BUILDING ENVELOPE DESIGN FOR INDOOR AIR TEMPERATURE IN HOT AND DRY CLIMATE, YEMEN

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By

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LIST OF ABBREVIATIONS

T_i	Indoor air temperature	Ro1	Roof No 1
T_o	Outdoor air temperature	Ro2	Roof No 2
T_n	Natural temperature	Ro3	Roof No 3
R1	Room number one	Ro4	Roof No 4
R2	Room number two	Ro5	Roof No 5
R3	Room number three	Ro6	Roof No 6
R4	Room number four (hall)	Ro7	Roof No 7
T_i Ss	Indoor south surface temperature	Ro8	Roof No 8
T_o Ss	Outdoor south surface temperature	W1	Wall No 1
T_i Ws	Indoor west surface temperature	W2	Wall No 2
T_o Ws	Outdoor west surface temperature	W3	Wall No 3
T_i Ns	Indoor north surface temperature	W4	Wall No 4
T_o Ns	Outdoor north surface temperature	W5	Wall No 5
T_i Rs	Indoor roof surface temperature	W6	Wall No 6
T_o Rs	Outdoor roof surface temperature	W7	Wall No 7
Dif	Difference	W8	Wall No 8
T_is	Indoor surface temperature	W9	Wall No 9
T_os	Outdoor surface temperature	W10	Wall No 10
T_c	Thermal comfort	W11	Wall No 11
WWR	Window to wall ratio	W12	Wall No 12
N	North	D1	Design No 1
NE	North East	D2	Design No 2
E	East	D3	Design No 3
SE	South East	D4	Design No 4
S	South	D5	Design No 5
SW	South West	D6	Design No 6
W	West	D7	Design No 7
NW	North West	D8	Design No 8
$T_{i\ max}$	Maximum indoor temperature	D9	Design No 9
$T_{i\ min}$	Minimum indoor temperature	D10	Design No 10
$T_{o\ max}$	Maximum outdoor temperature		
$T_{o\ min}$	Minimum outdoor temperature		

REKA BENTUK SAMPUL BANGUNAN UNTUK SUHU UDARA DALAMAN DI IKLIM PANAS DAN KERING, YAMAN

ABSTRAK

Reka bentuk pasif pada sampul bangunan adalah salah satu kaedah yang paling berkesan untuk mengurangkan kesan kondisi udara luar yang tinggi, pengurangan penyerapan haba dan juga untuk penambahbaikan termal dalam bangunan untuk negara beriklim panas dan kering di Yaman. Tambahan lagi, kurangnya keprihatinan para arkitek tempatan pada hari ini terhadap reka bentuk sampul bangunan untuk mengurangkan suhu udara di dalam bangunan. Oleh itu, kajian ini membincangkan hasil kajian eksperimen dan simulasi untuk mengurangkan suhu udara di dalam bangunan dengan mengaplikasikan pengubahsuaian terhadap reka bentuk sampul bangunan. Tujuannya adalah untuk mengurangkan suhu udara di dalam rumah yang dibina daripada batu bata lumpur untuk iklim panas dan kering di Wadi Hadhramaut, Yaman, serta dapat memberi rekomendasi kaedah yang efisien untuk reka bentuk sampul bangunan. Kajian ini dijalankan dalam dua fasa: fasa pertama ialah kerja lapangan di dalam dan luar bangunan untuk empat kajian kes dalam bandar baru dan lama di Bandar Tarim, Yaman. Beberapa pengubahsuaian dinding luaran seperti unjuran teduhan dan bumbung dengan warna putih kapur telah dibuat. Fasa kedua ialah simulasi komputer menggunakan perisian IES (VE) untuk menganalisa kesan-kesan pengubahsuaian dinding luaran yang berbeza. Pengubahsuaian ini dilakukan pada bumbung, dinding, orientasi dan nisbah tingkap dengan dinding bangunan serta tambahan teduhan luaran. Kajian dijalankan pada setiap parameter dan pada peringkat terakhir, gabungan pengubahsuaian yang ideal dihasilkan. Hasil kajian menunjukkan dengan penggunaan kombinasi gabungan pada semua pengubahsuaian, suhu udara di dalam bangunan dapat dikurangkan berbanding suhu

diukur dalam kerja lapangan. Reka bentuk No. 4 (D4) ialah reka bentuk terbaik dinding luaran yang mencatatkan perbezaan purata tertinggi (0.76ºC) pada suhu udara dalaman. Dari segi bilangan jangkamasa keselesaan termal tahunan, reka bentuk No. 3 dan 6 (D3 dan D6) ialah reka bentuk dinding luaran terbaik yang mana ia menambahbaik jangkamasa keselesaan termal tahunan kepada 7.87%.

