	Case No.1	Case No. 2	case no.3	Case NO. 4
01/03/2009	16.5	20	16	18
02/03/2009	16.5	20.5	17	19
03/03/2009	17	20.5	17	20
04/03/2009	17.5	20.5	17.5	19.5
05/03/2009	17.5	21	18	19.5
06/03/2009	18.5	21	16.5	19.5
07/03/2009	18	20.5	16	18.5
08/03/2009	18.5	21	16.5	19
09/03/2009	17.5	21	17	19
10/03/2009	17	21	17	19
11/03/2009	17.5	21	17.5	19.5
12/03/2009	17.5	21	17.5	19.5
13/03/2009	17.5	21	17.5	19.5
14/03/2009	17.5	21	17.5	20
15/03/2009	17.5	21.5	18	21
16/03/2009	18	21	18	20
17/03/2009	18.5	21	18	20
18/03/2009	18	21	18	20
19/03/2009	18	20.5	17.5	19.5
20/03/2009	18	21.5	17.5	19.5
21/03/2009	18.5	21	17.5	20
22/03/2009	17.5	20.5	17	19.5
23/03/2009	17.5	20.5	16	19.5
24/03/2009	17	20.5	17	18.5
25/03/2009	16	20.5	17	19
26/03/2009	17	21	17.5	19.5
27/03/2009	16.5	21.5	18	21.5
28/03/2009	18	22	19.5	23.5
29/03/2009	21	23	20	23
30/03/2009	21	23	20.5	23.5

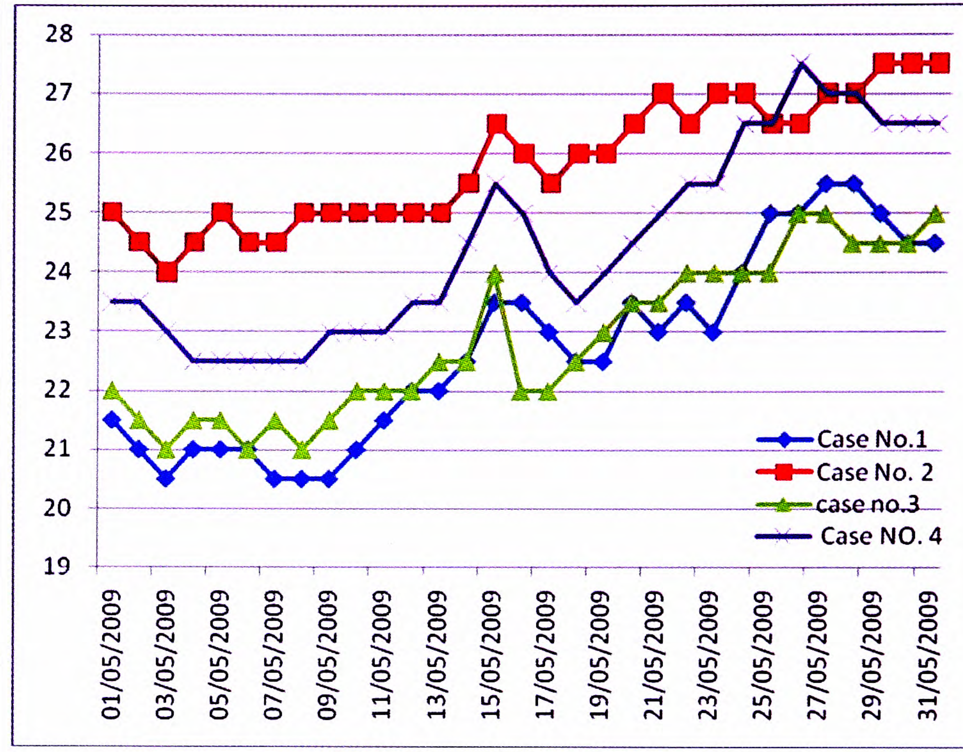


April indoor temperature inside the 4 case studies				
Time-13:22- °C	Case No.1	Case No. 2	case no.3	Case NO. 4
01/04/2009	21.5	23.5	21	24
02/04/2009	21	23	20.5	23.5
03/04/2009	20	23	20.5	23
04/04/2009	20	23	20	22.5
05/04/2009	19.5	22.5	20	22
06/04/2009	19	22.5	20	21
07/04/2009	19	22.5	20	21.5
08/04/2009	20	22.5	20.5	22
09/04/2009	20	23	21	22.5
10/04/2009	20.5	24	21	23
11/04/2009	20.5	23.5	21	23
12/04/2009	21	23.5	20.5	22.5
13/04/2009	20.5	23	20.5	21.5
14/04/2009	20.5	23.5	20.5	22.5
15/04/2009	20.5	23	20.5	22
16/04/2009	21	23.5	21	22
17/04/2009	21.5	23.5	21	23
18/04/2009	22	24	21.5	23
19/04/2009	21	24	21	22.5
20/04/2009	21	23.5	21	22
21/04/2009	20.5	23	20	21.5
22/04/2009	20.5	23	20.5	21.5
23/04/2009	20.5	23.5	21	22
24/04/2009	20	24	21	21.5
25/04/2009	20.5	24	21.5	22.5
26/04/2009	21	24.5	22.5	23.5
27/04/2009	22.5	25.5	23	24.5
28/04/2009	22.5	25	22.5	24.5
29/04/2009	22	25	22	24
30/04/2009	22	25	22	24

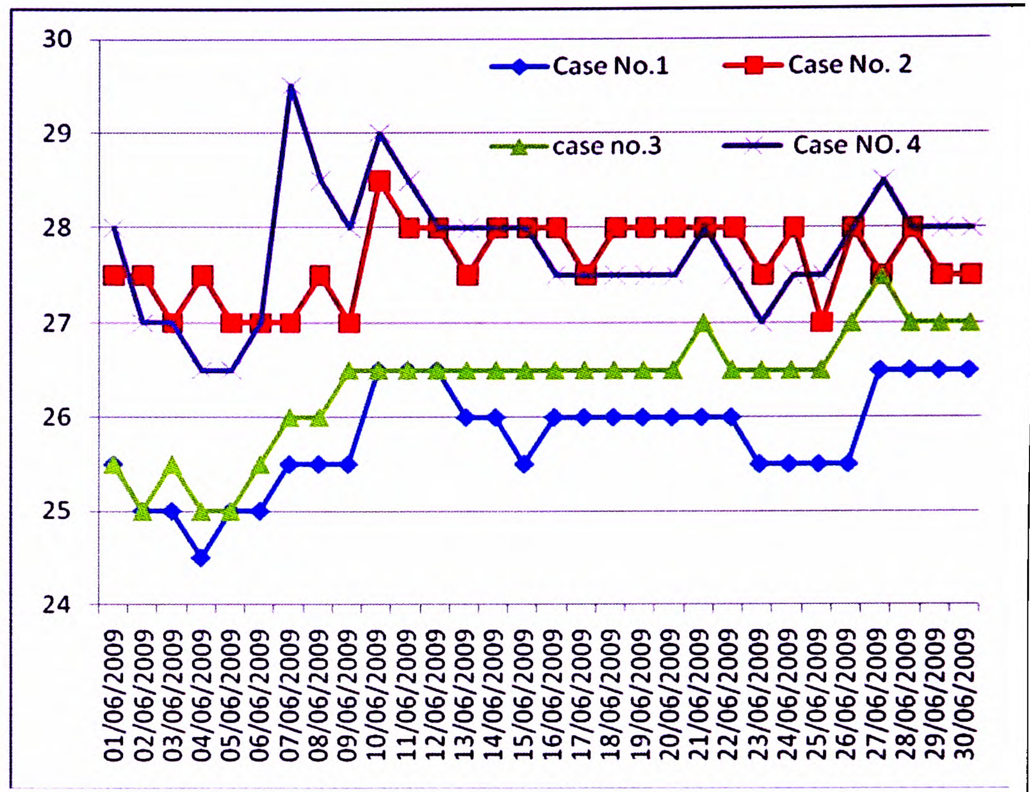


May indoor temperature inside the 4 case studies

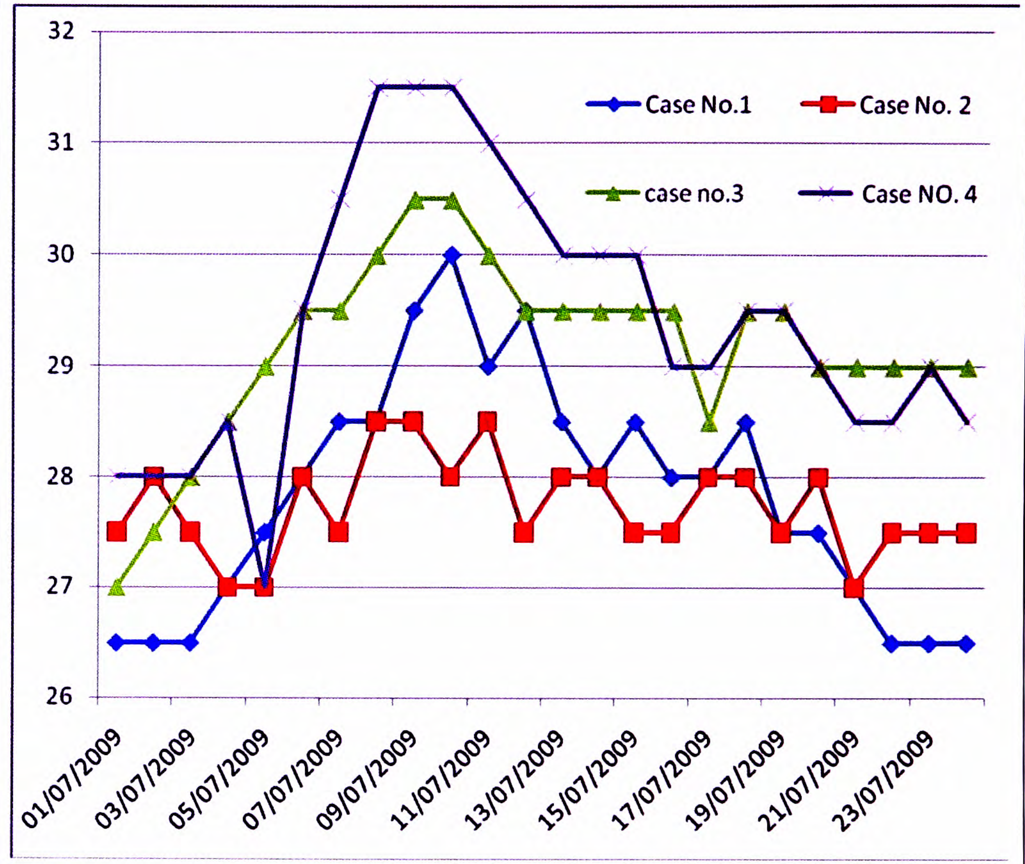
Time-13:22- °C	Case No.1	Case No. 2	case no.3	Case NO. 4
01/05/2009	21.5	25	22	23.5
02/05/2009	21	24.5	21.5	23.5
03/05/2009	20.5	24	21	23
04/05/2009	21	24.5	21.5	22.5
05/05/2009	21	25	21.5	22.5
06/05/2009	21	24.5	21	22.5
07/05/2009	20.5	24.5	21.5	22.5
08/05/2009	20.5	25	21	22.5
09/05/2009	20.5	25	21.5	23
10/05/2009	21	25	22	23
11/05/2009	21.5	25	22	23
12/05/2009	22	25	22	23.5
13/05/2009	22	25	22.5	23.5
14/05/2009	22.5	25.5	22.5	24.5
15/05/2009	23.5	26.5	24	25.5
16/05/2009	23.5	26	22	25
17/05/2009	23	25.5	22	24
18/05/2009	22.5	26	22.5	23.5
19/05/2009	22.5	26	23	24
20/05/2009	23.5	26.5	23.5	24.5
21/05/2009	23	27	23.5	25
22/05/2009	23.5	26.5	24	25.5
23/05/2009	23	27	24	25.5
24/05/2009	24	27	24	26.5
25/05/2009	25	26.5	24	26.5
26/05/2009	25	26.5	25	27.5
27/05/2009	25.5	27	25	27
28/05/2009	25.5	27	24.5	27
29/05/2009	25	27.5	24.5	26.5
30/05/2009	24.5	27.5	24.5	26.5
31/05/2009	24.5	27.5	25	26.5



June indoor temperature inside the 4 case studies				
Time - 13:22- °C	Case No.1	Case No. 2	case no.3	Case NO. 4
01/06/2009	25.5	27.5	25.5	28
02/06/2009	25	27.5	25	27
03/06/2009	25	27	25.5	27
04/06/2009	24.5	27.5	25	26.5
05/06/2009	25	27	25	26.5
06/06/2009	25	27	25.5	27
07/06/2009	25.5	27	26	29.5
08/06/2009	25.5	27.5	26	28.5
09/06/2009	25.5	27	26.5	28
10/06/2009	26.5	28.5	26.5	29
11/06/2009	26.5	28	26.5	28.5
12/06/2009	26.5	28	26.5	28
13/06/2009	26	27.5	26.5	28
14/06/2009	26	28	26.5	28
15/06/2009	25.5	28	26.5	28
16/06/2009	26	28	26.5	27.5
17/06/2009	26	27.5	26.5	27.5
18/06/2009	26	28	26.5	27.5
19/06/2009	26	28	26.5	27.5
20/06/2009	26	28	26.5	27.5
21/06/2009	26	28	27	28
22/06/2009	26	28	26.5	27.5
23/06/2009	25.5	27.5	26.5	27
24/06/2009	25.5	28	26.5	27.5
25/06/2009	25.5	27	26.5	27.5
26/06/2009	25.5	28	27	28
27/06/2009	26.5	27.5	27.5	28.5
28/06/2009	26.5	28	27	28
29/06/2009	26.5	27.5	27	28
30/06/2009	26.5	27.5	27	28



July indoor temperature inside the 4 case studies				
Time - 13:22- °C	Case No.1	Case No. 2	case no.3	Case NO. 4
01/07/2009	26.5	27.5	27	28
02/07/2009	26.5	28	27.5	28
03/07/2009	26.5	27.5	28	28
04/07/2009	27	27	28.5	28.5
05/07/2009	27.5	27	29	27
06/07/2009	28	28	29.5	29.5
07/07/2009	28.5	27.5	29.5	30.5
08/07/2009	28.5	28.5	30	31.5
09/07/2009	29.5	28.5	30.5	31.5
10/07/2009	30	28	30.5	31.5
11/07/2009	29	28.5	30	31
12/07/2009	29.5	27.5	29.5	30.5
13/07/2009	28.5	28	29.5	30
14/07/2009	28	28	29.5	30
15/07/2009	28.5	27.5	29.5	30
16/07/2009	28	27.5	29.5	29
17/07/2009	28	28	28.5	29
18/07/2009	28.5	28	29.5	29.5
19/07/2009	27.5	27.5	29.5	29.5
20/07/2009	27.5	28	29	29
21/07/2009	27	27	29	28.5
22/07/2009	26.5	27.5	29	28.5
23/07/2009	26.5	27.5	29	29
24/07/2009	26.5	27.5	29	28.5



Appendix 5: Sample of the 24 hours measurements taken in the 4 case studies in September each 1 hour.

Time - /Celsius(0C)	Case No.1	Case No. 2	Case No. 3	Case NO. 4
08/09/2008 23:22	28	27	28	26.5
09/09/2008 00:22	27.5	27	27.5	30.5
09/09/2008 01:22	27	27.5	27	30.5
09/09/2008 02:22	26.5	27.5	26.5	30.5
09/09/2008 03:22	26.5	26.5	26.5	30
09/09/2008 04:22	28	26	28	30
09/09/2008 05:22	28.5	26	28.5	30
09/09/2008 06:22	28.5	27	28.5	29
09/09/2008 07:22	28.5	27	28.5	29
09/09/2008 08:22	28.5	27.5	28.5	29.5
09/09/2008 09:22	29	28	29	30.5
09/09/2008 10:22	30	28.5	30	31
09/09/2008 11:22	29.5	28.5	29.5	30.5
09/09/2008 12:22	28	29	28	31
09/09/2008 13:22	27.5	28	27.5	30
09/09/2008 14:22	27.5	28	27.5	30.5
09/09/2008 15:22	28.5	27.5	28.5	30.5
09/09/2008 16:22	29.5	27.5	29.5	30.5
09/09/2008 17:22	29.5	28	29.5	30.5
09/09/2008 18:22	29.5	28	29.5	30.5
09/09/2008 19:22	29	27.5	29	30.5
09/09/2008 20:22	29	27.5	29	31
09/09/2008 21:22	29	27.5	29	31
09/09/2008 22:22	29	27	29	30.5
09/09/2008 23:22	28.5	27	28.5	30
10/09/2008 00:22	28.5	27	28.5	30
10/09/2008 01:22	28	26.5	28	29
10/09/2008 02:22	27.5	26.5	27.5	28.5
10/09/2008 03:22	27.5	27	27.5	29
10/09/2008 04:22	28	27	28	29
10/09/2008 05:22	28	27	28	29
10/09/2008 06:22	28	27.5	28	28.5
10/09/2008 07:22	28.5	27.5	28.5	28.5
10/09/2008 08:22	29	27	29	29.5
10/09/2008 09:22	29.5	26.5	29.5	30.5
10/09/2008 10:22	29.5	27.5	29.5	30
10/09/2008 11:22	29.5	28.5	29.5	30.5
10/09/2008 12:22	29.5	28.5	29.5	30
10/09/2008 13:22	29.5	28	29.5	30
10/09/2008 14:22	29.5	28	29.5	30
10/09/2008 15:22	29.5	28	29.5	30
10/09/2008 16:22	29.5	28	29.5	30.5
10/09/2008 17:22	29.5	28	29.5	30.5
10/09/2008 18:22	29	28	29	30.5
10/09/2008 19:22	29	27.5	29	30.5
10/09/2008 20:22	29.5	27.5	29.5	30.5
10/09/2008 21:22	29	27.5	29	30.5
10/09/2008 22:22	28	27.5	28	30
10/09/2008 23:22	28	27	28	30
11/09/2008 00:22	28	28	28	30
11/09/2008 01:22	27.5	27.5	27.5	30
11/09/2008 02:22	27.5	27	27.5	30
11/09/2008 03:22	27.5	27	27.5	29.5
11/09/2008 04:22	27.5	27	27.5	29.5
11/09/2008 05:22	27.5	27	27.5	29.5
11/09/2008 06:22	27.5	27	27.5	29
11/09/2008 07:22	27.5	26.5	27.5	29
11/09/2008 08:22	27.5	26.5	27.5	29
11/09/2008 09:22	28.5	26.5	28.5	30
11/09/2008 10:22	29	27.5	29	30.5
11/09/2008 11:22	29.5	28	29.5	31
11/09/2008 12:22	30	28.5	30	31
11/09/2008 13:22	30	29	30	31
11/09/2008 14:22	29.5	28.5	29.5	31.5
11/09/2008 15:22	29.5	28	29.5	30.5
11/09/2008 16:22	29.5	28	29.5	30.5
11/09/2008 17:22	29	28	29	30.5
11/09/2008 18:22	29	28	29	30

Time - /Celsius(0C)	Case No.1	Case No. 2	Case No. 3	Case NO. 4
20/09/2008 00:22	27.5	27	27.5	29
20/09/2008 01:22	27.5	27	27.5	29
20/09/2008 02:22	27	26.5	27	29
20/09/2008 03:22	27	26	27	28.5
20/09/2008 04:22	26	26	26	29
20/09/2008 05:22	26	26	26	29
20/09/2008 06:22	26	26.5	26	28.5
20/09/2008 07:22	25.5	27	25.5	28.5
20/09/2008 08:22	25.5	26.5	25.5	28.5
20/09/2008 09:22	26	26	26	28.5
20/09/2008 10:22	26.5	26.5	26.5	28.5
20/09/2008 11:22	27	27	27	29
20/09/2008 12:22	27	27.5	27	29
20/09/2008 13:22	27	27.5	27	29
20/09/2008 14:22	27	27.5	27	29
20/09/2008 15:22	27	27.5	27	29
20/09/2008 16:22	27	27	27	29
20/09/2008 17:22	27	27	27	29
20/09/2008 18:22	27	27	27	29
20/09/2008 19:22	27	27	27	28.5
20/09/2008 20:22	27	26.5	27	28.5
20/09/2008 21:22	27	26.5	27	28.5
20/09/2008 22:22	26	26.5	26	28.5
20/09/2008 23:22	26.5	27	26.5	28.5
21/09/2008 00:22	26.5	27	26.5	28.5
21/09/2008 01:22	26.5	26.5	26.5	28.5
21/09/2008 02:22	26	27	26	28.5
21/09/2008 03:22	26	26	26	28
21/09/2008 04:22	26.5	26	26.5	27.5
21/09/2008 05:22	26.5	26	26.5	27.5
21/09/2008 06:22	26.5	26.5	26.5	27.5
21/09/2008 07:22	27	26.5	27	27.5
21/09/2008 08:22	27	26.5	27	27.5
21/09/2008 09:22	26.5	26.5	26.5	28.5
21/09/2008 10:22	26.5	26.5	26.5	28.5
21/09/2008 11:22	27	27	27	28.5
21/09/2008 12:22	26.5	27.5	26.5	28.5
21/09/2008 13:22	26.5	27	26.5	28.5
21/09/2008 14:22	27	26.5	27	28.5
21/09/2008 15:22	26.5	26.5	26.5	28.5
21/09/2008 16:22	27	26.5	27	28.5
21/09/2008 17:22	27.5	26.5	27.5	28.5
21/09/2008 18:22	28.5	27	28.5	28.5
21/09/2008 19:22	27	27	27	28.5
21/09/2008 20:22	26.5	27	26.5	28.5
21/09/2008 21:22	26.5	27	26.5	28.5
21/09/2008 22:22	27	27	27	28
21/09/2008 23:22	26.5	27	26.5	28
22/09/2008 00:22	26.5	27	26.5	28
22/09/2008 01:22	26	27	26	27
22/09/2008 02:22	26.5	27	26.5	26.5
22/09/2008 03:22	26	26	26	26
22/09/2008 04:22	25.5	26	25.5	25.5
22/09/2008 05:22	26.5	26	26.5	25.5
22/09/2008 06:22	27	26.5	27	25
22/09/2008 07:22	26.5	26.5	26.5	25
22/09/2008 08:22	27	26	27	26.5
22/09/2008 09:22	27	26	27	28.5
22/09/2008 10:22	27.5	26	27.5	29
22/09/2008 11:22	27.5	26	27.5	28
22/09/2008 12:22	28	27	28	28
22/09/2008 13:22	27.5	27.5	27.5	28.5
22/09/2008 14:22	27.5	27.5	27.5	28.5
22/09/2008 15:22	28	28	28	28.5
22/09/2008 16:22	28	27.5	28	28.5
22/09/2008 17:22	28	27.5	28	28
22/09/2008 18:22	27.5	27	27.5	28
22/09/2008 19:22	27	27	27	28.5

11/09/2008 19:22	28.5	27.5	28.5	30
11/09/2008 20:22	28.5	27.5	28.5	30
11/09/2008 21:22	28.5	27.5	28.5	30
11/09/2008 22:22	28.5	28	28.5	29.5
11/09/2008 23:22	28.5	28.5	28.5	29.5
12/09/2008 00:22	28.5	27.5	28.5	29.5
12/09/2008 01:22	28.5	27	28.5	29.5
12/09/2008 02:22	28.5	27	28.5	29.5
12/09/2008 03:22	28.5	27	28.5	29.5
12/09/2008 04:22	28	27	28	29.5
12/09/2008 05:22	28	27	28	29
12/09/2008 06:22	28	27.5	28	28.5
12/09/2008 07:22	28	27.5	28	27.5
12/09/2008 08:22	28.5	27	28.5	28.5
12/09/2008 09:22	29	27	29	30
12/09/2008 10:22	29.5	27	29.5	30
12/09/2008 11:22	30	27	30	30
12/09/2008 12:22	30	28	30	29.5
12/09/2008 13:22	29.5	28	29.5	29.5
12/09/2008 14:22	30	28	30	29.5
12/09/2008 15:22	28.5	27.5	28.5	30
12/09/2008 16:22	28.5	28	28.5	30
12/09/2008 17:22	28	28	28	30.5
12/09/2008 18:22	28.5	28.5	28.5	30
12/09/2008 19:22	28	27.5	28	30
12/09/2008 20:22	28.5	28	28.5	30
12/09/2008 21:22	28	27.5	28	30
12/09/2008 22:22	28.5	27	28.5	30
12/09/2008 23:22	28.5	27	28.5	30
13/09/2008 00:22	28.5	27	28.5	30
13/09/2008 01:22	29	27.5	29	29.5
13/09/2008 02:22	28	27	28	29.5
13/09/2008 03:22	27.5	27.5	27.5	29.5
13/09/2008 04:22	27.5	27.5	27.5	29
13/09/2008 05:22	27.5	27	27.5	29
13/09/2008 06:22	27.5	27.5	27.5	29
13/09/2008 07:22	27	28	27	29
13/09/2008 08:22	27	27.5	27	29.5
13/09/2008 09:22	27.5	27.5	27.5	29.5
13/09/2008 10:22	29.5	27	29.5	29.5
13/09/2008 11:22	30.5	27.5	30.5	29.5
13/09/2008 12:22	30.5	27.5	30.5	29.5
13/09/2008 13:22	29.5	27	29.5	29.5
13/09/2008 14:22	29	27.5	29	29.5
13/09/2008 15:22	28	27	28	30
13/09/2008 16:22	30	27.5	30	30.5
13/09/2008 17:22	29	27.5	29	30.5
13/09/2008 18:22	29	27.5	29	30.5
13/09/2008 19:22	29	27	29	30.5
14/09/2008 00:22	29	28	29	30
14/09/2008 01:22	29	27.5	29	30
14/09/2008 02:22	29	27.5	29	29.5
14/09/2008 03:22	29	27.5	29	29
14/09/2008 04:22	29	27.5	29	29
14/09/2008 05:22	28.5	27	28.5	28.5
14/09/2008 06:22	28.5	27	28.5	29.5
14/09/2008 07:22	29	27	29	29.5
14/09/2008 08:22	29	27	29	30
14/09/2008 09:22	29	27	29	30
14/09/2008 10:22	29.5	27.5	29.5	30
14/09/2008 11:22	29.5	27.5	29.5	30
14/09/2008 12:22	30	27.5	30	30.5
14/09/2008 13:22	30	27.5	30	30.5
14/09/2008 14:22	30	27.5	30	30.5
14/09/2008 15:22	30	27.5	30	30.5
14/09/2008 16:22	29.5	27.5	29.5	30.5
14/09/2008 17:22	29	27.5	29	30.5
14/09/2008 18:22	30	27.5	30	30.5
14/09/2008 19:22	30	27.5	30	30.5
14/09/2008 20:22	29.5	27	29.5	30
14/09/2008 21:22	29	27	29	30
14/09/2008 22:22	29	27	29	30
14/09/2008 23:22	29	27.5	29	29.5

22/09/2008 20:22	27	26.5	27	28.5
22/09/2008 21:22	27	27	27	28
22/09/2008 22:22	26.5	27.5	26.5	28
22/09/2008 23:22	26.5	27.5	26.5	28.5
23/09/2008 00:22	26.5	27	26.5	28
23/09/2008 01:22	26	27	26	28
23/09/2008 02:22	26.5	27	26.5	28
23/09/2008 03:22	26.5	26.5	26.5	28
23/09/2008 04:22	25.5	26	25.5	28
23/09/2008 05:22	25	26	25	28
23/09/2008 06:22	24.5	26.5	24.5	28
23/09/2008 07:22	25	26.5	25	28
23/09/2008 08:22	25.5	26.5	25.5	28
23/09/2008 09:22	26.5	26.5	26.5	28.5
23/09/2008 10:22	27	26.5	27	28.5
23/09/2008 11:22	27.5	27	27.5	28.5
23/09/2008 12:22	27.5	27	27.5	28.5
23/09/2008 13:22	27.5	27.5	27.5	28.5
23/09/2008 14:22	27	27	27	29.5
23/09/2008 15:22	26.5	27.5	26.5	30
23/09/2008 16:22	27	28	27	29
23/09/2008 17:22	26.5	27.5	26.5	29
23/09/2008 18:22	27	27.5	27	29
23/09/2008 19:22	27	27	27	29
23/09/2008 20:22	26.5	26.5	26.5	29
23/09/2008 21:22	26.5	27	26.5	29
23/09/2008 22:22	26.5	27	26.5	29
23/09/2008 23:22	26.5	27	26.5	29
24/09/2008 00:22	27	27	27	29
24/09/2008 01:22	26.5	27	26.5	29
24/09/2008 02:22	26.5	27	26.5	28.5
24/09/2008 03:22	26	27	26	28.5
24/09/2008 04:22	26	27	26	28.5
24/09/2008 05:22	26	27	26	28.5
24/09/2008 06:22	26	27	26	28.5
24/09/2008 07:22	26	27	26	28.5
24/09/2008 08:22	26.5	26.5	26.5	28.5
24/09/2008 09:22	26	26.5	26	29
24/09/2008 10:22	26.5	26.5	26.5	29.5
24/09/2008 11:22	27	26.5	27	29
24/09/2008 12:22	27.5	27.5	27.5	29
24/09/2008 13:22	27.5	27.5	27.5	29
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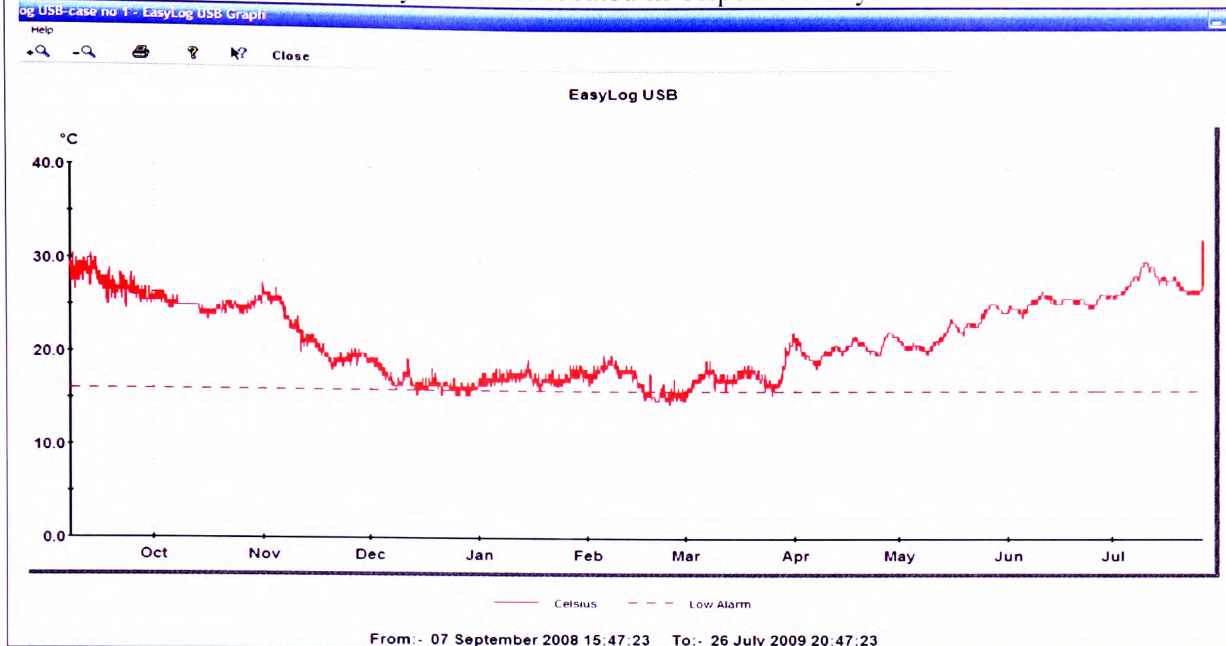
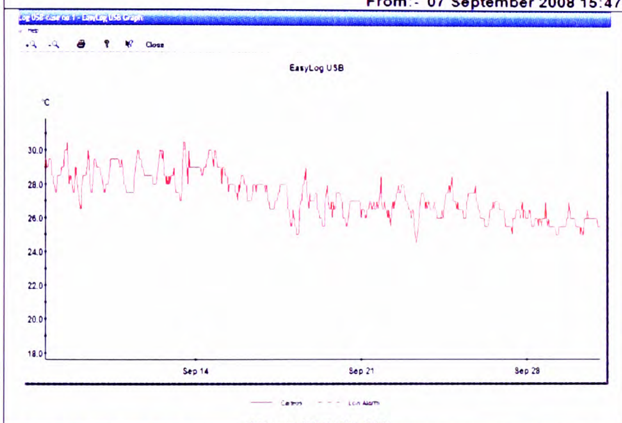
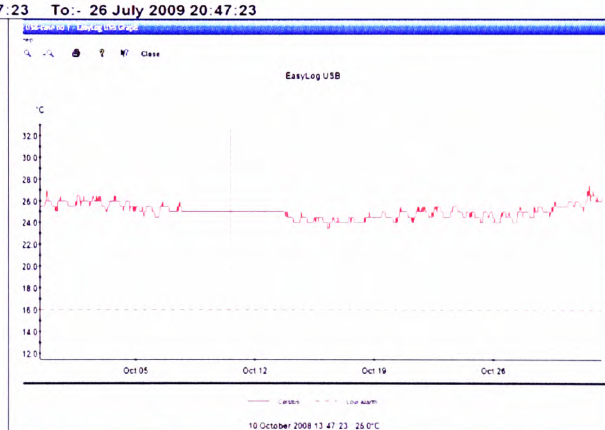
01/10/2008 23:22	26	26.5	26	27
01/10/2008 00:22	25.5	26.5	25.5	27

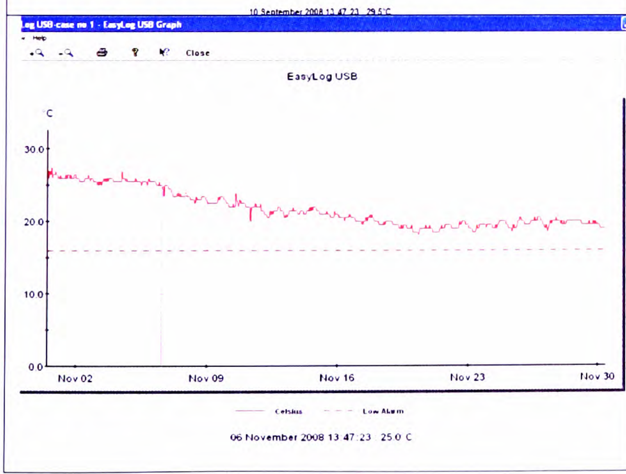
Appendix 6: Internal temperature measurements for the 4 case studies- extra data not included in the analysis in chapter 6

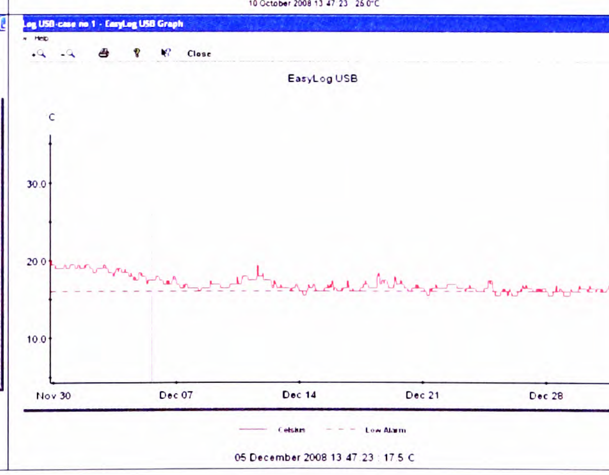
Case study 1 – Covered courtyard house located in Tripoli old city