BUILDING ENVELOPE DESIGN FOR INDOOR AIR TEMPERATURE IN HOT AND DRY CLIMATE, YEMEN

ABSTRACT

Passive design on building envelope is one of the most effective methods of minimising the impact of harsh outdoor condition, reducing the heat gain as well as to improving the indoor thermal condition in hot and dry climate in Yemen. Local architects of today give less attention to building envelope design to reduce indoor air temperature. This research discusses the results of the experimental and simulation studies with the purpose to reduce the indoor air temperature by applying modifications on the building envelope design. It aims to reduce the indoor air temperature of residential houses built from mud bricks in hot and dry climate of Wadi Hadhramout, Yemen, and finds recommendations for efficient method in building envelope design. The investigation was performed in two phases: first phase is indoor and outdoor fieldwork measurements in four case studies in old and new urban area at Tarim city, Yemen. Several modifications on building envelope such as fix shading projection and painting roof whitewash colour were performed. Second phase is: computer simulation using IES (VE) software was carried out to investigate the effects of other different envelope modifications. The modifications were carried out on the roof, wall, orientation, window to wall ratio and external shading devices. The investigation was carried out on each parameter and then in the last stage the combination of all ideal modifications was made. The results showed that by applying a combination of all ideal modifications, the indoor air temperature was able to be reduce compared to the fieldwork measurements. Design No.4 (D4) is the

best building envelope design which recorded the highest average difference (0.76ºC) of indoor air temperature. In terms of the number of annual thermal comfort hours, design No.3 and 6 (D3 and D6) are the best envelope designs in which they improved the annual number of thermal comfort hours to 7.87%.

CHAPTER ONE: INTRODUCTION

1.1 INTRODUCTION

This chapter will briefly explain the key words of this study. Meanwhile, the primary motivation of this study, in general, will explain what is going on in this study. The research background, problem statement, previous reviewed research studies, objectives, importance of the research, research questions and an overview of the thesis structure will be discussed in this chapter.

1.2 RESEARCH BACKGROUND

This study discusses and focuses on the performance of mud brick house envelope in hot and dry climate to enhance the indoor air temperature, which is the major problem during the summer season due to excessive outdoor condition. The measurable scales of this performance are focused on passive cooling. Houses selected in this study are traditional and modern mud brick houses in Tarim city at Wadi Hadhramout, Yemen. The main subjects are: building envelope, indoor air temperature, hot and dry climate and mud brick.

The abundance and easy availability of mechanical cooling systems help in propagating the inaccurate idea among common people in such a way that providing thermal comfort has become just as easy as pressing a button. Another thing that helps in the growth of this misconception is the lack of awareness of the problems related to increasing energy use and the benefits of minimised consumption. The climate responsive building design which incorporates passive features are very good options for energy conservation (Singh et al., 2011). According to Martin (1980), heating and cooling systems may be used where building design alone cannot achieve suitable conditions for maintaining thermal comfort.

In this section of research background, can start by briefly define the main keywords in this study. The first subject is building envelope which is defined by ASHRAE (2007) as the building elements that separate uncontrolled outdoor environment from controlled indoor environment. It is one of the most important factors in designing energy-efficient buildings. Its design strongly affects heating and cooling loads (ASHRAE, 2007). However, its components include: foundation, walls, roofs, floors, window and doors (California Energy, 2009; ASHRAE, 2007; Szokolay, 2001a; Lang, 2004). One of the most basic significant functions of the building envelope is to control the environmental factors such as heat, air movement, daylight and sound in order to provide comfort for users with minimal energy consumption (Oral et al., 2004). It is the most important design parameter among other parameters effecting indoor thermal comfort (Manioğlu and Yılmaz, 2008). (Lang, 2004).

In terms of building envelope design, Givoni (1998) reported that the appropriate design is the design aimed at minimising or maximising the impact of solar radiation depending on the climate and related design objective considering building shape, orientation, wall, roof, external colour and window shade devices. Envelope design as a means of improving indoor condition is the integrated design of building parameters as a total system to obtain comfortable and energy savings (Okba, 2005). Moreover, Huovila et al. (2007) pointed out, that in relation to how the building envelope is designed, that it is also how building is located in the local environment: a building must be designed with taking into account passive solar issues, such as building orientation and siting, window size and location glazing area, natural lighting and ventilation, as well as shading device strategies. Others such as Bouchlaghem (2000) addressed the aspect of building envelope in terms of improving thermal performance saying that there are mainly two types of parameters affecting the thermal performance of a building. The first type is the fluctuant climatic factors that the building is subject to, such as solar radiation, air temperature, relative humidity and wind direction, the second type is under the control of the architect such as layout and siting, materials properties, window location and size, shading, insulation and finishing. However, some of these factors have more influence over the building thermal response than others.

From the energy consumption point of view, the selection of proper material, design and construction of a building's facades has a major effect on the building energy consumption (Hammad and Abu-Hijleh, 2010; Bader, 2010). During the early stages of the building design process, the solar radiation and the neighbouring buildings (building surrounding areas) should be determined, and the shape of the building structure to achieve the self-shaded facades during the hot summer days, the best selections for building envelop materials and exterior and interior finishes material, shading devices, window size and glazing should also be identified (Capeluto, 2003).

The second subject is the indoor air temperature, In simple terms, temperature is a measure of the motion of molecules (Bluyssen, 2009) and it is also defined as *''the symptom of the presence of heat in a substance''* (Szokolay, 2008). The degree of heat contained in a body or fluid medium describes the concept of temperature (Fathy, 1986). In other words, it measures how hot or cold the air is, and it is measured in Celsius scale, Kelvin scale and Fahrenheit scale. Heat flows from a higher (hotter) temperature zone (or body) to a lower (colder) temperature one. Such heat flow can take place in three forms (Capehart et al., 2002) (Binggeli, 2003) (Szokolay, 2008) :

1. Conduction within a body or bodies in contact, by the 'spread' of molecular movement.
2. Convection between a solid body and liquid or gas. The convection heat flow rate depends on area contact, difference in temperature and convection coefficient.
3. Radiation from a body with a warmer surface to another which is cooler.

Air temperature is one of the main climatic factors, and dry blub temperature (DBT) is the variable most generally used to describe climate (Rosenlund, 2000; Groth, 2007). Moreover, air temperature is direct result of solar radiation. According to Givoni (1976) the rate of heating and cooling of the surface of the earth is the main factor determining the temperature of the air above it. As is well-known, the indoor air temperature is influenced by the outdoor air temperature and by the indoor surface temperature which is also influenced at a high degree by the absorbed heat from direct exposure to solar radiation and in a small degree by the long wave radiation from the clear sky.

In terms of human comfort, which is considered the most important requirement for the indoor environment, air temperature is one of the main parameters affecting human comfort. It is well-known that maintaining indoor air temperature within thermal comfort is the key word of saving energy as well as the main purpose of passive house. Huovila et al. (2007) define passive house as a building which provides comfortable interior climate for residents without the use of active cooling or heating system. Generally, from another point of view, passive design is the design that does not require any mechanical system whether for heating or cooling. It is designed for enhanced comfortable conditions over outside environment without the use of any electric mechanical systems (Reardon et al., 2008; Yeang, 2006). These authors noted that a house that takes the advantage of natural climate to maintain thermal comfort is considered as a passively-designed house. Thus, in relations to the local climate, passive ideas should be considered from the initial design stage. Ji and Plainiotis (2006) sited that passive design is not an attachment or supplement to architectural design, but a design process that is integrated with architectural design.

From the previous statement, it can be noted that the intricate design of building envelope will reduce external heat gain, indoor air temperature, increase ventilation, and day lighting as well as improve indoor thermal comfort, which comes out with elimination, or at least reduce the requirement of mechanical heating and cooling systems, which means reducing energy consumption.

The third subject in this study is the hot and dry climate. The indoor environment of houses is greatly influenced by the climate prevailing in the region. However, hot and dry climate is the most dominant climate in the world (Peel et al., 2007). It is the climate which is characterised by summer day time temperature which is very high, large diurnal (day–night) temperature variation, winter cool or warm, winter night which is very cold, dry air, with seldom rains of less than 250 mm annual (Meir and Roaf, 2002; Rosemary and Susan, 2007; Szokolay, 2008; Huddart and Stott, 2010). Therefore, the house envelope design must take into consideration the indoor thermal comfort to avoid any negative impact on the occupants thermal comfort sensation.

Efficient use of energy has become a key issue for most energy policies. Papadopoulos and Giama (2007) posited that energy efficient buildings decrease the quantity of fossil fuels consumed and thus decrease the amount of carbon dioxide and sulphur dioxide emitted into the atmosphere. Golubchikov and Badyina (2012) add that generation energy is the major contributor of CO2 emissions and climate change and it also results in many other forms of environmental pollution. Building sector energy consumption grew 18% between 2000 and 2010, to reach around one-third of global final energy use (International Energy Agency, 2013). Buildings are one of the major sectors that consume energy. According to Yılmaz (2007), buildings sector consumes more than half of all electricity, in addition to its being responsible for more than one-third of all greenhouse gas emissions. Moreover, residential buildings sector in the developing countries consumes more than half of the electricity distributed (Synnefa et al., 2007). At the present time, climate consideration in building design has become a necessity to meet this growing energy demand (Singh et al., 2010).

According to Yemen Government Report (2005) as shown in Figure 1.1 residential buildings consume about 58% of total electrical energy generated in the year 2004, with an increase of about 12% than 1990 in Figure 1.2. Furthermore, Figure 1.3 shows that the increase in electric consumption in residential buildings through the years was very high compared with other sectors where the increase was moderate. The choices of material, design and construction of a building’s facades have major impact on the energy consumption of buildings. However, reducing energy consumption in buildings can be achieved through several ways such as proper urban planning and landscape design, building layout, orientation, ventilation, shape, windows, selection of proper materials, finishing, insulation and shading.

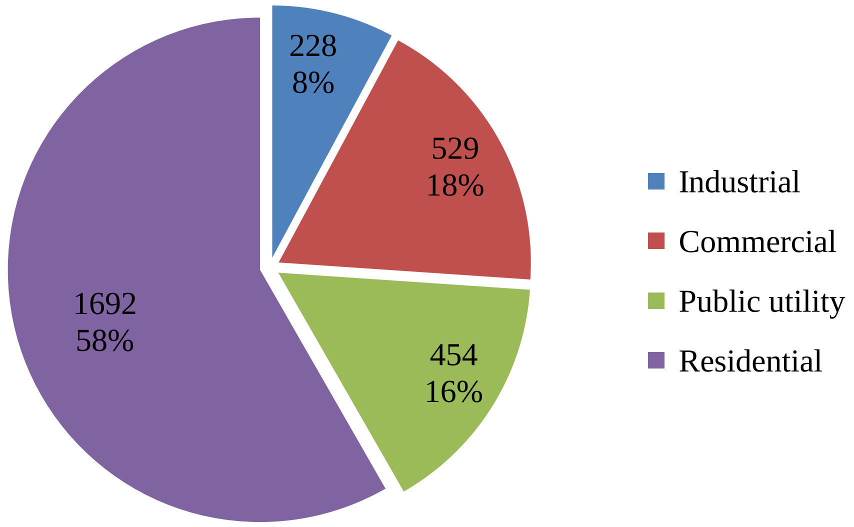

Figure 1.1 Electricity consumption for different sectors GW/H for the year 2004 in Yemen
Source: Yemen Government Report (2005)