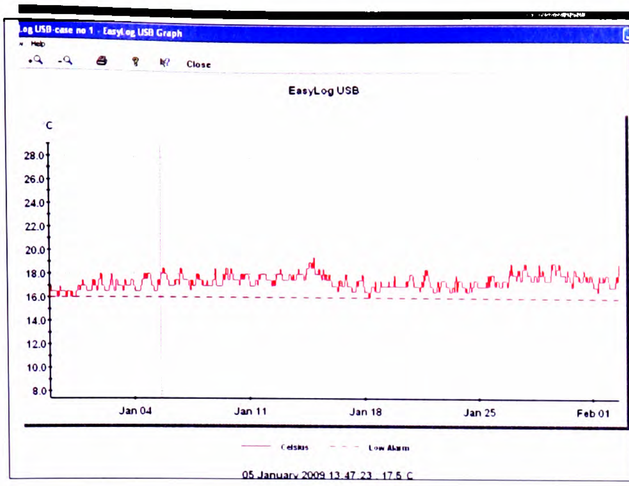








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Jan 18
Jan 25
Feb 01
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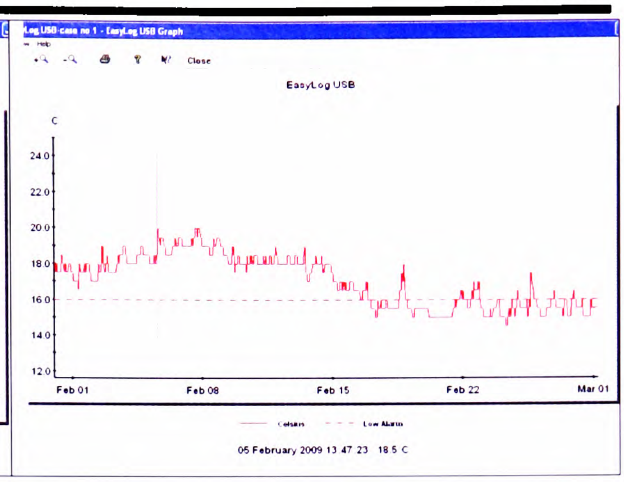
Low Alarm
05 January 2009 13 47 23 17.5 C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Mar 01
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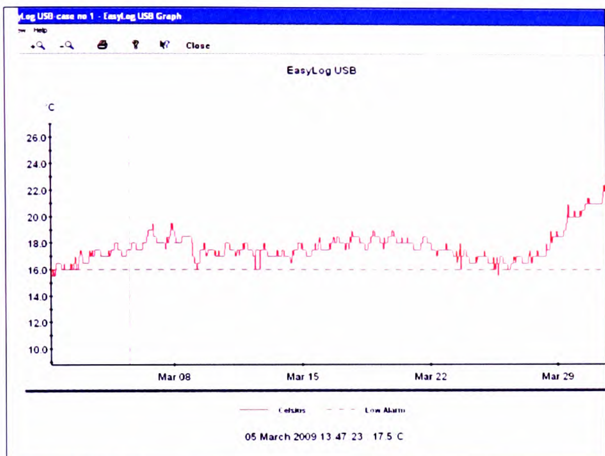
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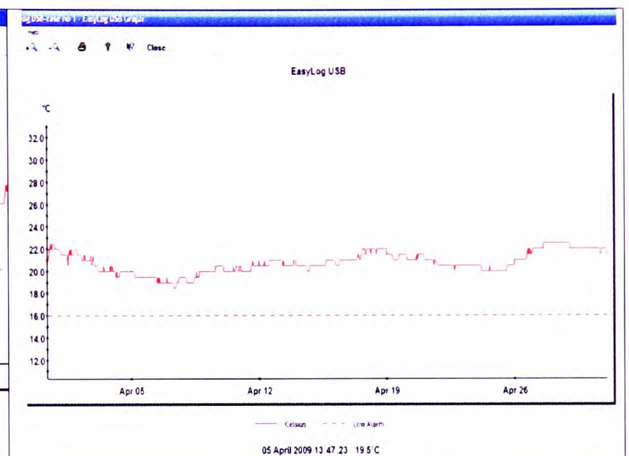
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Apr 19
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Low Alarm
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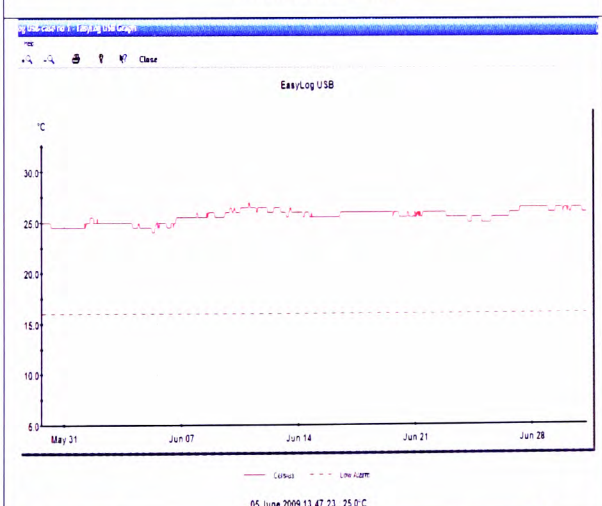
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Jun 07
Jun 14
Jun 21
Jun 28
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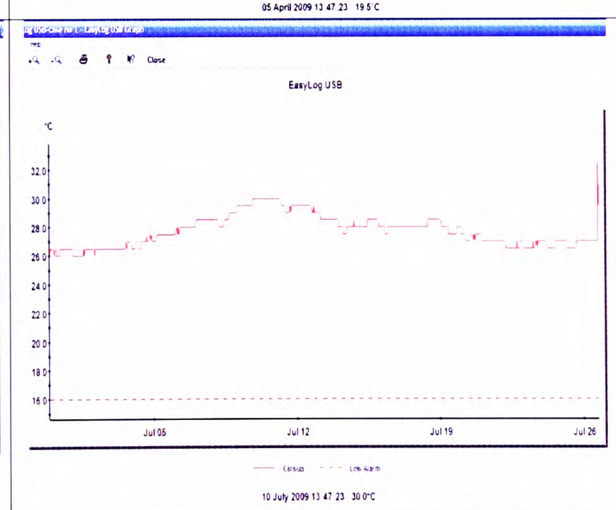
05 June 2009 13 47 23 25.0°C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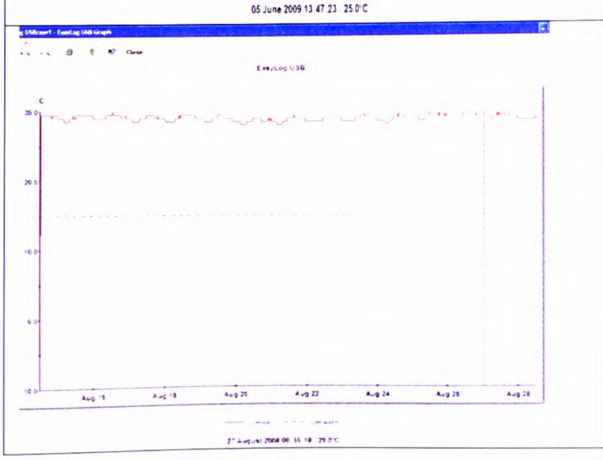
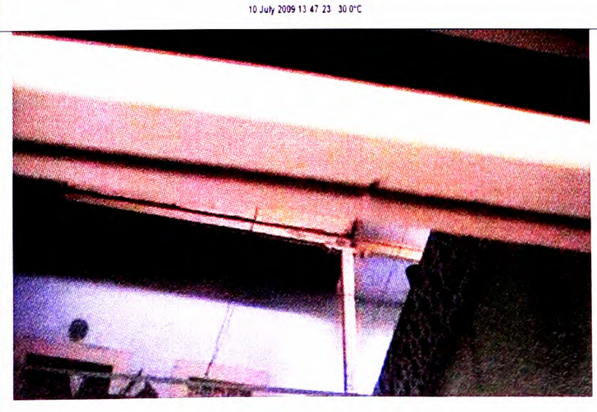
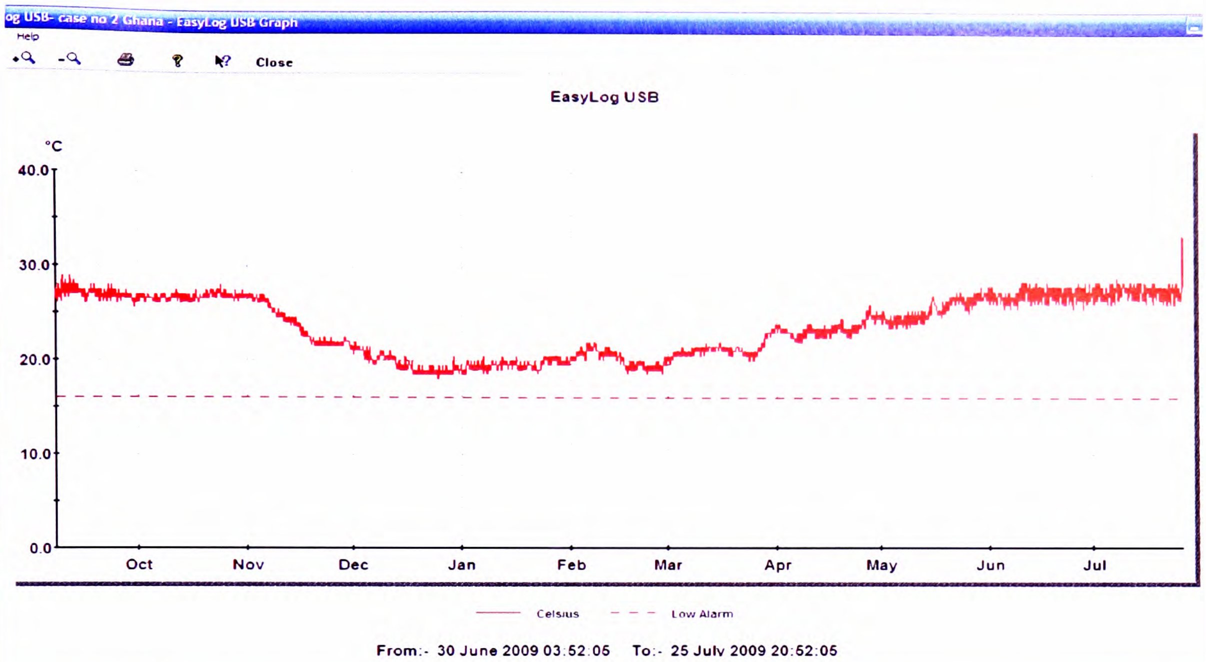
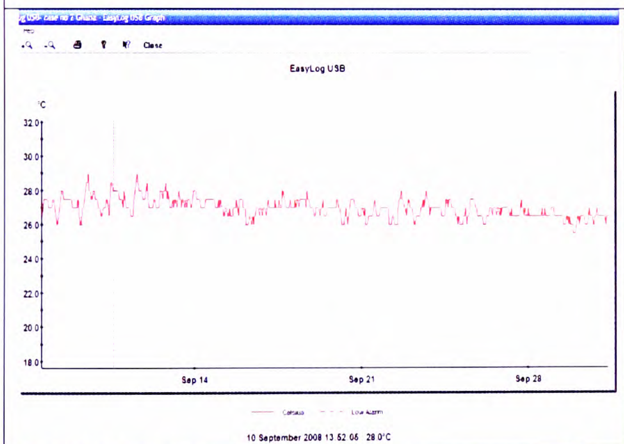
10 July 2009 13 47 23 30.0°C

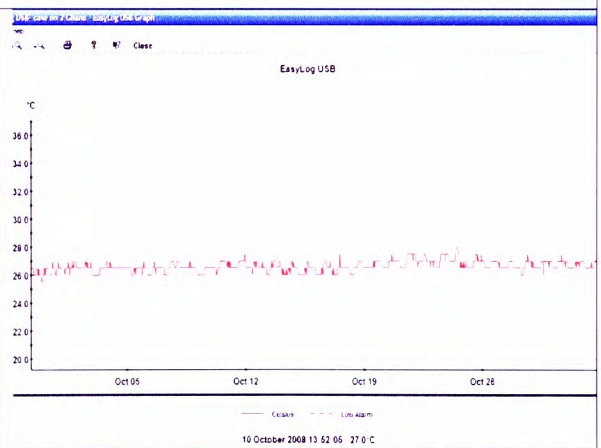


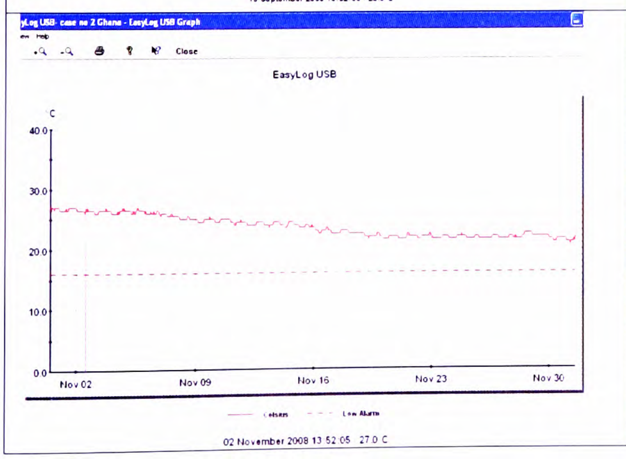


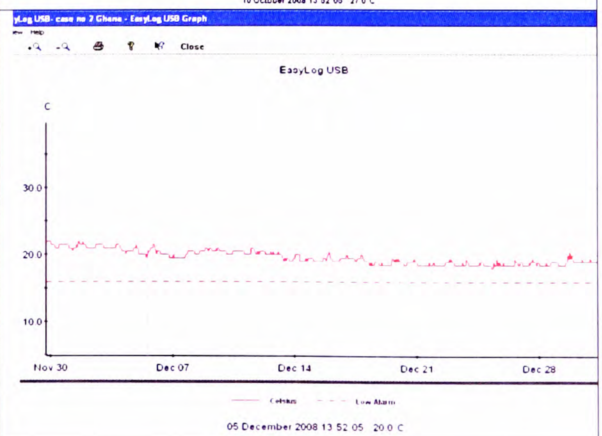
Case study 2 – Open courtyard house located in Tripoli old city

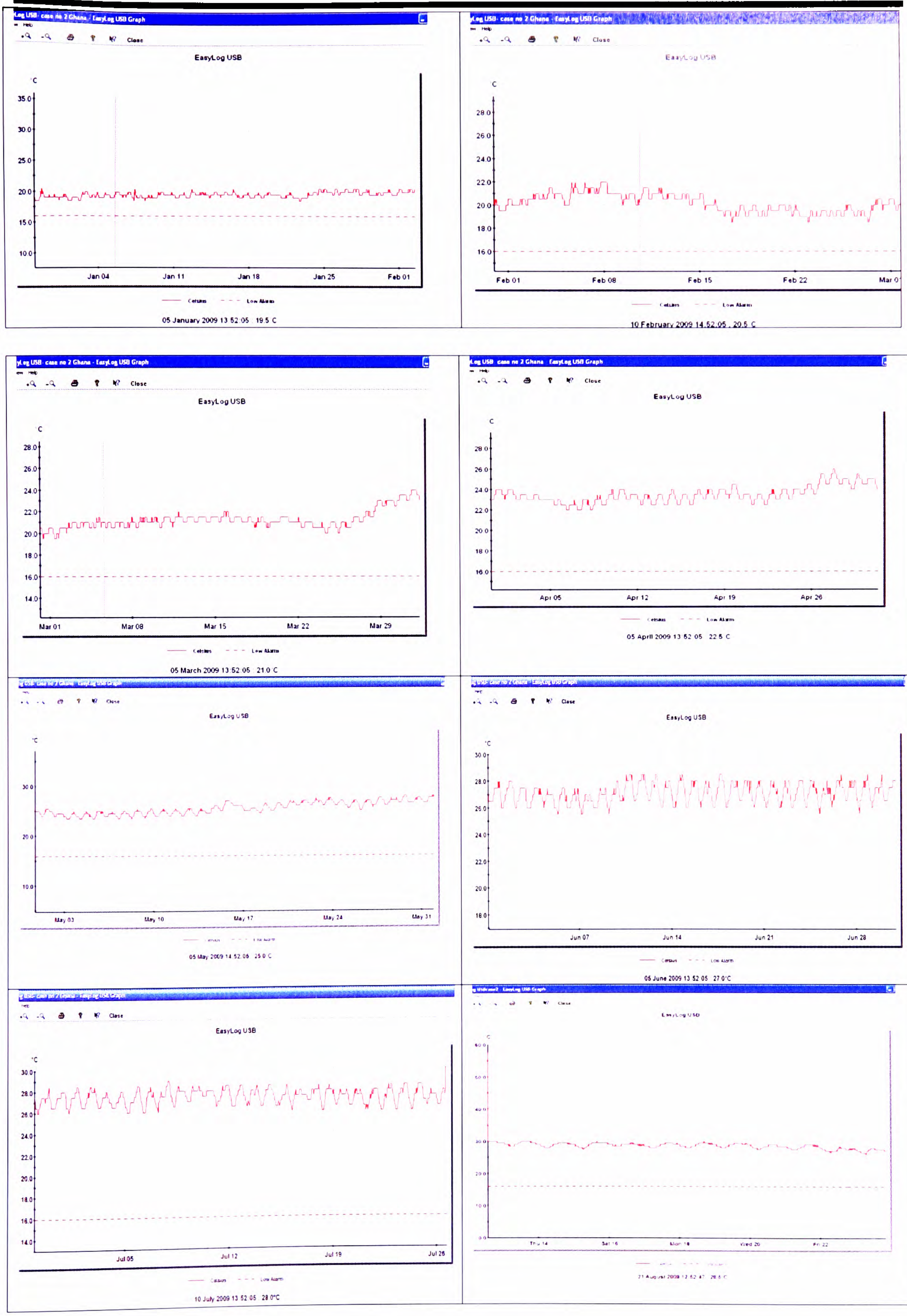


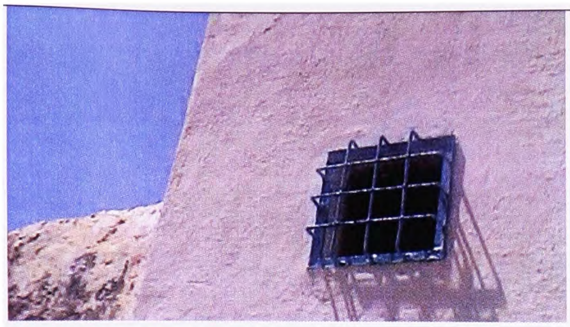








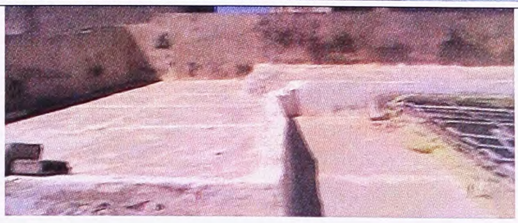

EasyLog USB
05 January 2009 13:52:05 19.5 C
EasyLog USB
10 February 2009 14:52:05 20.5 C
EasyLog USB
05 March 2009 13:52:05 21.0 C
EasyLog USB
05 April 2009 13:52:05 22.5 C
EasyLog USB
05 May 2009 14:52:05 25.0 C
EasyLog USB
05 June 2009 13:52:05 27.0°C
EasyLog USB
10 July 2009 13:52:05 28.0°C