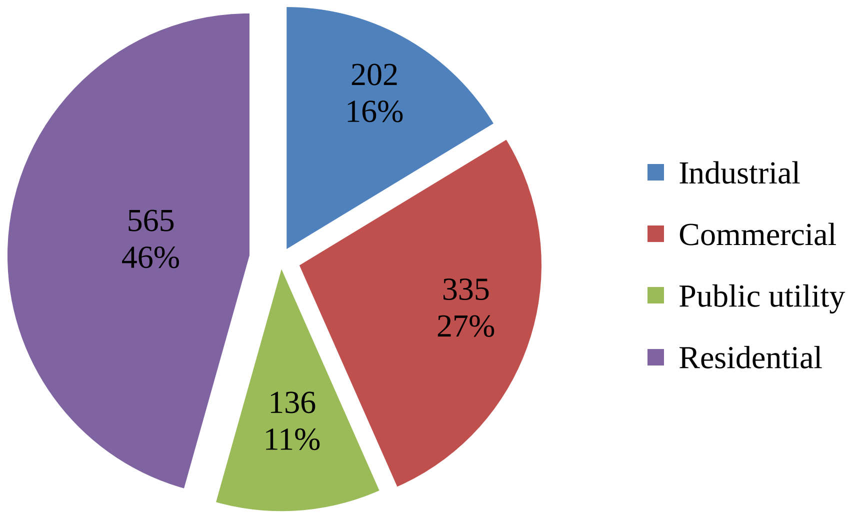

Figure 1.2 Electricity consumption for different sectors GW/H for the year 1990 in Yemen
Source: Yemen Government Report (2005)

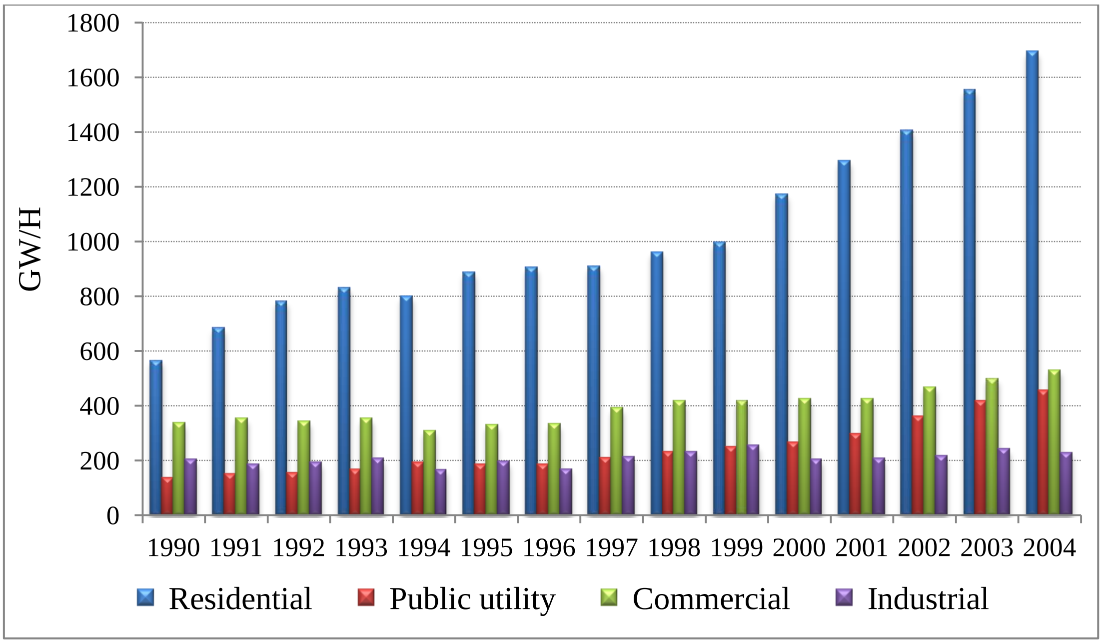

Figure 1.3 Electricity consumption for different sectors GW/H in Yemen
Source: Yemen Government Report (2005)

In Wadi Hadhramout particularly, according to a Branch of the Ministry of Electricity in Wadi Hadhramout (Refer to appendix H), Figure 1.4, 1.5 and 1.6 have shown that residential buildings consume electricity ranging from 68% to 79% of total electrical energy generated. Moreover, Figure 1.7 has shown remarkable increase in electric consumption through the past eleven years. The responsibility of architects and engineers for a passive design presents an important factor. However, Studies aimed at minimising energy consumption for heating and cooling of these houses have become a necessity.

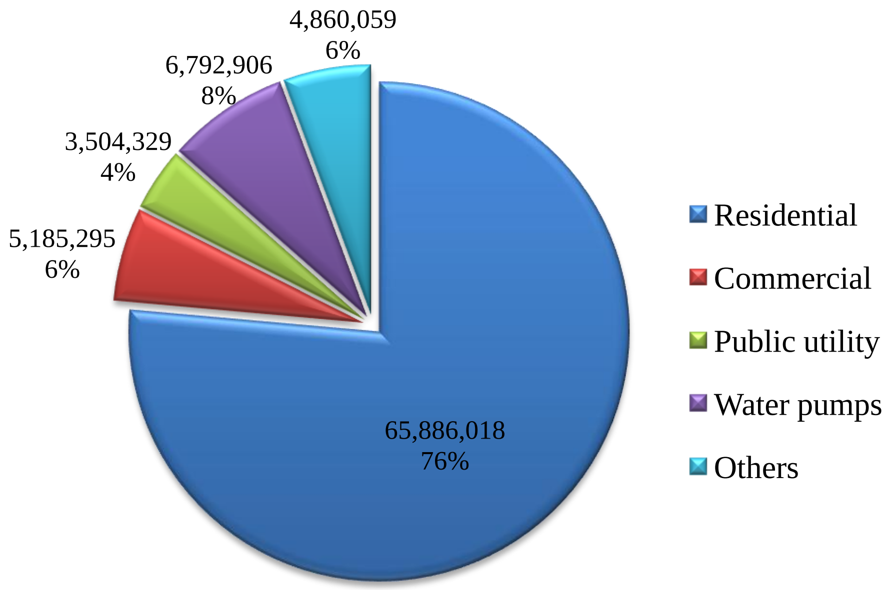

Figure 1.4 Electric consumption for different sectors in Wadi Hadhramout (kw/h) for the year 1999

Source: Ministry of Electricity (2010)

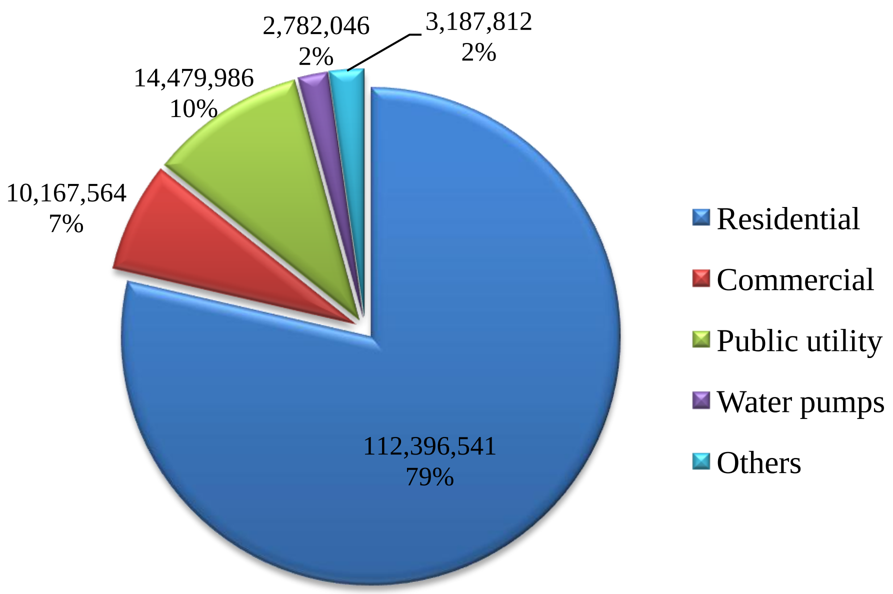

Figure 1.5 Electric consumption for different sectors in Wadi Hadhramout (kw/h) for the year 2004

Source: Ministry of Electricity (2010)

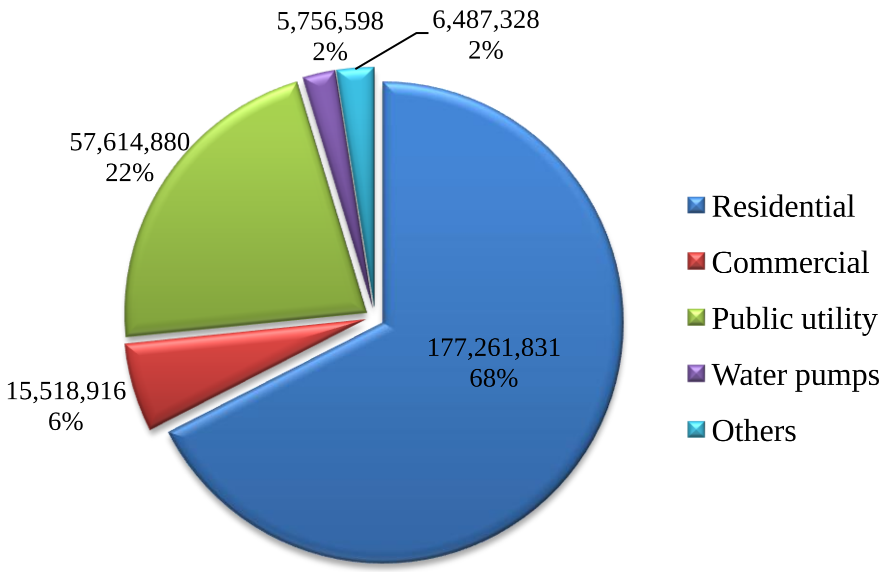

Figure 1.6 Electric consumption for different sector in Wadi Hadhramout (kw/h) for year 2009

Source: Ministry of Electricity (2010)