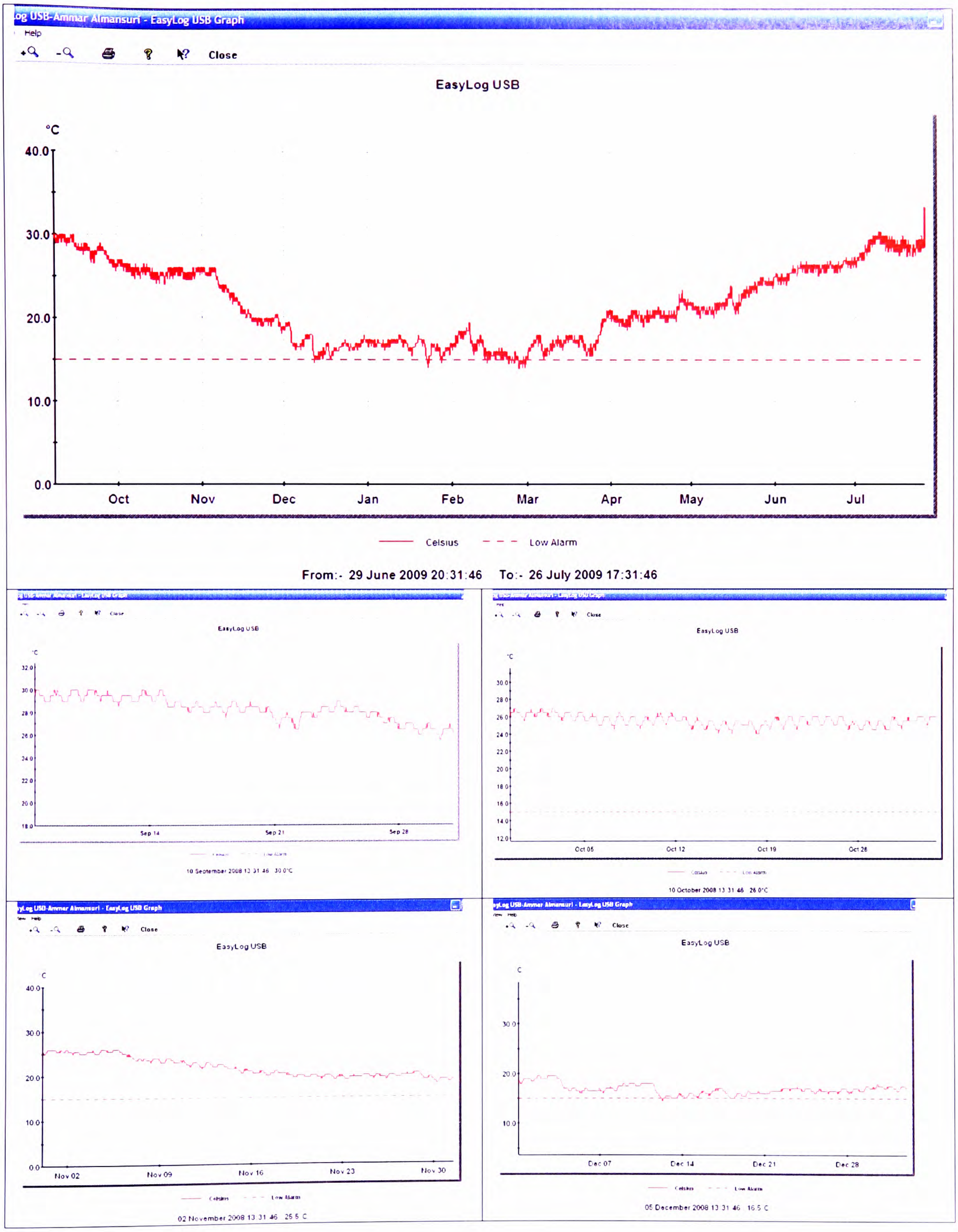


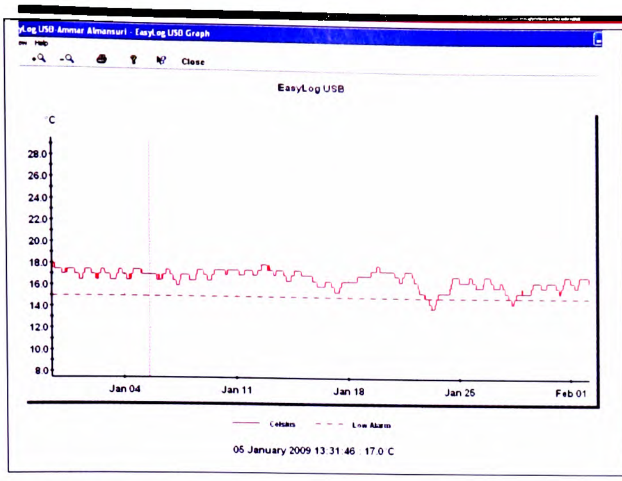




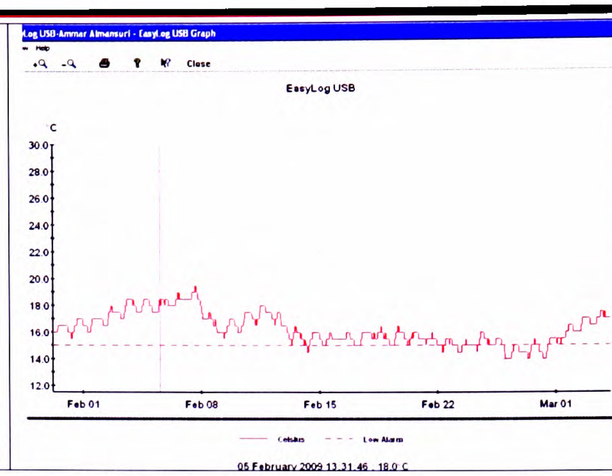



Case study 3 –attached house located in Tripoli contemporary area

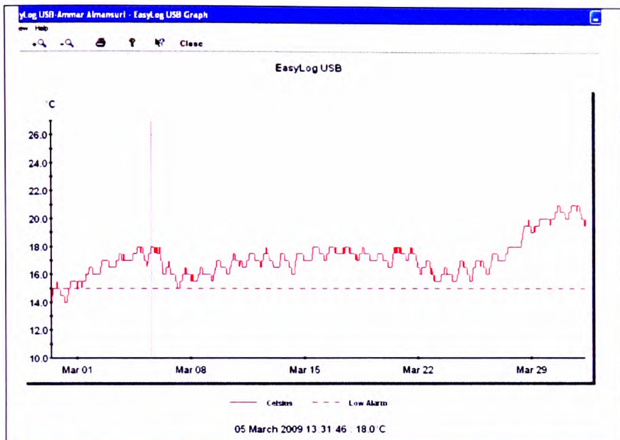




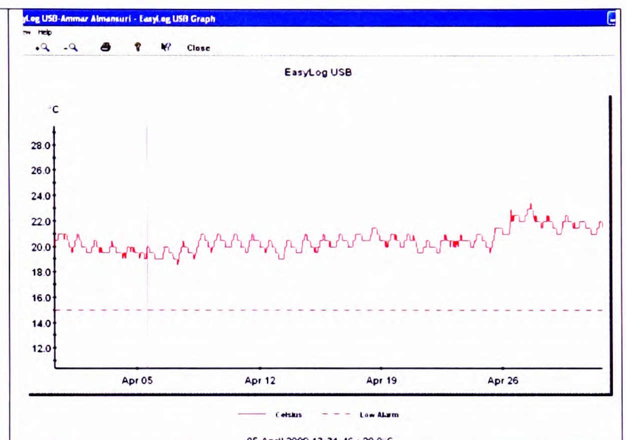
EasyLog USB
°C
Jan 04
Jan 11
Jan 18
Jan 25
Feb 01
Celsius
Low Alarm
05 January 2009 13:31:46 : 17.0 C



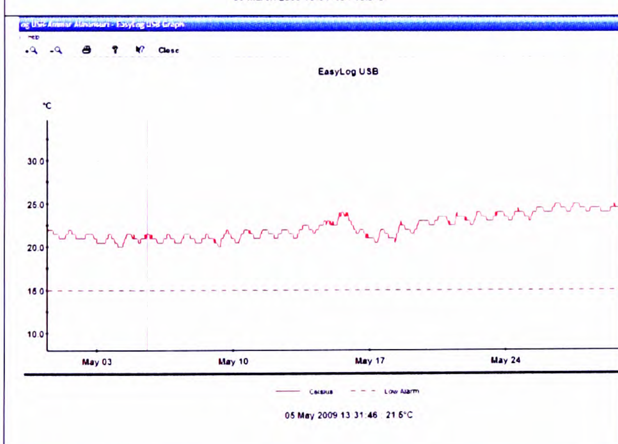
EasyLog USB
°C
Feb 01
Feb 08
Feb 15
Feb 22
Mar 01
Celsius
Low Alarm
05 February 2009 13:31:46 : 18.0 C



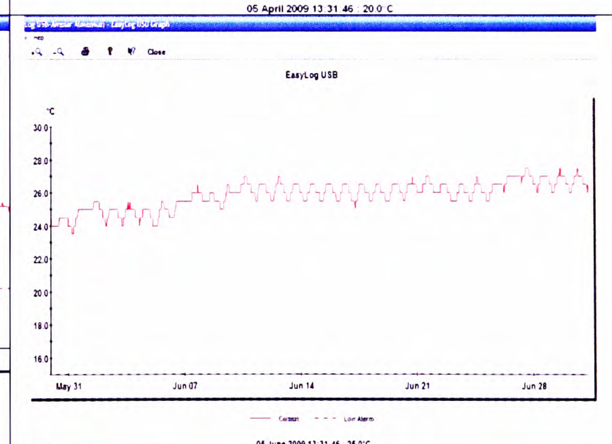
EasyLog USB
°C
Mar 01
Mar 08
Mar 15
Mar 22
Mar 29
Celsius
Low Alarm
05 March 2009 13:31:46 : 18.0 C



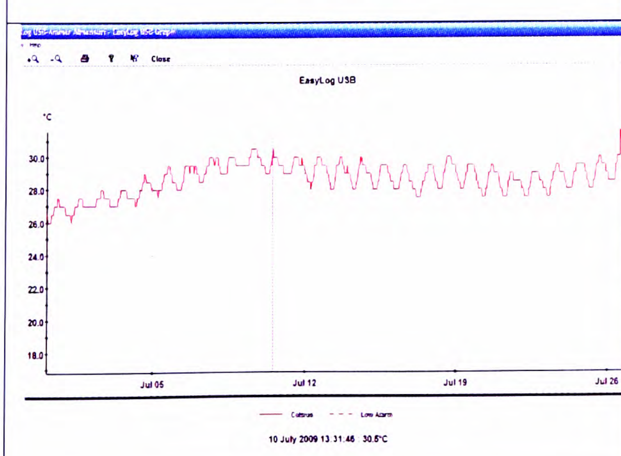
EasyLog USB
°C
Apr 05
Apr 12
Apr 19
Apr 26
Celsius
Low Alarm
05 April 2009 13:31:46 : 20.0 C



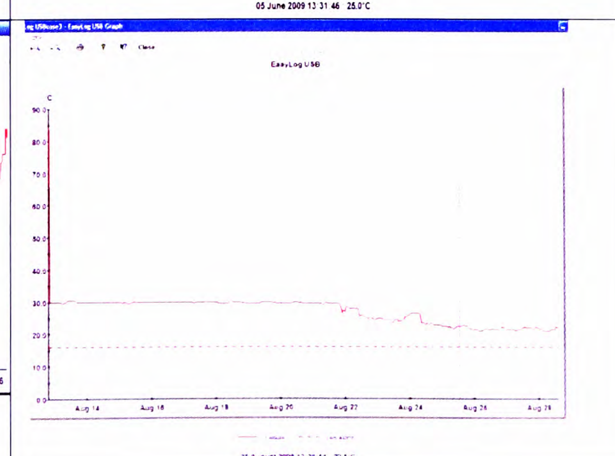
EasyLog USB
°C
May 03
May 10
May 17
May 24
Celsius
Low Alarm
05 May 2009 13:31:46 : 21.5°C



EasyLog USB
°C
May 31
Jun 07
Jun 14
Jun 21
Jun 28
Celsius
Low Alarm
05 June 2009 13:31:46 : 25.0°C

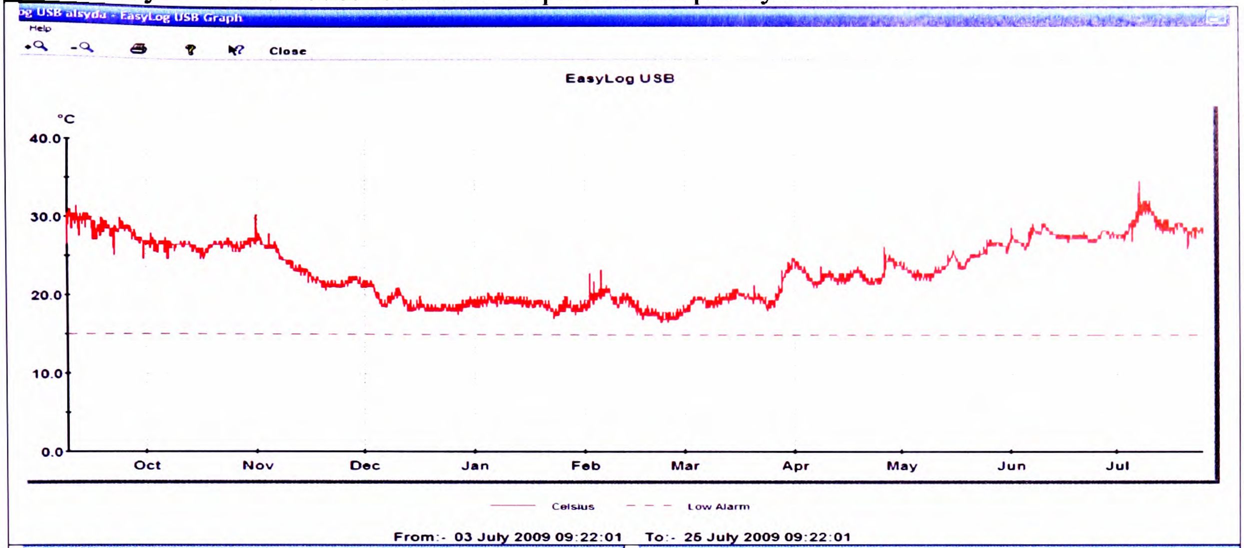


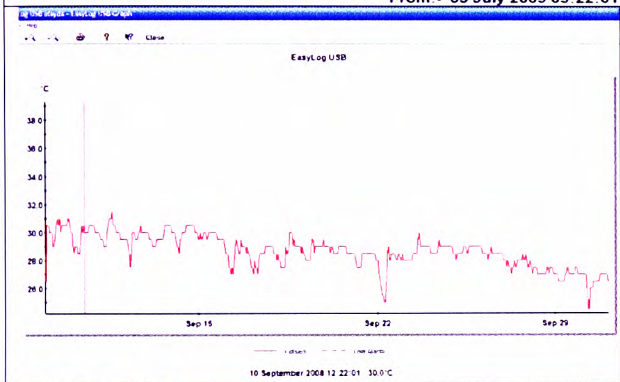
EasyLog USB
°C
Jul 05
Jul 12
Jul 19
Jul 26
Celsius
Low Alarm
10 July 2009 13:31:46 : 30.5°C

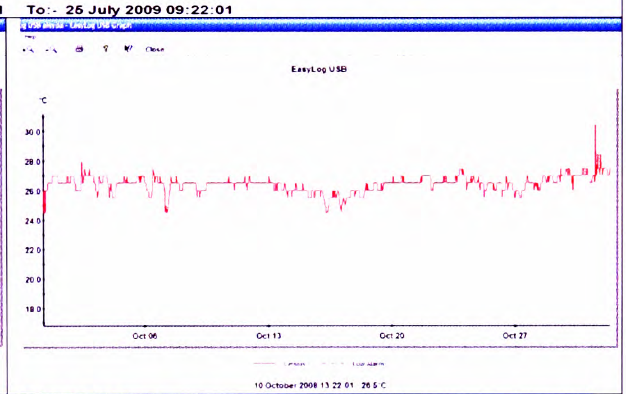


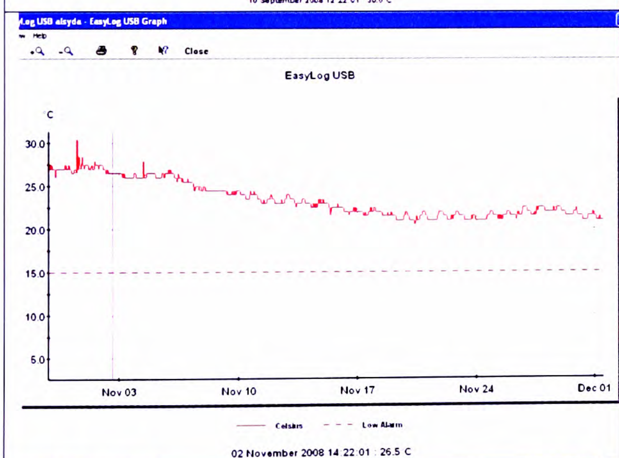
EasyLog USB

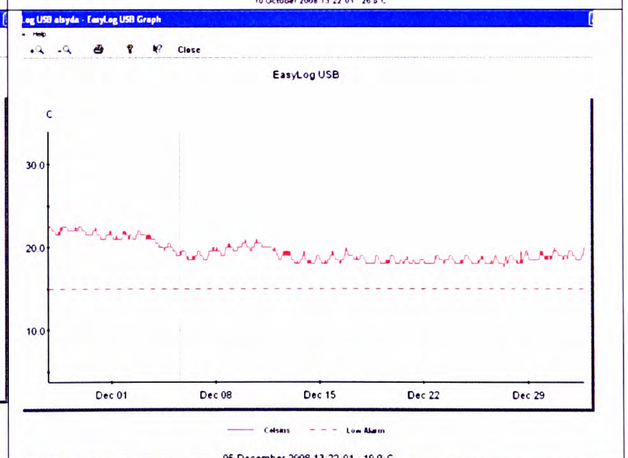
Case study 4 – Villa house located in Tripoli contemporary area

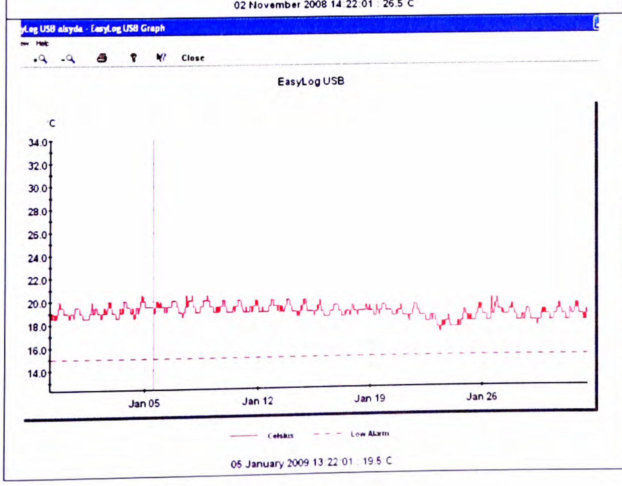


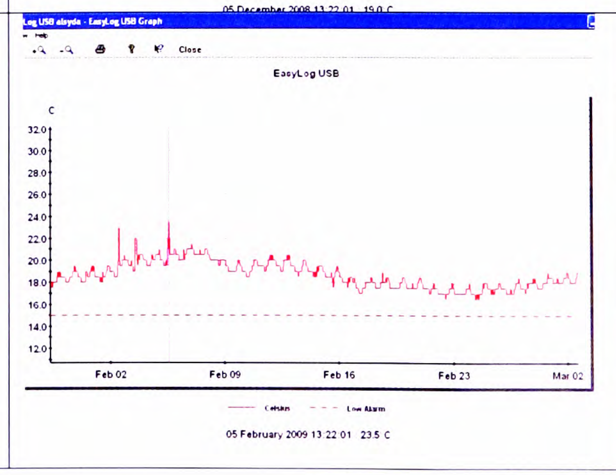


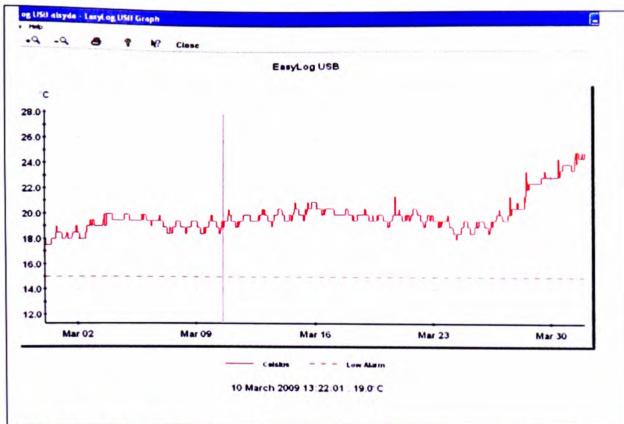


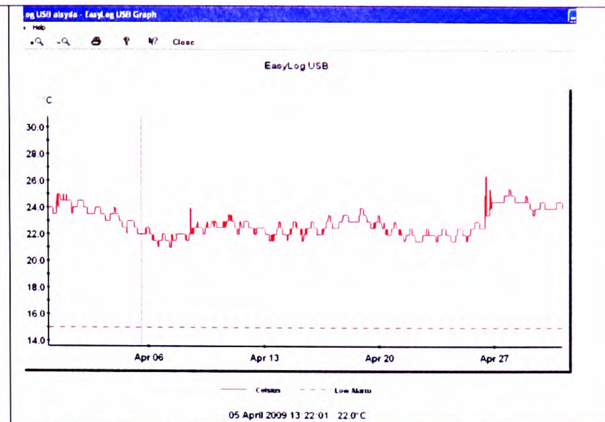


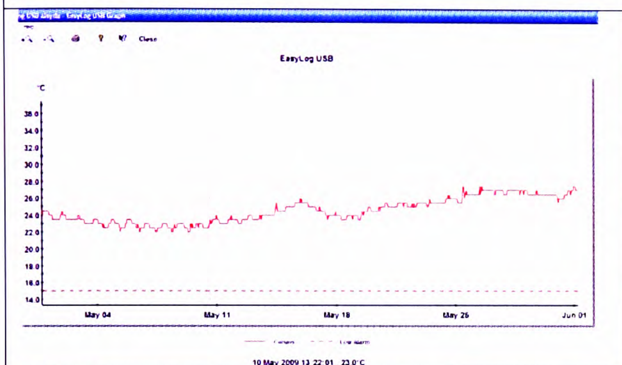


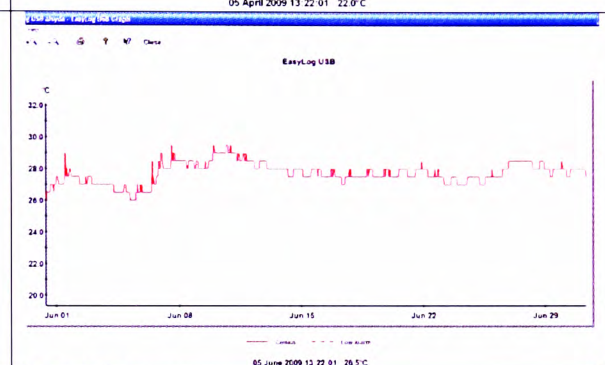


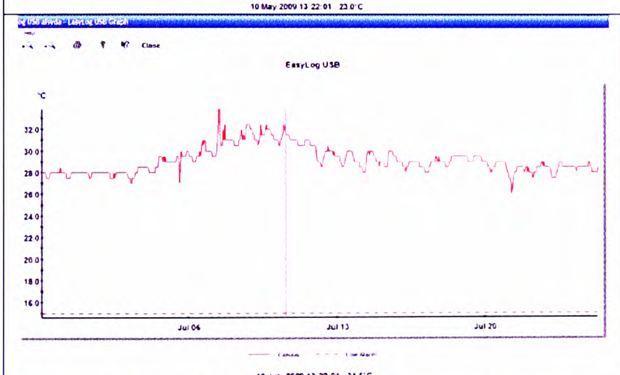


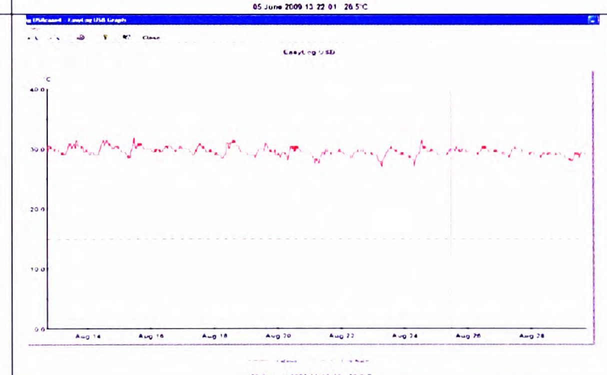

EasyLog USB
°C
Mar 02
Mar 09
Mar 16
Mar 23
Mar 30
Celsius
Low Alarm
10 March 2009 13:22:01 : 19.0°C