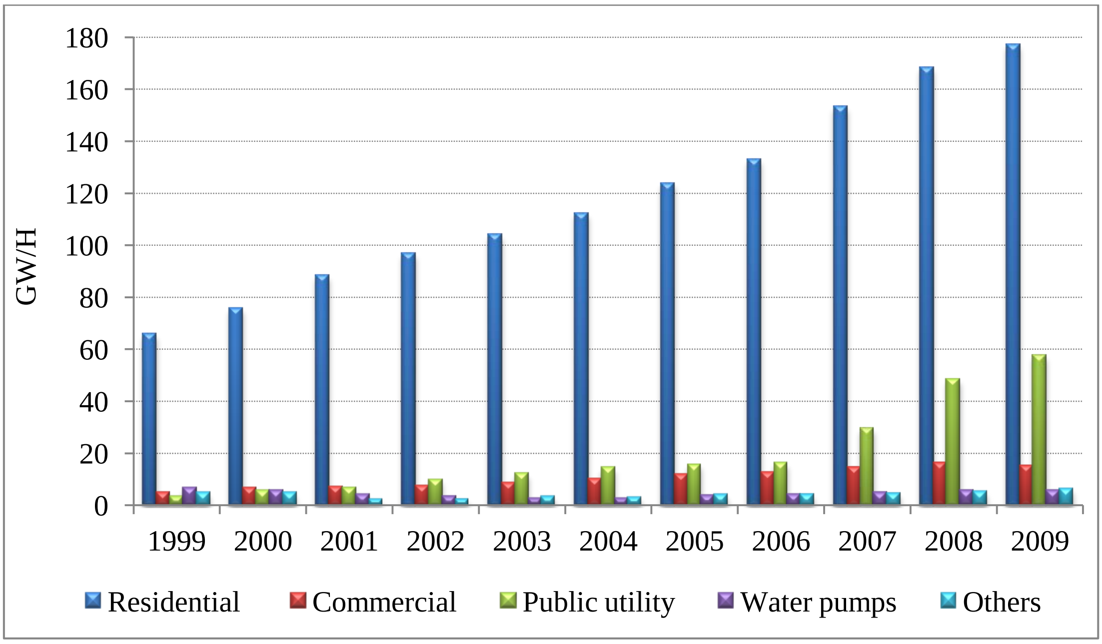

Figure 1.7 Electricity consumption in Wadi Hadhramout for different sectors GW/H

Source: Ministry of Electricity (2010)

This study will focus on the optimization of the indoor air temperature of the modern houses in Tarim city at Wadi Hadhramout, particularly on the most common houses in the new city extension. With the assistance of simulation software, the study will investigate the effects of different building envelope parameters, which have effects on indoor air temperature, such as roof, wall, window to wall ratio (WWR), external shading projection, and orientation as a passive cooling technique for the purpose of minimising dependence on the mechanical system and providing thermal comfort for the users.

1.3 PREVIOUS RELATED RESEARCH STUDIES

Many studies were conducted in hot and dry climate by a number of researchers aimed at enhancing indoor condition of residential buildings. They are varied in addressing this purpose. While some studied the thermal performance of envelope materials and design, others studied the appropriateness of building design to the local climate. Other studies focus on means of passive techniques to provide thermal comfort for occupants, with difference in the number of parameters, while some studied only one or two parameters of passive techniques such as orientation and insulation and so on. However, some of these studies are listed and briefly mentioned below.

a- Saleh (1990)

A study has been conducted by Saleh (1990a) in hot and dry climate in Saudi Arabia. He investigated the effect of six different wall designs and three different roof designs on the indoor air temperature and surface temperature as well as the cooling load generated by the heat flow from walls and roofs. The study also aims at verifying the hypothesis, which says that the mud brick is a thermal regulating material. The results of six model simulation indicated that the mud brick model, in terms of space air temperature, performs better than other models except the insulated one, in terms of indoor surface temperature the mud brick model remained lower than ambient air temperature for longer periods than that of the other models. The study noted that the mud brick is classified as not a good heat conductor and concluded by proving the hypothesis and considered the mud brick as a thermal regulating material.

b- Algifri et al. (1992)

Algifri et al. (1992) conducted a thermal behaviour study on mud brick and concrete houses in hot and dry climate in Yemen at Seiyun city. The quantitative results of the analysis indicate the good performance of mud houses, where the inside surface temperature of concrete house was higher than ambient temperature in comparison with mud brick house which recorded lower surface temperature than the ambient temperature. He reported that mud brick is a good construction material for energy saving.

c- Qadhi and Algifri (2000)

Qadhi and Algifri (2000) carried out a comparative study on the thermal properties of mud and concrete construction materials. The studies concluded that the local building material (mud brick) has excellent thermal properties which maintain the indoor condition within thermal comfort range. However, both studies were not concerned with any type of passive cooling techniques which enhance indoor air temperature such as orientation window size etc.

d- Alani (2000)

Alani (2000) made an analytical study of the energy of a house built with mud brick and another one built with concrete conducted by Algifri, in which the results showed the efficiency of mud house (walls and roof) to maintain the indoor thermal comfort during summer period. The study also cited some thermal and durability properties of mud brick.

e- Al-Sanea and Zedan (2002)

Many studies were conducted on the effects of orientation on indoor thermal comfort. Al-Sanea and Zedan (2002) reported in the study conducted in Riyadh hot and dry climate during summer season, that the wall orientation has a significant effect on the heat transfer and on the yearly cooling load.

f- Nahar et al. (2003)

Several studies have been conducted with a focus on roofs. Nahar et al. (2003) tested the cooling performance of different passive techniques on the roof such as painting by white cement, roof pond, evaporative cooling, air void thermal insulation, broken white glazed tile pieces. It has been found that evaporative cooling is the best cooling technique, but it consumes water. Thus instead of evaporative cooling, the study recommended the second best technique which was white glazed tiles over the roof for enhancing comfort condition in arid area.

g- Marsh and Al-Oraier (2005)

A study of traditional mud brick houses was conducted by Marsh and Al-Oraier (2005) in hot and dry climate. The study was to determine the most effective passive cooling techniques required to enhance occupant comfort in these buildings.