EasyLog USB
°C
Apr 06
Apr 13
Apr 20
Apr 27
05 April 2009 13:22:01 : 22.0°C


EasyLog USB
°C
May 04
May 11
May 18
May 25
Jun 01
10 May 2009 13:22:01 : 23.0°C


EasyLog USB
°C
Jun 01
Jun 08
Jun 15
Jun 22
Jun 29


EasyLog USB
°C
Jul 06
Jul 13
Jul 20
10 July 2009 13:22:01 : 31.5°C



Appendix 7: Tripoli temperature variations measured during two years (2008-2009)

January/2008

النهاية العظمى والصغرى لدرجة الحرارة بالدرجة المئوية (°C)

الصغرى (min.)	العظمى (max.)	المدى	الصغرى (حشائش)	التاريخ
104 (101)	160	56		1
097	158	61		2
065	173	108		3
075	195	120		4
100	174	74		5
083	183	100		6
064	179	115		7
105	160	55		8
105	182	77		9
120	166	046		10
110	176	066		11
107	175	068		12
092	188	096		13
080	192	112		14
084	196	112		15
080	197	117		16
110 8.0	158	048		17
120	147	027		18
125	171	046		19
112	174	062		20
096	160	064		21
085	170	085		22
105	157	052		23
100	145	045		24
110	170	060		25
108	156	048		26
090	159	069		27
093	188 153	059		28
100	170	070		29
075	185	110		30
080	188	108		31
2952	5342	2356		المجموع
.95	17.2	076		المتوسط

متوسط العظمى + الصغرى / 2

13

المتوسط 13.4

February 2008

النهاية العظمى والصغرى لدرجة الحرارة بالدرجة المئوية (°C)

الصغرى (min.)	العظمى (max.)	المدى	الصغرى (حشائش)	التاريخ
8.1	20.2	09.2		1
8.3	20.5	11.0		2
6.8	19.5	07.7		3
2.0	19.5	07.6		4
7.0	20.4	10.1		5
03.3	16.7	09.9		6
07.3	16.5	07.2		7
11.0	11.4	00.4		8
10.3	13.0	02.2		9
09.0	14.1	05.1		10
07.4	14.0	06.6		11
05.0	16.0	11.0		12
04.5	16.8	12.3		13
03.5	15.1	11.6		14
09.2	21.0	11.8		15
10.3	16.0	06.3		16
08.5	14.4	05.9		17
06.5	12.8	06.3		18
03.5	16.0	12.5		19
06.4	19.6	13.2		20
9.9	20.0	10.5		21
09.3	21.0	11.7		22
09.0	18.3	09.3		23
07.8	20.0	12.2		24
07.8	20.2	12.2		25
09.0	20.5	11.8		26
7.3	21.8	14.3		27
10.5	19.5	09.0		28
07.7	18.0	10.3		29
				30
				31
2331	5261	277.7		المجموع
08.0	18.1	09.5		المتوسط

المتوسط = 13.1

13

March 2008

(°C)

الصغرى (min.)	العظمى (max.)	المدى	الصغرى (حشائش)	التاريخ
07.0	18.2	11.2		1
09.5	21.0	11.5		2
09.4	25.0	15.6		3
11.4	23.3	11.9		4
11.8	26.5	15.7		5
10.0	15.5	05.5		6
06.8	17.4	10.6		7
06.6	19.5	13.3		8
05.8	18.5	12.7		9
08.1	20.1	12.0		10
10.1	22.4	12.3		11
08.7	20.0	11.3		12
11.0	21.8	10.8		13
09.1	24.0	14.9		14
14.5	31.0	16.5		15
16.5	31.0	14.5		16
13.2	21.0	07.8		17
10.8	30.0	19.2		18
16.2	28.7	12.6		19
15.5	24.5	09.0		20
13.0	15.4	02.4		21
08.5	29.8	21.3		22
11.8	25.5	13.7		23
13.2	20.0	06.8		24
11.0	22.5	11.5		25
09.1	22.2	13.1		26
11.5	26.8	15.3		27
10.7	21.8	11.1		28
11.4	18.2	06.8		29
08.0	19.9	11.9		30
11.0	26.5	15.5		31
324.8	709.1	385.3		المجموع
10.5	22.9	12.4		المتوسط

16.7

13

April 2008

النهاية العظمى والصغرى لدرجة الحرارة بالدرجة المئوية (°C)

الصغرى (min.)	العظمى (max.)	المدى	الصغرى (حشائش)	التاريخ
10.6	19.0	08.4		1
07.5	18.0	10.5		2
08.4	20.7	12.3		3
09.8	20.0	10.2		4
11.8	16.7	04.9		5
08.0	23.5	15.5		6
10.2	34.2	24.0		7
19.5	36.5	17.0		8
17.8	35.0	17.2		9
20.2	38.5	18.3		10
23.0	41.0	18.0		11
16.4	26.8	10.4		12
15.6	20.8	05.2		13
11.5	18.4	06.9		14
09.4	21.7	12.3		15
11.5	27.6	16.1		16
17.8	34.4	16.6		17
15.4	32.7	17.3		18
24.5	41.8	17.3		19
12.2	24.9	12.7		20
16.0	27.8	11.8		21
14.0	22.0	08.0		22
10.2	24.4	14.2		23
10.2	24.0	13.8		24
12.9	21.7	08.8		25
12.9	21.0	08.1		26
11.8	21.0	09.2		27
09.2	20.6	11.4		28
12.0	32.6	20.6		29
20.2	33.3	13.1		30
				31
4155	8056	3901		المجموع
13.9	26.9	13.00		المتوسط

المتوسط = 20.4

13

May 2008

النهاية العظمى والصغرى لدرجة الحرارة بالدرجة المئوية (°C)

الصغرى (min.)	العظمى (max.)	المدى	الصغرى (حشائش)	التاريخ
23.0	35.5	10.8		1
17.7	26.0	08.3		2
16.8	21.8	05.0		3
15.0	25.5	10.5		4
14.5	27.0	12.5		5
16.5	26.5	02.7		6
14.5	27.5	13.0		7
16.4	26.0	09.6		8
18.2	33.5	15.3		9
18.4	26.6	08.2		10
17.0	23.4	06.4		11
17.2	25.2	07.9		12
17.0	27.0	10.0		13
13.4	25.2	11.8		14
14.6	31.7	17.1		15
17.4	36.0	18.6		16
22.8	41.5	18.7		17
23.6	33.4	09.8		18
19.6	33.6	14.0		19
16.8	30.2	13.4		20
16.7	30.2	13.5		21
15.0	24.5	14.5		22
16.6	33.2	16.6		23
17.0	35.0	18.0		24
22.0	36.8	14.8		25
23.0	38.0	15.0		26
26.5	42.8	16.3		27
28.0	44.6	16.6		28
20.0	33.0	13.0		29
18.9	25.3	09.4		30
17.5	31.8	14.3		31
5722	9563	3854		المجموع
18.4	31.2	12.4		المتوسط

المتوسط = 24.8

13

June 2008

النهاية العظمى والصغرى لدرجة الحرارة بالدرجة المئوية (°C)

الصغرى (min.)	العظمى (max.)	المدى	الصغرى (حشائش)	التاريخ
18.4	36.0	17.6		1
21.7	35.0	13.3		2
19.6	24.2	04.6		3
17.2	25.3	08.1		4
18.4	28.8	10.4		5
17.6	28.0	10.4		6
18.1	25.4	03.5		7
15.2	26.3	11.1		8
20.0	27.2	07.2		9
19.0	28.5	09.5		10
20.4	27.6	07.2		11
20.0	31.5	11.5		12
20.6	25.1	04.7		13
18.8	28.7	09.9		14
18.6	33.2	14.6		15
22.0	39.0	17.0		16
27.0	42.2	15.2		17
24.5	45.5	21.0		18
21.8	26.9	05.1		19
19.8	26.3	06.5		20
15.5	24.0	08.5		21
19.4	29.6	10.2		22
20.0	31.4	11.4		23
19.8	34.4	14.6		24
19.0	33.7	14.7		25
18.2	34.2	15.0		26
18.4	34.2	15.8		27
22.4	31.5	09.1		28
22.2	31.7	09.5		29
23.4	35.0	11.6		30
				31
6002	9336	3288		المجموع
20.0	31.1	11.0		المتوسط

المتوسط = 25.6

13 11.2

July 2008

الصغرى (min.)	العظمى (max.)	المدى	الصغرى (مشتش)	التاريخ
النهاية العظمى والصغرى لدرجة الحرارة بالدرجة المئوية (°C)				
25.0	36.3	11.3		1
23.2	31.0	07.8		2
21.3	34.5	13.2		3
22.6	36.0	13.4		4
24.0	36.0	12.0		5
19.6	35.0	15.4		6
21.5	37.8	16.3		7
25.7	40.5	14.8		8
25.6	38.8	13.2		9
23.5	36.6	13.1		10
25.3	37.6	12.3		11
24.6	41.4	16.8		12
25.5	45.1	16.6		13
27.0	38.6	11.6		14
25.2	34.2	09.0		15
25.4	30.5	05.1		16
23.5	32.5	09.0		17
23.2	35.2	12.0		18
24.5	40.2	15.7		19
24.5	32.0	07.5		20
23.0	31.6	08.6		21
23.6	31.4	07.8		22
24.5	28.6	04.1		23
20.5	30.0	09.5		24
19.5	36.0	16.5		25
25.5	41.2	15.7		26
23.6	30.3	06.7		27
22.8	30.7	07.9		28
21.1	30.5	09.4		29
21.8	31.8	10.0		30
22.0	32.5	10.5		31
7316	10845	352.8		المجموع
23.6	35.0	11.4		المتوسط

المتوسط الشهري: 29.3

13

August 2008

الصغرى (min.)	العظمى (max.)	المدى	الصغرى (مشتش)	التاريخ
النهاية العظمى والصغرى لدرجة الحرارة بالدرجة المئوية (°C)				
20.8	33.2	124		1
20.7	32.4	076		2
22.4	32.3	099		3
21.5	32.7	107		4
20.0	35.5	155		5
21.0	34.0	130		6
21.4	33.2	118		7
21.3	36.2	149		8
23.4	38.4	150		9
25.0	31.6	066		10
22.4	33.5	11.1		11
22.8	36.8	14.0		12
22.0	36.0	14.0		13
22.0	34.7	12.7		14
21.0	38.5	17.5		15
21.0	30.8	09.8		16
22.0	33.4	11.4		17
22.6	38.2	15.6		18
21.6	34.7	11.1		19
21.0	33.5	12.5		20
20.5	32.4	11.9		21
23.3	31.0	07.7		22
20.5	31.4	10.9		23
20.0	35.8	15.8		24
25.2	34.0	08.8		25
21.0	31.6	10.6		26
23.5	31.5	08.0		27
24.6	31.2	06.6		28
25.0	31.4	06.4		29
24.7	34.8	10.1		30
21.3	31.4	10.1		31
6875	10461	6317		المجموع
22.2	33.7	22.0		المتوسط

المتوسط الشهري: 28.0

13

September 2008

الصغرى (min.)	العظمى (max.)	المدى	الصغرى (مشتش)	التاريخ
النهاية العظمى والصغرى لدرجة الحرارة بالدرجة المئوية (°C)				
20.4	33.8	13.4		1
21.4	33.7	12.3		2
20.4	32.5	12.1		3
25.2	40.0	14.8		4
25.5	36.5	11.0		5
23.8	38.2	14.4		6
23.8	37.2	13.4		7
21.7	37.0	15.3		8
22.8	35.5	12.7		9
23.6	34.5	10.9		10
22.8	34.0	11.2		11
22.2	36.2	14.0		12
22.5	37.4	12.5		13
25.8	39.2	13.4		14
19.0	28.8	09.7		15
20.2	31.5	11.3		16
20.4	32.6	12.2		17
21.0	33.8	12.8		18
24.2	33.0	08.8		19
24.4	28.8	04.4		20
21.0	28.2	07.2		21
[illegible]	32.7	14.9		22
21.5	33.2	11.7		23
21.5	28.3	06.8		24
22.0	30.8	08.8		25
22.2	29.0	07.0		26
22.4	27.5	05.1		27
20.6	23.8	03.2		28
20.0	28.0	08.0		29
19.4	28.0	08.6		30
				31
6863	9666	3221		المجموع
22.9	32.2	10.9		المتوسط

المتوسط 27.6

13

08-4

October 2008

الصغرى (min.)	العظمى (max.)	المدى	الصغرى (مشتش)	التاريخ
النهاية العظمى والصغرى لدرجة الحرارة بالدرجة المئوية (°C)				
21.3	30.0	08.7		1
22.0	29.0	07.0		2
17.9	28.3	10.4		3
21.2	28.5	07.3		4
20.6	26.5	05.9		5
17.0	29.4	12.4		6
18.2	30.2	12.0		7
20.3	26.9	06.6		8
16.0	29.0	13.0		9
21.4	28.5	07.1		10
22.2	29.2	07.0		11
20.5	26.5	06.0		12
17.4	25.4	08.0		13
15.0	26.0	11.0		14
16.4	27.5	11.1		15
16.0	28.5	12.5		16
19.2	30.0	10.8		17
15.8	28.8	13.0		18
18.0	28.6	10.6		19
20.0	31.6	11.6		20
19.9	32.7	12.8		21
20.2	27.8	07.6		22
21.4	27.5	06.1		23
19.0	27.0	08.0		24
17.5	28.5	11.0		25
19.9	31.0	11.0		26
18.0	30.0	12.0		27
21.2	33.3	12.1		28
19.0	34.0	15.0		29
22.5	30.2	07.7		30
21.2	34.5	13.3		31
5962	9049	3106		المجموع
19.2	29.2	10.0		المتوسط

المتوسط الشهري: 24.2

13

November 2008

الصغرى (min.)	العظمى (max.)	المدى	الصغرى (مشتش)	التاريخ
النهاية العظمى والصغرى لدرجة الحرارة بالدرجة المئوية (°C)				
18.8	26.3	07.5		1
16.8	28.0	11.2		2
22.0	31.0	09.0		3
20.0	32.5	12.5		4
17.9	26.4	08.5		5
18.9	25.0	06.1		6
14.0	22.5	08.5		7
12.4	23.4	11.0		8
12.5	23.8	11.3		9
14.0	22.0	08.0		10
11.5	22.0	10.5		11
12.0	24.6	12.6		12
14.5	24.6	10.1		13
13.5	22.0	08.5		14
10.7	20.5	09.8		15
07.5	20.2	12.7		16
10.0	20.3	10.3		17
12.7	18.5	05.8		18
11.8	20.7	08.9		19
11.6	22.4	10.8		20
11.0	23.6	12.6		21
13.2	21.0	07.8		22
13.2	21.0	07.8		23
13.5	24.4	10.9		24
12.6	22.5	09.9		25
11.0	24.6	13.6		26
12.8	24.8	12.0		27
17.5	24.5	07.0		28
09.0	18.5	09.5		29
07.5	22.2	14.7		30
				31
4044	7038	2994		المجموع
13.5	23.5	10.0		المتوسط

18.5 = المتوسط

13 06

December 2008

الصغرى (min.)	العظمى (max.)	المدى	الصغرى (مشتش)	التاريخ
النهاية العظمى والصغرى لدرجة الحرارة بالدرجة المئوية (°C)				
11.5	21.8	10.3		1
11.8	22.6	10.8		2
10.6	17.5	06.9		3
08.7	15.0	06.3		4
05.0	13.6	08.6		5
09.4	16.1	06.7		6
07.0	15.0 14.9	08.0		7
10.0	19.8	09.8		8
12.5	20.0	07.5		9
13.0	22.5	09.5		10
09.8	18.8	09.0		11
07.2	14.6	07.4		12
05.0	15.0	10.0		13
06.9	18.0	11.1		14
07.9	21.8	13.9		15
08.2	18.5	10.3		16
10.2	14.8	04.6		17
10.0	17.0	07.0		18
07.0	16.8	09.8		19
10.8	16.0	05.2		20
11.5	16.8	05.3		21
09.8	17.4 15.5	05.7		22
11.5	16.1	04.6		23
08.5	17.8	09.3		24
07.5	16.8	09.3		25
09.5	16.8	07.3		26
09.0	19.0	10.0		27
06.4	20.4	14.0		28
10.2	21.6	11.4		29
10.9	20.0	09.1		30
09.0	17.0	08.0		31
2863	5593	2667		المجموع
09.2	[illegible]	08.6		المتوسط