However, the study examined the effect of different parameters on indoor air temperature. By applying the tested modification on one example model, the study suggested some strategies to maximise comfort condition, and it concluded that the application of passive design modification can have a significant effect on internal comfort levels.

h- Kumar et al. (2005)

Kumar et al. (2005) described the performance evaluation of solar shading insulation as one of solar passive cooling techniques, and he noticed about 2.5°C to 4.5°C of reduction in indoor air temperature obtained by solar shading. Further reduction of 4.4°C to 6.8°C in room temperature was obtained when the results was modified with insulation and controlled air exchange rate. The study suggests that solar shading with insulation and air exchange is quite useful to maintain indoor air temperature lower than that in the conventional building.

i- Amer (2006)

Amer (2006) introduced several passive modification to the roof in hot and dry climate in order to reduce the indoor air temperature, and the result showed a fall in indoor air temperature from the ambient temperature up to 6ºC when the roof is painted white, and 3ºC when thermal insulation layer has been added.

j- Al Hamdi and Kaki (2007)

Many studies have been conducted in Saudi Arabia regarding appropriate cooling techniques in hot and dry climate. Al Hamdi and Kaki (2007) conducted a comparative study which focused on investigating the thermal performance of the mud brick old building and modern buildings constructed with concrete. The study was to determine the pattern of change in indoor air temperature and wall surface temperature as well. The results showed good performance of mud brick house, where the indoor air temperature of old mud brick house was lower than concrete block house by about 4°C, and the indoor surface temperature of mud brick house was cooler than indoor surface temperature of concrete block with about 7.6°C.

k- Al Hamdi (2007)

Al Hamdi (2007), in his study, talks about some of passive cooling techniques such as wind catcher, water roof pond system, natural ventilation, and some passive heating techniques such as direct and indirect solar radiation and direct roof soil coupled system. However, the study noted that the use of passive cooling and heating strategies contribute in reducing energy consumption, and it also draws some recommendations regarding the use of these passive techniques.

l- Gutierrez and Labaki (2007)

Another experimental study conducted by (Gutierrez and Labaki, 2007) was about the thermal performance of fixed exterior shading devices on north and west orientation. Horizontal louvers, vertical fins and eggcrate typology made of concrete and wood were the investigated devices. Results showed that the most significant performance was the horizontal concrete louver on north facade. However, in relation to materials, the concrete devices obtained the most excellent results, and it recorded that indoor air temperature lowers the wood, in spite of the good insulation properties of wood. The study also noted that the facade orientation has great effect on the performance of shading devices.

m- Ghisi and Felipe Massignani (2007)

Ghisi and Felipe Massignani (2007) studied the thermal performance of residential buildings, and the objective was to compare the thermal performance of eight unoccupied bedrooms with four different orientation. The assessment includes the correlation between the indoor air temperature and thermal properties of the wall and window and drawing the shading on the window. The study concluded that the two parameters in which show the best correlation with maximum air temperatures and should be minimised in summer for improved indoor thermal condition are U-value and facade area. The thermal capacity and thermal time lag are the two parameters that show the best correlation in winter and should be maximised to improve indoor thermal condition.

n- Albatici (2009)

In a study conducted by Albatici (2009), aimed to define possible design action to improve indoor comfort condition, the first three steps were monitoring the indoor thermal condition of one pilot building; second, modelling and simulating the thermal behaviour of this pilot building, and then suggestion of changes in some passive building elements (insulation, material properties, glass area and sun space) in order to evaluate the best options. The study in the end draw a guideline regarding the investigated passive elements towards the right design for low energy and with local techniques and materials.

o- Khalil et al. (2010)

Efforts have been made by Khalil et al. (2010) in hot and dry climate in Egypt to evaluate the thermal performance of different construction materials (insulated and non-insulated concrete, double, plant and active concrete covering). The results of this study reported that heat transfer through the material (U-value) plays a major role. The study also emphasised on the use of insulation which was damping the thermal stress and maintaining the indoor condition near comfort zone. Natural night ventilation was recommended to improve the indoor condition. Indoor air temperature recorded thermal damping of 96%, 90%, 89% and 76% for insulated concrete, double, planted and non-insulated concrete respectively. More experimental studies have been carried out in different passive cooling techniques. However, in terms of insulation there are many studies investigating the performance of insulation. While some studied the effect of insulation in reducing energy consumption, others studied the optimum thickness, location in the wall and roof and tested different kinds of insulation materials (Ozel and Pihtili, 2007; Mishra et al., 2012; Al-Sanea and Zedan, 2002; Çomakli and Yüksel, 2003; Cabeza et al., 2010; Fertelli, 2013).

p- Kamal (2010)

A theoretical study by Kamal (2010) discussed different shading strategies that can be used to shade buildings, thus providing natural cooling and assisting in minimised energy consumption in buildings. The study also reported the ways and techniques in which it can shade and protect buildings from direct sunlight. He also mentioned a number of points that must be taken into account for summer shading as well as a brief classification of shading devices. Meanwhile, in terms of shading as a simple method of passive cooling in order to protect buildings from the sun, its use is highly recommended and their thermal performance and benefits are recognised and discussed by many researchers (Baker, 2001; Etzion, 2001; Brown and Dekay, 2001). However, many studies have been conducted to determine the performance of self-shading building envelope and external shading devices as a passive cooling technique and effective element for saving energy and improving indoor thermal condition (Fadzil and Sia, 2003; Capeluto, 2003; Al-Musaed et al., 2007; Bakhlah et al., 2008; Laouadi and Galasiu, 2009; Tariq and Jinia, 2012).