المتوسط: 13.6

13

January/2009

النهاية العظمى والصغرى لدرجة الحرارة بالدرجة المئوية (°C)				التاريخ
الصغرى (min.)	العظمى (max.)	المدى	الصغرى (حشائش)	
08.5	18.5	10.0		1
09.8	20.0	10.2		2
09.8	19.6	09.8		3
11.5	20.4	08.9		4
11.0	16.8	05.8		5
09.5	15.8	06.3		6
05.8	19.4	13.6		7
08.8	21.0	12.2		8
07.0	18.5	09.0		9
10.0	17.3	07.3		10
09.0	17.2	07.7		11
13.7	21.4	07.7		12
13.0	17.5	04.5		13
10.8	16.6	05.8		14
11.8	15.9	04.5		15
09.0	16.5	07.5		16
07.0	19.0	12.0		17
11.5	20.5	09.0		18
13.8	18.9	05.1		19
14.1	16.7	02.6		20
12.8	18.8	06.0		21
10.0	15.5	05.5		22
08.0	15.8	07.8		23
13.6	20.2	06.6		24
12.0	17.6	05.6		25
08.1	23.5	15.4		26
10.7	16.5	05.8		27
09.4	15.5	06.1		28
08.8	17.9	09.1		29
09.8	15.5	05.7		30
07.5	21.2	13.7		31
3155	5665	2968		المجموع
10.2	18.3	08.0		المتوسط

14.3 = المتوسط

13 06.39

February 2009

النهاية العظمى والصغرى لدرجة الحرارة بالدرجة المئوية (°C)				التاريخ
الصغرى (min.)	العظمى (max.)	المدى	الصغرى (حشائش)	
09.8	21.0	11.2		1
12.4	28.8	16.4		2
14.8	26.4	11.6		3
11.0	21.4	10.4		4
10.0	26.2	16.2		5
15.2	24.2	09.0		6
14.5	24.8	10.3		7
11.0	18.0	07.0		8
08.1	16.6	08.5		9
06.5	21.7	15.2		10
12.0	18.5	06.5		11
07.5	17.0	09.5		12
08.8	15.0	06.2		13
09.4	14.2	04.8		14
07.0	13.7	06.7		15
06.1	11.0	06.9		16
03.2	17.5	14.3		17
08.0	14.8	06.8		18
08.0	16.5	08.5		19
04.7	16.4	11.7		20
06.8	13.6	06.8		21
06.3	15.3	09.0		22
07.0	14.0	07.0		23
10.2	16.0	05.8		24
09.3	14.0	04.7		25
09.0	14.6	05.6		26
06.8	16.5	09.7		27
06.9	19.0	12.1		28
				29
				30
				31
2503	5097	2584		المجموع
08.9	18.2	09.2		المتوسط

المتوسط الشهري: 13.6

March 2009

النهاية العظمى والصغرى لدرجة الحرارة بالدرجة المئوية (°C)				التاريخ
الصغرى (min.)	العظمى (max.)	المدى	الصغرى (حشائش)	
10.3	21.0	10.7		1
10.8	20.0	09.2		2
09.8	21.5	11.7		3
14.7	25.8	11.1		4
15.4	22.0	06.6		5
11.8	17.2	05.0		6
09.0	15.0	06.0		7
12.0	15.6	03.6		8
06.5	20.8	14.3		9
08.0	19.5	11.5		10
06.8	22.0	15.2		11
03.6	13.2	09.6		12
03.0	13.7	10.7		13
05.8	21.9	16.1		14
08.4	23.8	15.4		15
12.3	20.5	08.2		16
11.8	17.5	05.7		17
11.8	18.5	06.7		18
11.6	18.8	07.2		19
10.0	20.5	10.5		20
11.5	16.8	05.3		21
06.0	15.4	09.4		22
08.6	14.7	06.1		23
04.4	20.5	16.1		24
10.0	17.5	07.5		25
07.0	24.2	17.2		26
08.0	26.2	18.2		27
09.4	25.5	16.1		28
21.2	32.9	11.7		29
18.9	33.0	14.1		30
18.0	32.4	14.4		31
3344	6689	3311		المجموع
10.8	21.6	10.7		المتوسط

16.2 = المتوسط

13 07

April 2009

النهاية العظمى والصغرى لدرجة الحرارة بالدرجة المئوية (°C)				التاريخ
الصغرى (min.)	العظمى (max.)	المدى	الصغرى (حشائش)	
13.0	21.5	8.5		1
08.5	22.8	14.3		2
10.0	21.4	11.4		3
12.0	19.6	7.6		4
10.0	18.6	8.6		5
10.4	20.0	9.6		6
10.8	25.5	14.7		7
15.0	30.1	15.1		8
14.0	30.5	16.5		9
12.0	22.5	10.5		10
11.5	27.5	16.0		11
13.0	23.0	10.0		12
14.0	22.6	8.6		13
13.0	22.7	9.7		14
11.6	26.0	14.4		15
11.8	29.8	18.0		16
14.0	31.5	17.5		17
17.0	28.0	11.0		18
15.5	19.5	4.0		19
15.8	23.8	8.0		20
14.2	19.1	4.9		21
10.2	23.5	13.3		22
13.5	19.7	6.2		23
11.3	23.8	12.5		24
13.5	29.0	15.5		25
20.6	35.2	14.6		26
14.5	36.0	21.5		27
13.5	22.5	9.0		28
12.0	26.8	14.8		29
15.4	23.5	8.1		30
				31
3916	7460	3544		المجموع
13.1	24.9	11.8		المتوسط

13

May 2009

النهاية العظمى والصغرى لدرجة الحرارة بالدرجة المئوية (°C)				التاريخ
الصغرى (min.)	العظمى (max.)	المدى	الصغرى (حشائش)	
12.0	24.6	12.6		1
13.9	22.0	08.1		2
14.5	17.7	03.2		3
13.5	23.8	10.3		4
12.8	23.6	10.8		5
13.9	20.2	06.3		6
12.8	21.5	08.7		7
12.2	24.6	12.4		8
13.5	29.1	15.6		9
15.0	29.2	14.2		10
16.4	25.5	09.1		11
15.5	26.4	10.9		12
16.9	33.0	16.1	✓	13
21.4	36.4	15.0		14
22.9	36.0	13.1		15
17.3	23.5	06.2		16
17.6	21.7	04.1		17
15.5	25.8	10.3		18
16.0	32.0	16.0		19
17.2	31.1	13.9		20
13.5	24.9	11.4		21
15.6	31.5	15.9		22
19.5	32.0	12.5		23
18.0	33.0	15.0		24
18.7	36.2	17.5		25
19.5	35.2	15.7		26
19.5	30.6	11.1		27
20.0	26.0	06.0		28
20.0	25.5	05.5		29
20.0	27.0	07.0		30
19.4	34.4	15.0		31
5185	8460	3297		المجموع
16.7	28.3	10.6		المتوسط

المتوسط الشهري: 22.4

13

June 2009

النهاية العظمى والصغرى لدرجة الحرارة بالدرجة المئوية (°C)				التاريخ
الصغرى (min.)	العظمى (max.)	المدى	الصغرى (حشائش)	
15.9	31.6	12.7		1
21.0	32.8	11.8		2
21.2	35.6	14.4		3
23.2	35.8	12.6		4
20.8	33.8	13.0		5
[illegible]	[illegible]	12.6		6
21.3	40.3	19.0		7
21.4	41.6	14.2		8
23.5	33.0	10.5		9
21.8	35.5	13.7		10
23.9	30.8	06.9		11
20.8	30.4	09.9		12
21.0	33.4	12.4		13
21.0	33.2	12.2		14
22.0	33.5	11.5		15
22.2	33.6	11.4		16
21.5	35.5	14.0		17
25.2	33.4	08.2		18
21.8	29.0	05.2		19
19.2	28.2	09.0		20
18.8	30.0	11.2		21
21.2	33.0	11.8		22
20.0	33.0	13.0		23
20.1	32.5	12.4		24
23.0	34.4	11.4		25
21.5	32.5	09.0		26
24.2	30.3	06.1		27
21.7	33.5	11.8		28
21.3	35.3	14.0		29
22.8	32.1	09.3		30
22.4	31.5	09.1		31
7062	10545	3483		المجموع
22.8	34.0	11.2		المتوسط

July 2009

النهاية العظمى والصغرى لدرجة الحرارة بالدرجة المئوية (°C)				التاريخ
الصغرى (min.)	العظمى (max.)	المدى	الصغرى (حشائش)	
24.2	33.3	09.1		1
21.6	36.4	14.8		2
23.5	36.5	13.0		3
24.2	41.0	16.8		4
26.9	33.7	06.8		5
26.0	33.5	07.5		6
23.0	29.8	06.8		7
21.5	31.6	10.1		8
21.5	36.2	14.7		9
21.8	37.0	15.2		10
24.9	36.5	11.6		11
23.9	37.4	13.5		12
23.9	36.4	12.5		13
25.0	39.6	14.6		14
27.1	40.2	13.1		15
25.0	38.5	13.5		16
26.0	38.0	12.0		17
23.9	32.5	08.6		18
22.0	32.8	10.8		19
22.5	32.0	09.5		20
22.8	32.6	09.8		21
23.5	31.4	07.9		22
23.5	30.7	07.2		23
22.8	32.5	09.7		24
23.8	33.4	14.6		25
27.3	39.5	12.2		26
25.5	37.4	11.9		27
25.6	36.5	10.9		28
25.8	35.7	09.9		29
24.0	33.4	09.4		30
25.1	33.0	07.9		31
7438	10892	3459		المجموع
24.0	35.2	11.2		المتوسط

13

August 2009

النهاية العظمى والصغرى لدرجة الحرارة بالدرجة المئوية (°C)				التاريخ
الصغرى (min.)	العظمى (max.)	المدى	الصغرى (حشائش)	
22.2	35.5	13.3		1
26.9	39.5	12.6		2
23.9	35.0	11.1		3
21.5	33.9	14.4		4
24.6	37.2	12.6		5
24.5	31.0	06.5		6
26.2	31.0	04.8		7
22.5	30.5	08.0		8
22.2	28.9	06.7		9
20.7	29.0	08.3		10
22.0	27.0	05.0		11
[illegible]	[illegible]	09.9		12
22.5	33.2	11.7		13
[illegible]	[illegible]	07.0		14
[illegible]	[illegible]	14.9		15
[illegible]	[illegible]	10.7		16
[illegible]	[illegible]	05.0		17
21.8	34.6	12.6		18
24.9	35.0	10.1		19
21.2	27.2	06.0		20
21.5	29.4	07.9		21
21.3	28.1	06.8		22
21.7	33.9	12.2		23
21.1	29.3	08.2		24
20.5	24.0	03.5		25
21.0	27.5	06.5		26
21.0	28.0	07.0		27
19.0	29.0	10.0		28
21.5	34.8	13.3		29
24.0	31.5	07.5		30
				31
6937	9726	2789		المجموع
23.1	32.4	09.3		المتوسط

13

September 2009

النهاية العظمى والصغرى لدرجة الحرارة بالدرجة المئوية (°C)				التاريخ
الصغرى (min.)	العظمى (max.)	المدى	الصغرى (حشائش)	
20.2	32.7	12.5		1
22.6	28.4	05.8		2
20.0	27.4	07.4		3
[illegible]	21.5	03.3		4
11.1	22.2	11.1		5
12.5	25.9	12.4		6
11.2	21.4	10.2		7
[illegible]	21.0	10.5		8
12.5	24.5	12.0		9
14.8	25.0	10.2		10
13.0	24.5	11.5		11
19.0	27.8	08.8		12
[illegible]	26.0	07.5		13
10.5	22.0	11.5		14
17.5	26.7	09.2		15
17.2	25.5	08.3		16
16.8	23.9	07.1		17
14.2	24.7	10.5		18
13.0	24.5	11.5		19
[illegible]	32.0	16.2		20
22.8	37.0	14.2		21
21.0	32.5	09.5		22
20.2	27.5	07.3		23
21.0	25.0	04.0		24
20.8	21.9	01.1		25
18.5	23.8	05.3		26
16.0	21.0	05.0		27
16.0	22.8	06.8		28
15.8	21.2	05.4		29
14.7	23.4	08.7		30
16.8	21.0	04.2		31
5583	7263	2384		المجموع
18.0	23.0	09.0		المتوسط

October 2009

النهاية العظمى والصغرى لدرجة الحرارة بالدرجة المئوية (°C)				التاريخ
الصغرى (min.)	العظمى (max.)	المدى	الصغرى (حشائش)	
16.5	22.1	05.6		1
15.2	23.5	08.3		2
16.5	24.3	[illegible]		3
15.0	26.7	11.7		4
[illegible]	24.5	11.8		5
16.5	26.5	[illegible]		6
[illegible]	19.0	08.3		7
[illegible]	23.7	11.9		8
[illegible]	23.0	10.0		9
12.0	[illegible]	06.5		10
14.4	20.0	08.6		11
[illegible]	21.5	09.7		12
[illegible]	21.0	11.6		13
11.6	22.9	11.3		14
[illegible]	24.6	13.6		15
11.8	25.2	13.4		16
[illegible]	[illegible]	14.8		17
[illegible]	26.1	15.7		18
12.0	24.6	12.6		19
13.0	21.9	08.9		20
14.0	23.2	09.2		21
13.9	21.5	07.6		22
14.7	20.5	05.8		23
14.9	20.7	05.8		24
13.5	21.0	07.5		25
11.6	22.1	10.7		26
09.5	24.2	14.7		27
09.0	23.5	14.5		28
10.5	23.8	13.3		29
10.4	23.0	13.6		30
				31
3934	7013	3079		المجموع
13.1	23.4	10.3		المتوسط

November 2008

النهاية العظمى والصغرى لدرجة الحرارة بالدرجة المئوية (°C)				التاريخ
الصغرى (min.)	العظمى (max.)	المدى	الصغرى (حشائش)	
18.8	26.3	07.5		1
16.8	28.0	11.2		2
22.0	31.0	09.0		3
20.0	32.5	12.5		4
17.9	26.4	08.5		5
18.9	25.0	06.1		6
14.0	22.5	08.5		7
12.4	23.4	11.0		8
12.5	23.8	11.3		9
14.0	22.0	08.0		10
11.5	22.0	10.5		11
12.0	24.6	12.6		12
14.5	24.6	10.1		13
13.5	22.0	08.5		14
10.7	20.5	09.8		15
07.5	20.2	12.7		16
10.0	20.3	10.3		17
12.7	18.5	05.8		18
11.8	20.7	08.9		19
11.6	22.4	10.8		20
11.0	23.6	12.6		21
13.2	21.0	07.8		22
13.2	21.0	07.8		23
13.5	24.4	10.9		24
12.6	22.5	09.9		25
11.0	24.6	13.6		26
12.8	24.8	12.0		27
13.5	20.5	07.0		28
09.0	18.5	09.5		29
07.5	22.2	14.7		30
				31
4044	7038	2994		المجموع
13.5	23.5	10.0		المتوسط

المتوسط = 18.5

13

December 2009

النهاية العظمى والصغرى لدرجة الحرارة بالدرجة المئوية (°C)				التاريخ
الصغرى (min.)	العظمى (max.)	المدى	الصغرى (حشائش)	
11.5	18.5	07.0		1
10.3	17.8	07.5		2
07.6	18.1	10.6		3
06.8	18.5	11.7		4
11.5	19.2	07.7		5
12.5	19.4	06.9		6
11.0	19.6	08.6		7
08.8	22.2	13.4		8
09.1	19.5	10.4		9
14.2	18.5	04.3		10
11.0	18.2	07.2		11
10.5	18.0	07.5		12
06.6	22.4	15.8		13
13.3	24.4	11.1		14
12.8	19.5	06.7		15
10.0	16.5	06.5		16
08.2	25.0	16.8		17
12.0	22.0	10.0		18
13.6	27.5	13.9		19
13.0	21.8	08.8		20
09.5	20.2	10.7		21
09.5	26.2	16.7		22
16.4	27.0	10.6		23
15.0	30.8	15.8		24
14.2	30.0	15.8		25
18.0	31.2	13.2		26
16.2	23.5	07.6		27
13.8	19.9	06.1		28
14.0	22.8	08.8		29
10.9	28.0	17.3		30
12.2	31.2	19.0		31
394.3	652.6	298.3		المجموع
11.4	21.0	09.6		المتوسط

(العظمى + الصغرى) / 2 = 16.1 = (11.4 + 21.0) / 2

13

Appendix 8: Tripoli climatic information provided by Weather Tool software.

Climate type "BSh" (Kvppen classification)
- Hot subtropical steppe (lat. 15-300N)
- Unbearably hot dry periods in summer, but passive cooling is possible

- Climate type "4B" (ASHRAE Standards 90.1-2004 and 90.2-2004 Climate Zone)
- Mixed - Dry, Probable Kvppen classification=BSk/BWh/H, Semiarid Mid Latitude/Arid Subtropical/Highlands

- Typical/Extreme Period Determination
- Wet Period=Aug:Sep
Week closest to this period average temperature selected for Typical Period
Typical Week Period selected: Aug 8:Aug 14, Average Temp= 27.470C, Deviation=| 0.290|0C
- Dry Period=Oct:Jul
Week closest to this period average temperature selected for Typical Period
Typical Week Period selected: Nov 12:Nov 18, Average Temp= 18.920C, Deviation=| 0.055|0C

- Summer is May:Jul
Extreme Summer Week (nearest maximum temperature for summer)
Extreme Hot Week Period selected: Jul 3:Jul 9, Maximum Temp= 45.600C, Deviation=|14.152|0C
Typical Summer Week (nearest average temperature for summer)
Typical Week Period selected: Jul 10:Jul 16, Average Temp= 26.050C, Deviation=| 0.001|0C

- Winter is Nov:Jan
Extreme Winter Week (nearest minimum temperature for winter)
Extreme Cold Week Period selected: Jan 18:Jan 24, Minimum Temp= 1.600C, Deviation=| 9.405|0C
Typical Winter Week (nearest average temperature for winter)
Typical Week Period selected: Nov 29:Dec 5, Average Temp= 14.110C, Deviation=| 0.714|0C

- Autumn is Aug:Oct
Typical Autumn Week (nearest average temperature for autumn)
Typical Week Period selected: Sep 19:Sep 25, Average Temp= 26.000C, Deviation=| 0.392|0C

- Spring is Feb:Apr
Typical Spring Week (nearest average temperature for spring)
Typical Week Period selected: Apr 12:Apr 18, Average Temp= 15.070C, Deviation=| 0.391|0C

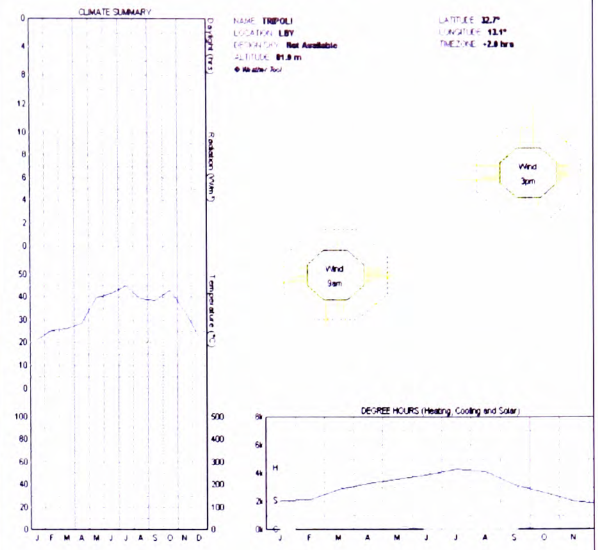
Tabulated Daily Solar Data

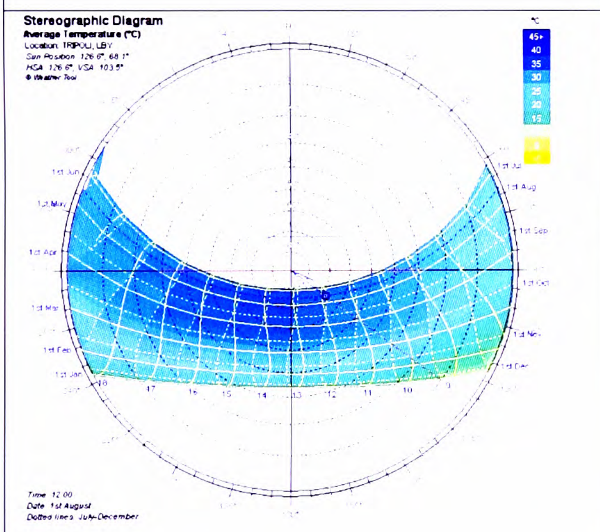
Latitude 32 7°
Longitude 13 1°
Timezone 30 0° [+2 0hrs]
Orientation -172 0°

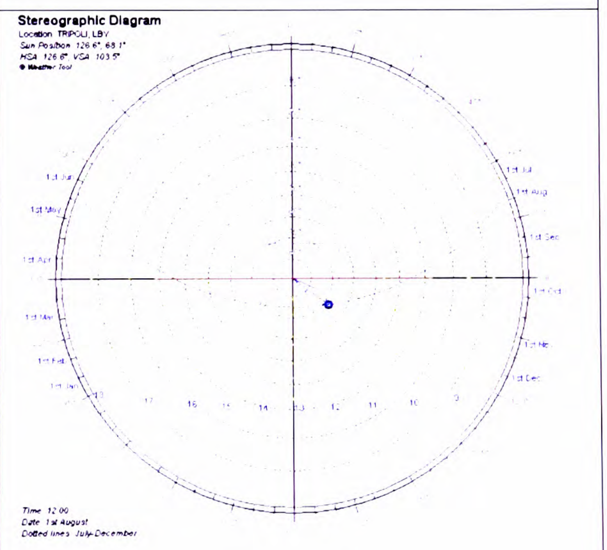
Date 1st August
Julian Date 213
Sunrise 06 24
Sunset 20 02

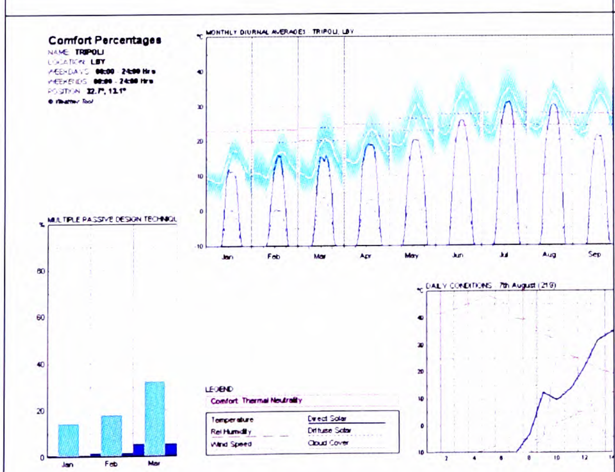
Local Correction -73 6 mins
Equation of Time -6 2 mins
Declination 18 3°

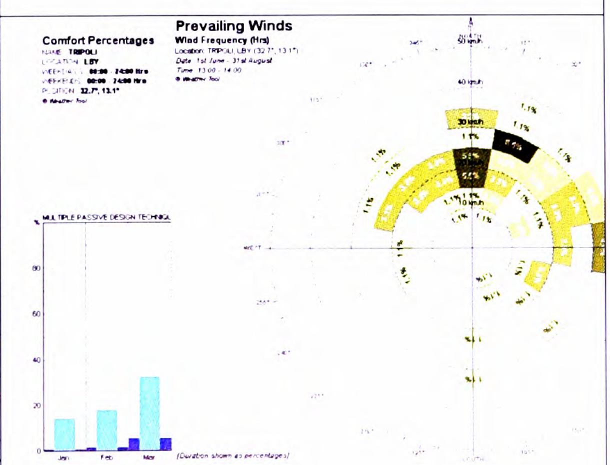
Local	(Solar)	Azimuth	Altitude	HSA	VSA
06 30	(05 16)	68 9°	1 0°	-119 1°	177 9°
07 00	(05 46)	72 8°	7 0°	-115 2°	164 0°
07 30	(06 16)	76 5°	13 1°	-111 5°	147 6°
08 00	(06 46)	80 2°	19 2°	-107 8°	131 2°
08 30	(07 16)	83 9°	25 5°	-104 1°	117 1°
09 00	(07 46)	87 7°	31 8°	-100 3°	106 1°
09 30	(08 16)	91 7°	38 1°	-96 3°	97 9°
10 00	(08 46)	96 2°	44 4°	-91 8°	91 9°
10 30	(09 16)	101 3°	50 6°	-86 7°	87 3°
11 00	(09 46)	107 4°	56 8°	-80 6°	83 9°
11 30	(10 16)	115 5°	62 6°	-72 5°	81 2°
12 00	(10 46)	126 6°	68 1°	-61 4°	79 1°
12 30	(11 16)	143 1°	72 6°	-44 9°	77 4°
13 00	(11 46)	167 2°	75 3°	-20 8°	76 2°
13 30	(12 16)	-164 7°	75 1°	7 3°	75 2°
14 00	(12 46)	-141 3°	72 2°	30 7°	74 6°
14 30	(13 16)	-125 4°	67 6°	46 6°	74 2°
15 00	(13 46)	-114 6°	62 1°	57 4°	74 1°
15 30	(14 16)	-106 8°	56 2°	65 2°	74 3°
16 00	(14 46)	-100 8°	50 1°	71 2°	74 9°
16 30	(15 16)	-95 7°	43 8°	76 3°	76 1°
17 00	(15 46)	-91 3°	37 5°	80 7°	78 1°
17 30	(16 16)	-87 3°	31 2°	84 7°	81 3°
18 00	(16 46)	-83 6°	24 9°	88 4°	86 7°
18 30	(17 16)	-79 9°	18 7°	92 1°	96 3°
19 00	(17 46)	-76 2°	12 5°	95 8°	114 6°
19 30	(18 16)	-72 4°	6 4°	99 6°	145 9°
20 00	(18 46)	-68 5°	0 5°	103 5°	177 9°

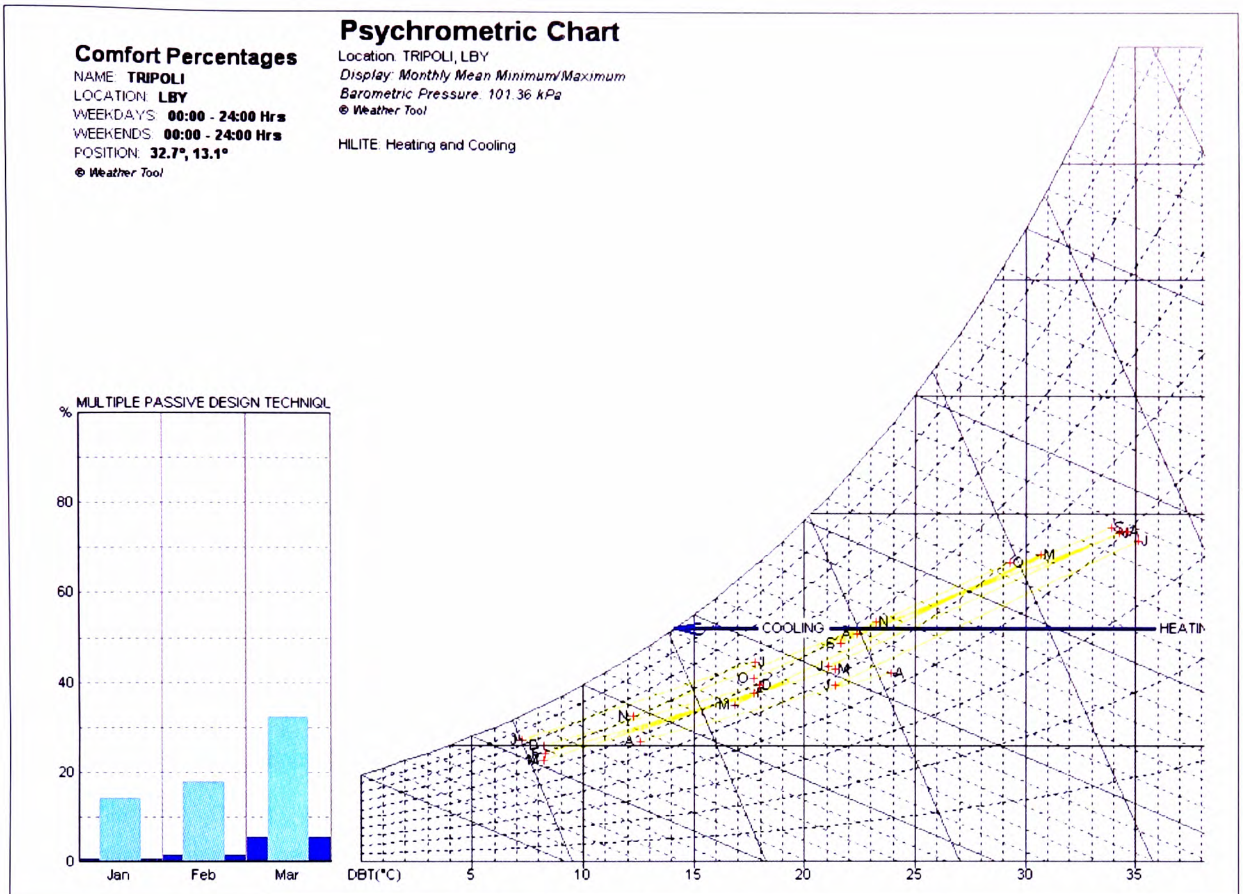


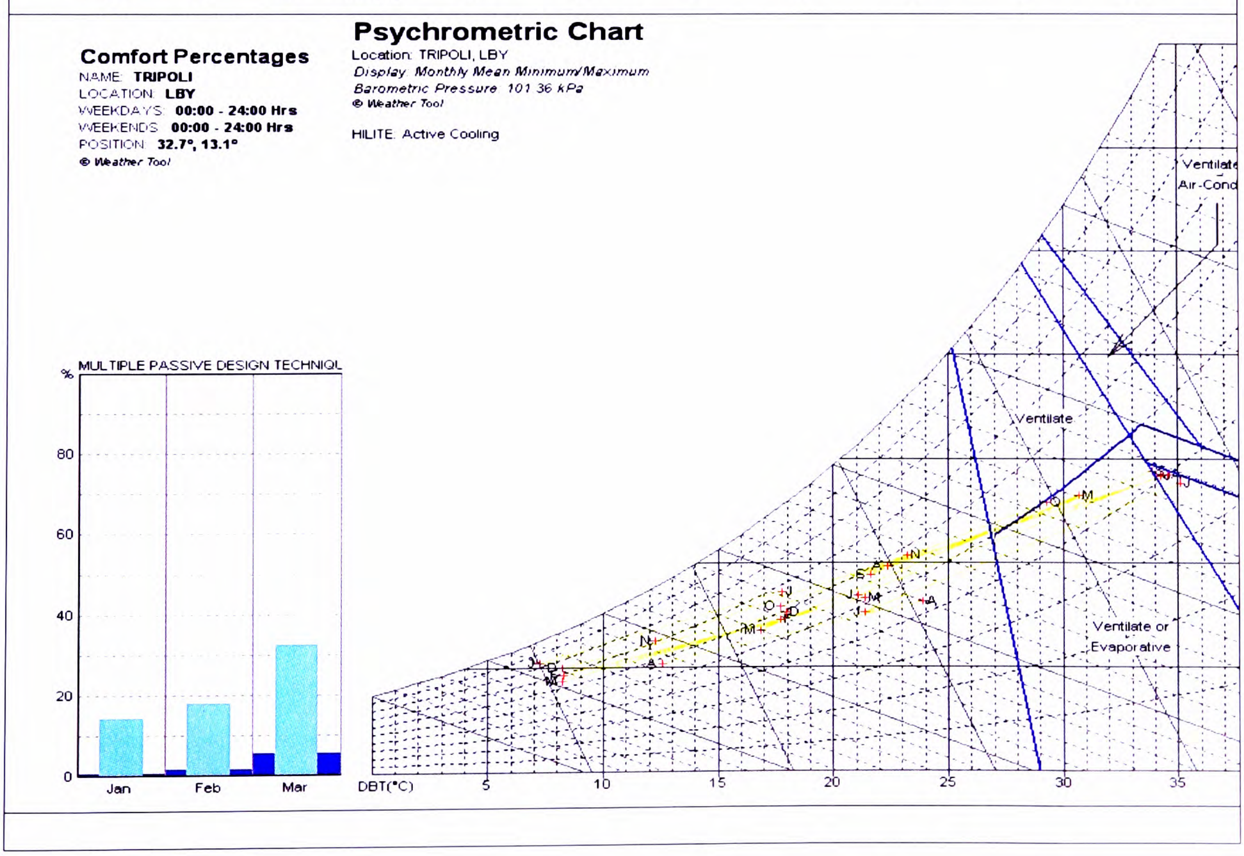









Psychrometric Chart
Location: TRIPOLI, LBY
Display: Monthly Mean Minimum/Maximum
Barometric Pressure: 101.36 kPa
© Weather Tool
HILITE: Heating and Cooling
Comfort Percentages
NAME: TRIPOLI
LOCATION: LBY
WEEKDAYS: 00:00 - 24:00 Hrs
WEEKENDS: 00:00 - 24:00 Hrs
POSITION: 32.7°, 13.1°
© Weather Tool
MULTIPLE PASSIVE DESIGN TECHNIQL
%
80
60
40
20
0
Jan
Feb
Mar
COOLING
HEATIN
DBT(°C)
5
10
15
20
25
30
35


Psychrometric Chart
Location: TRIPOLI, LBY
Display: Monthly Mean Minimum/Maximum
Barometric Pressure: 101.36 kPa
© Weather Tool
HILITE: Active Cooling
Comfort Percentages
NAME: TRIPOLI
LOCATION: LBY
WEEKDAYS: 00:00 - 24:00 Hrs
WEEKENDS: 00:00 - 24:00 Hrs
POSITION: 32.7°, 13.1°
© Weather Tool
MULTIPLE PASSIVE DESIGN TECHNIQL
%
80
60
40
20
0
Jan
Feb
Mar
Ventilate
Ventilate or
Evaporative
DBT(°C)
5
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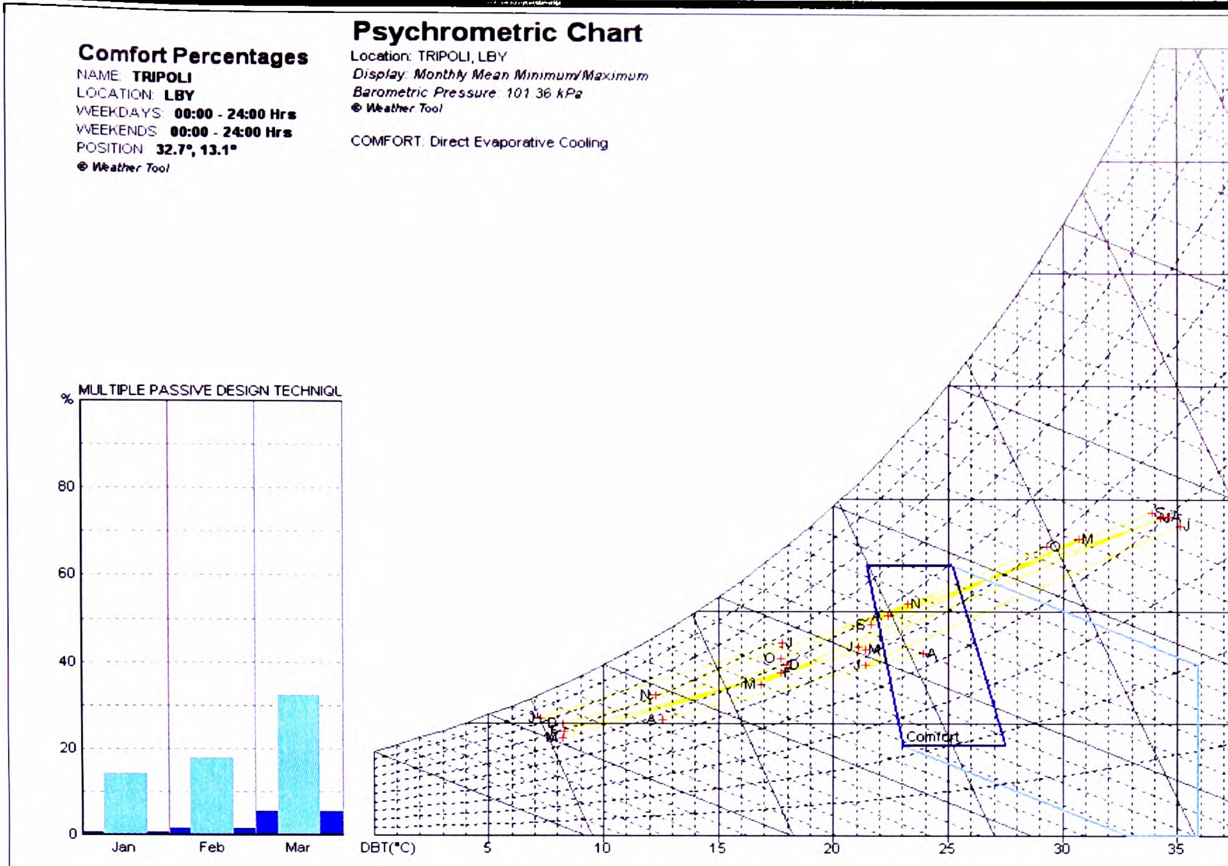
15
20
25
30
35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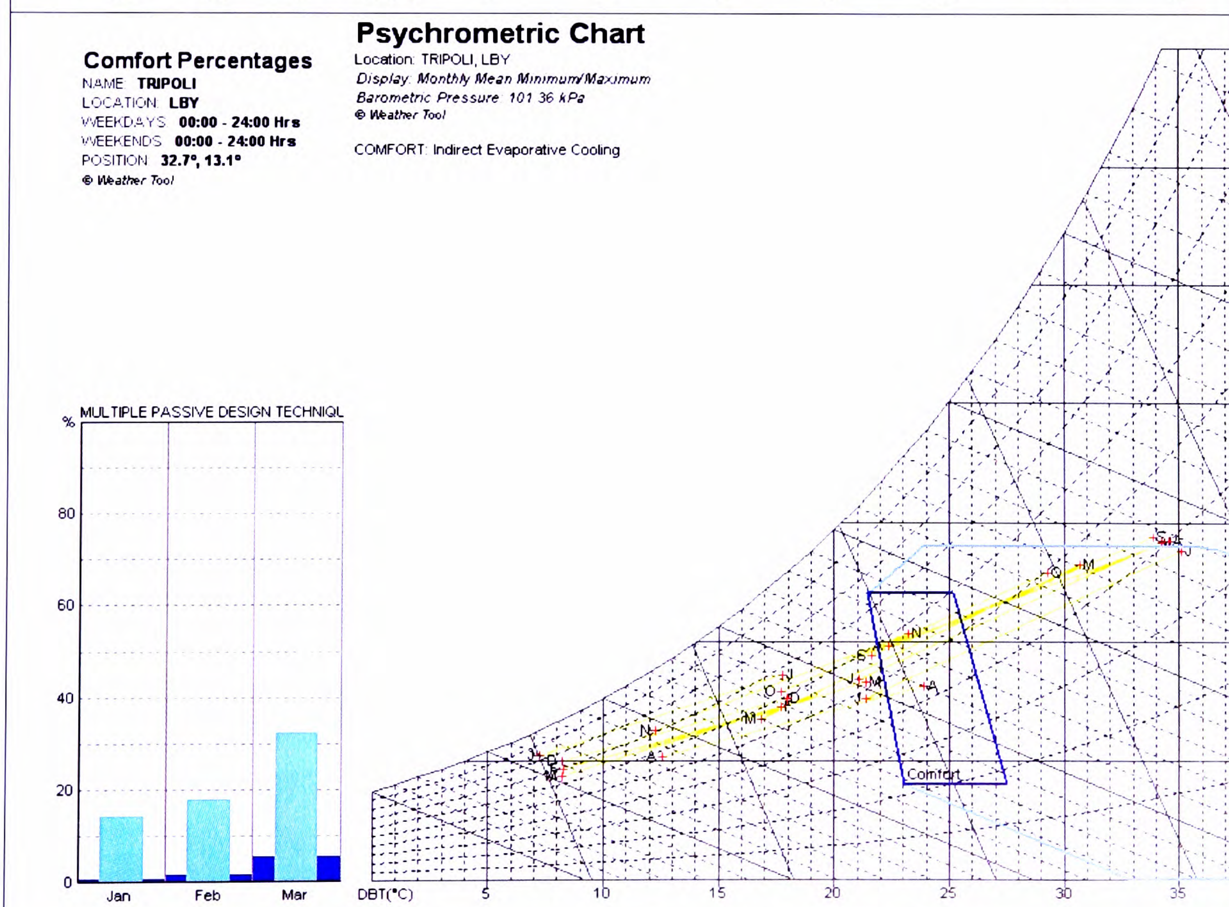
LOCATION: LBY
WEEKDAYS: 00:00 - 24:00 Hrs
WEEKENDS: 00:00 - 24:00 Hrs
POSITION: 32.7°, 13.1°
© Weather Tool
Psychrometric Chart
Location: TRIPOLI, LBY
Display: Monthly Mean Minimum/Maximum
Barometric Pressure: 101.36 kPa
© Weather Tool
COMFORT: Direct Evaporative Cooling
MULTIPLE PASSIVE DESIGN TECHNIQU
%
80
60
40
20
0
Jan
Feb
Mar
Comfort
DBT(°C)
5
10
15
20
25
30
35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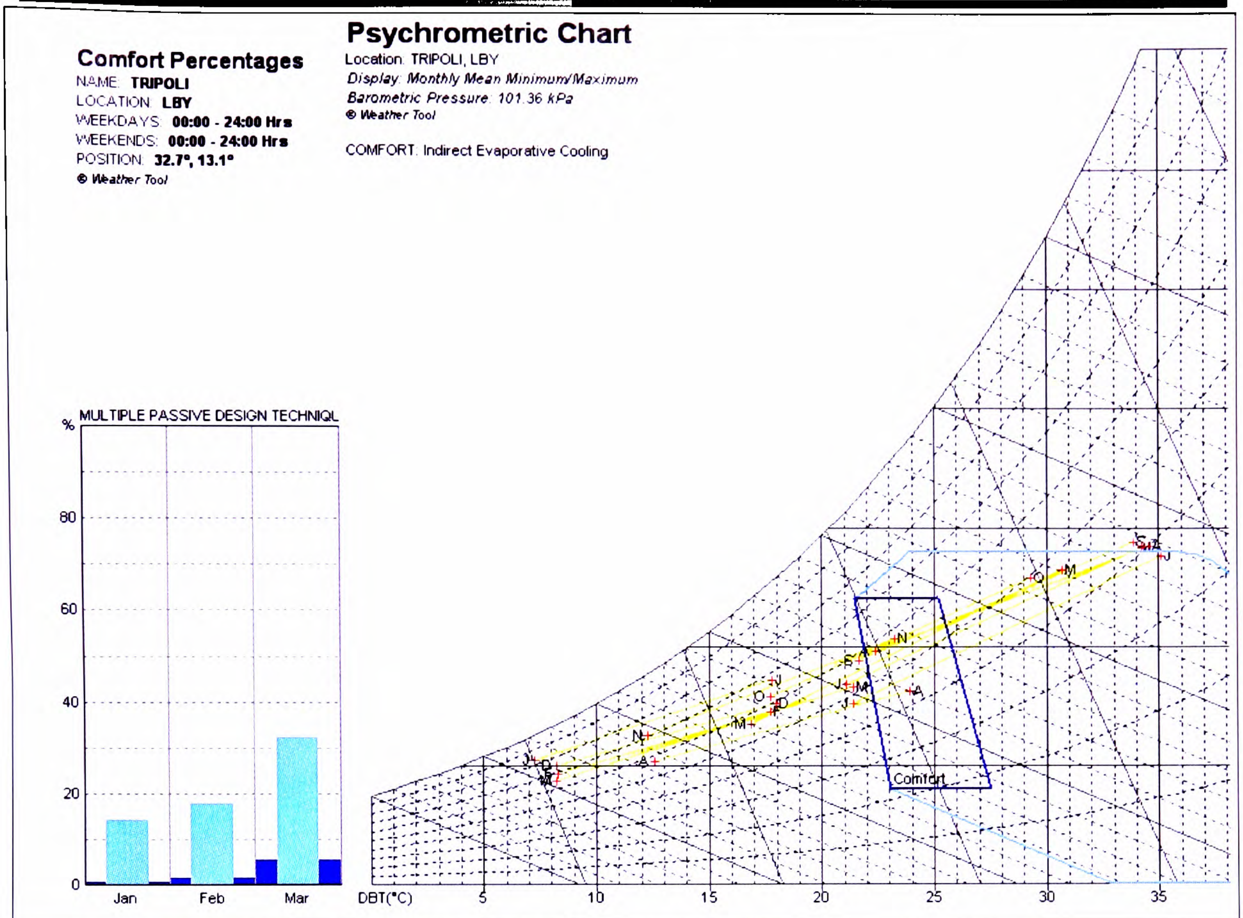
LOCATION: LBY
WEEKDAYS: 00:00 - 24:00 Hrs
WEEKENDS: 00:00 - 24:00 Hrs
POSITION: 32.7°, 13.1°
© Weather Tool
Psychrometric Chart
Location: TRIPOLI, LBY
Display: Monthly Mean Minimum/Maximum
Barometric Pressure: 101.36 kPa
© Weather Tool
COMFORT: Indirect Evaporative Cooling
MULTIPLE PASSIVE DESIGN TECHNIQU
%
80
60
40
20
0
Jan
Feb
Mar
Comfort
DBT(°C)
5
10
15
20
25
30
35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LOCATION: LBY
WEEKDAYS: 00:00 - 24:00 Hrs
WEEKENDS: 00:00 - 24:00 Hrs
POSITION: 32.7°, 13.1°
© Weather Tool
Psychrometric Chart
Location: TRIPOLI, LBY
Display: Monthly Mean Minimum/Maximum
Barometric Pressure: 101.36 kPa
© Weather Tool
COMFORT: Indirect Evaporative Cooling
MULTIPLE PASSIVE DESIGN TECHNIQU
%
80
60
40
20
0
Jan
Feb
Mar
Comfort
DBT(°C)
5
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15
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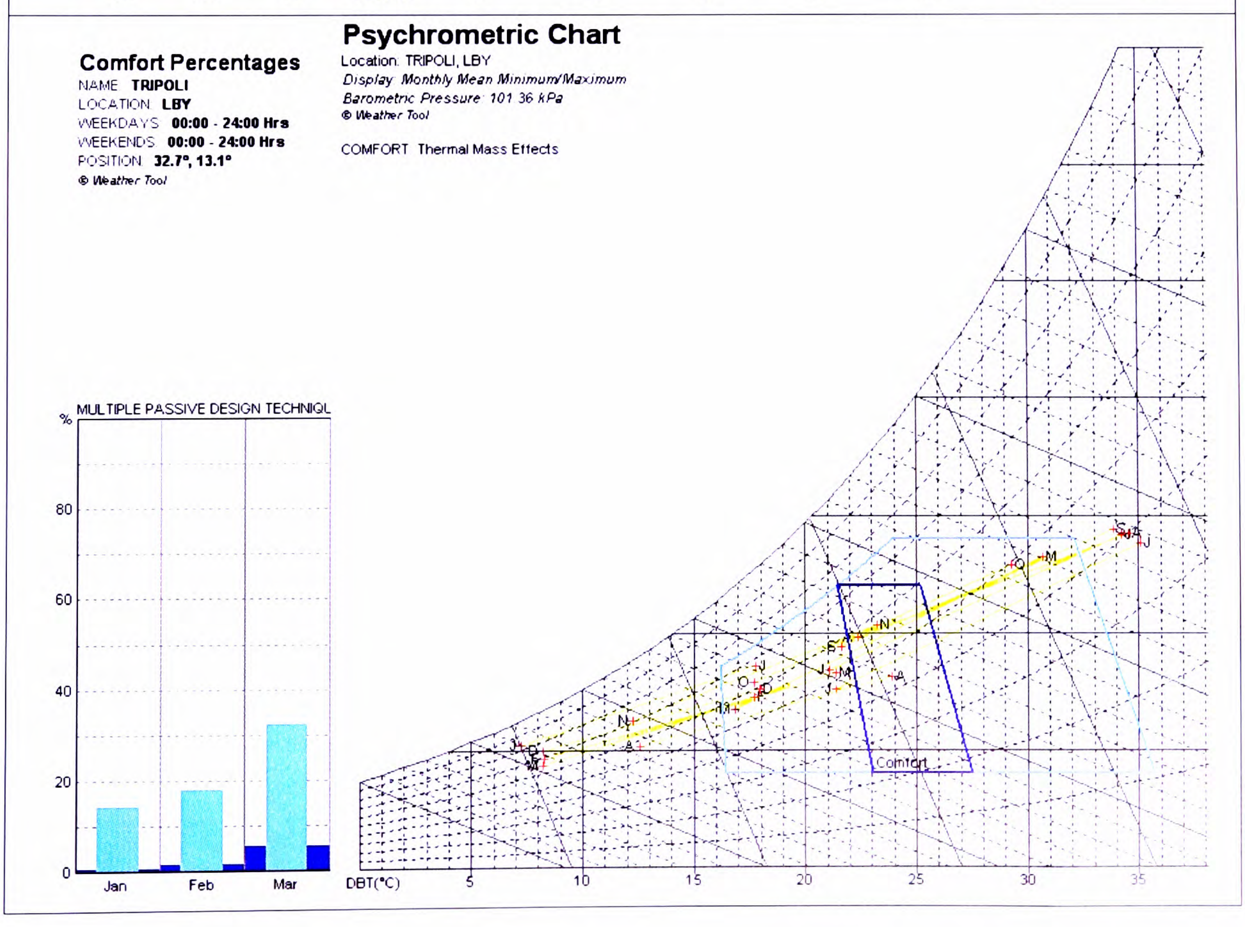
25
30
35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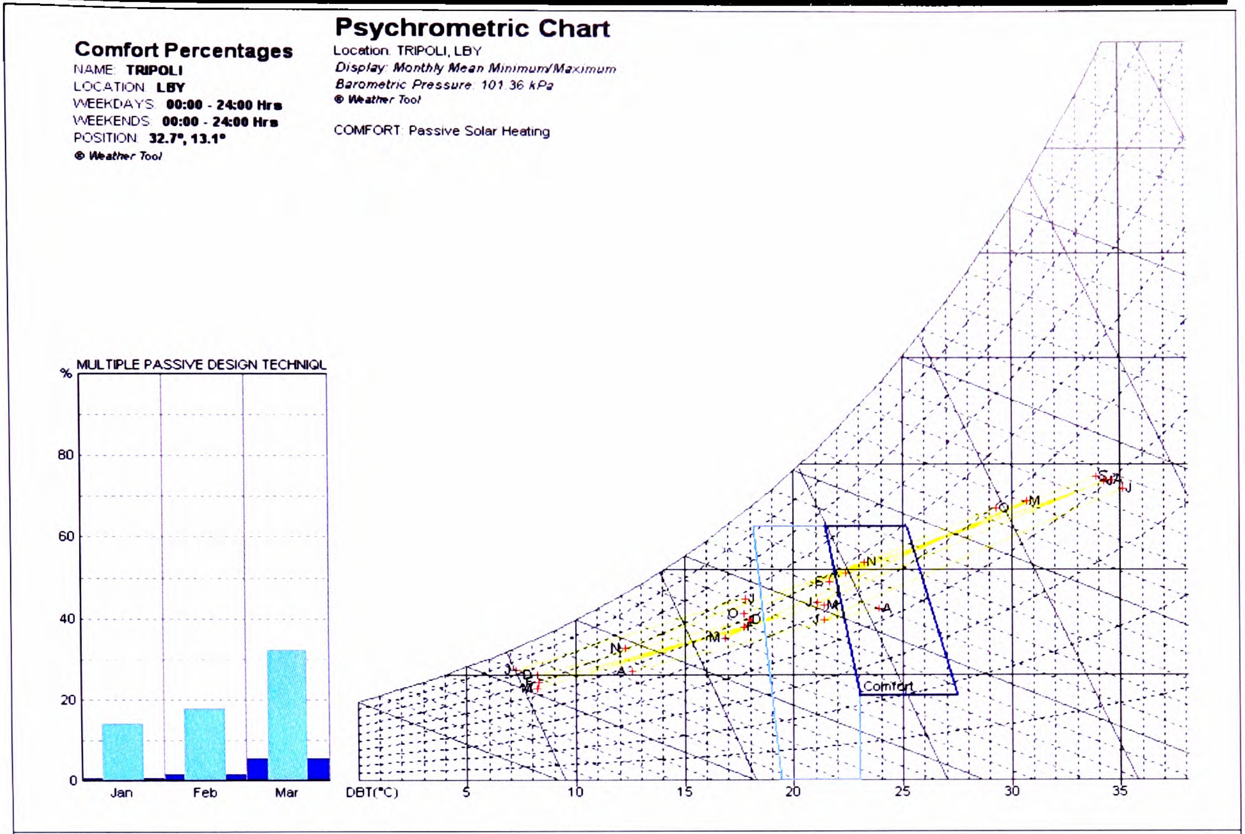
LOCATION: LBY
WEEKDAYS: 00:00 - 24:00 Hrs
WEEKENDS: 00:00 - 24:00 Hrs
POSITION: 32.7°, 13.1°
© Weather Tool
Psychrometric Chart
Location: TRIPOLI, LBY
Display: Monthly Mean Minimum/Maximum
Barometric Pressure: 101.36 kPa
© Weather Tool
COMFORT: Thermal Mass Effects
MULTIPLE PASSIVE DESIGN TECHNIQU
%
80
60
40
20
0
Jan
Feb
Mar
Comfort
DBT(°C)
5
10
15
20
25
30
35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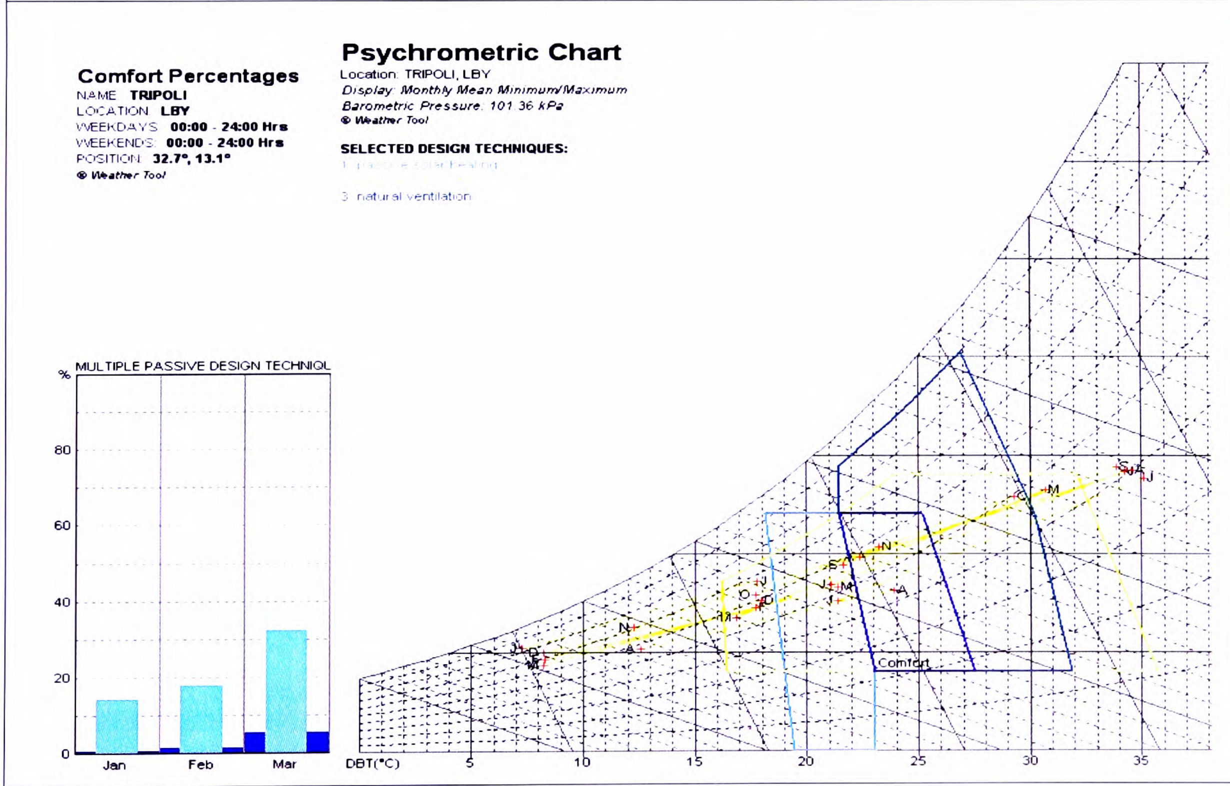
LOCATION: LBY
WEEKDAYS: 00:00 - 24:00 Hrs
WEEKENDS: 00:00 - 24:00 Hrs
POSITION: 32.7°, 13.1°
© Weather Tool
Psychrometric Chart
Location: TRIPOLI, LBY
Display: Monthly Mean Minimum/Maximum
Barometric Pressure: 101.36 kPa
© Weather Tool
COMFORT: Passive Solar Heating
MULTIPLE PASSIVE DESIGN TECHNIQL
%
80
60
40
20
0
Jan
Feb
Mar
Comfort
DBT(°C)
5
10
15
20
25
30
35


Comfort Percentages
NAME: TRIPOLI
LOCATION: LBY
WEEKDAYS: 00:00 - 24:00 Hrs
WEEKENDS: 00:00 - 24:00 Hrs
POSITION: 32.7°, 13.1°
© Weather Tool
Psychrometric Chart
Location: TRIPOLI, LBY
Display: Monthly Mean Minimum/Maximum
Barometric Pressure: 101.36 kPa
© Weather Tool
SELECTED DESIGN TECHNIQUES:
3. natural ventilation
MULTIPLE PASSIVE DESIGN TECHNIQL
%
80
60
40
20
0
Jan
Feb
Mar
Comfort
DBT(°C)
5
10
15
20
25
30
35