q- Al-sudais (2010)

Al-sudais (2010) conducted a study on the effect of window to wall ratio (20%, 50%, 75% and 100%), window with multiple panes (single, duple and triple), and orientation towards south and west on the performance of indoor thermal condition of the tested room. By the comparison of these parameters, the study made recommendations regarding the performance of window to wall ratio on thermal condition. The main conclusion was in the case of the building oriented to the south with window to wall ratio of 25%, it is preferable to use window with single pane glass, because the comparison results show no significant difference between the three types (single, duple and triple).

r- Khoukhi and Fezzioui (2012)

Khoukhi and Fezzioui (2012) conducted a study on traditional houses in hot and dry climate in Algeria; and the study evaluated the thermal comfort of modern houses by conducting comparative analysis with existing traditional houses, in which they tabulated the percentage of hours within thermal comfort. The study concluded that the modern houses were inappropriate for hot and dry climate, and there are no other solutions to ensure thermal comfort in summer apart from the air-conditioned system.

s- Kim et al. (2012)

Kim et al. (2012) conducted a comparative study of external shading devices in residential houses in terms of energy saving for heating and cooling; and the analysis by energy simulations programme IES-VE (Integrated Environmental Solution – Virtual Environment) has shown that the experimental shading device provides the most efficient performance with different adjustments of the slat angle.

t- Kokogiannakis et al. (2012)

Effects of material surface properties on thermal performance have been observed by Kokogiannakis et al. (2012). He analysed the energy impact of different external and internal surface coating. The study concluded that, roof coatings can have a significant influence on the energy performance of buildings with low insulation levels in the roof.

u- Hamdani et al. (2012)

Hamdani et al. (2012) conducted a study on the effect of orientation and insulation on indoor air temperature in hot and dry climate in Algeria. He noted that changing orientation of buildings has not had a significant impact on interior temperature especially in hot season. The study noted that the use of high thermal inertia (The resistance of a material to temperature change) is the key property in controlling temperature fluctuation.

v- Leskovar and Premrov (2012)

Leskovar and Premrov (2012) conducted a study to determine the ideal windows to wall ratios in relation to energy efficiency in well-insulated houses with prefabricated timber frame structural. The results point out that the optimal windows area for walls with lower U-values is slightly smaller than in walls with higher U-values.

w- Sherif et al. (2012)

Sherif et al. (2012) investigated the effect of the depth and perforation configuration of the external perforated window solar screens on the annual energy load in hot and dry climate in Egypt. The result proved that the deep perforated solar screens in the South and West orientations efficiently achieved up to 30% of the total energy load. However, the study recommended perforation of 80% to 90% and depth/opening width ratio of 1:1.

x- Bencheikh (2013)

Bencheikh (2013) investigated the performance of passive cooling system by evapo-reflective roof in buildings for hot arid climates. Result showed reduction in indoor air temperature up to 6 to 10ºC compared to indoor air temperature of room with exposed roof. Moreover, by allowing natural ventilation at night, further reduction up to 3 to 3ºC was obtained.

y- Sedki et al. (2013)

Recent field measurements of indoor air temperature and relative humidity were conducted by Sedki et al. (2013b) to analyse the effects of orientation on indoor thermal comfort in hot and dry climate during winter in Egypt. IES-VE (Integrated Environmental Solution – Virtual Environment) was used after calibration to predict indoor air temperature. The study concluded that there is no significant effect for the orientation on improving thermal conditions in this specific week of the survey period.

1.4 PROBLEM STATEMENT

In hot and dry climate, minimising indoor air temperature by passive techniques is very important, as argued by all worldwide researchers who noted that the building envelope design has significant effect in reducing heat gain from the outdoor thus minimising energy consumption. The problems are buildings in developing countries mostly designed without taking enough consideration of the climate condition (Rosenlund, 2000). Moreover, most architects ignore the effect of the passive techniques such as envelope design, orientation, materials, etc. and its importance to reduce the indoor air temperature. Hence, its contribution in obtaining indoor thermal comfort, and unfortunately, the resort to using mechanical system for cooling to provide comfort (Nahar et al., 2003; Koranteng and Abaitey, 2009; Heidari, 2010).

Lack of studies so far is conducted to guide the architecture to the optimal design of the building envelope of mud brick house in hot and dry climate in Yemen. Few studies have been conducted to determine how much passive cooling techniques contribute in reducing the indoor air temperature for naturally ventilated mud brick houses in hot and dry climate in Wadi Hadhramout, Yemen. Furthermore, there is no guideline for building envelope design of natural ventilation building and no energy efficiency codes for the building sector, which are necessary to guide and provide the designers with necessary information to obtaining thermal comfort condition and minimising energy consumption.

There is a need of study in Yemen to determine the amount of energy consumption for cooling in residential buildings. However, a study conducted in Saudi Arabia by (Elhadidy et al., 2001) reported that air conditioning in residential buildings consumed about 73% of total electricity; and this excessive consumption of electric energy for just air-conditioning system, makes it necessary to design energy-efficient buildings (Ahmad, 2004). Residential buildings are now becoming more influenced by external climate; and energy and thermal comfort were not considered as important issues in settlements planning (Eliasson, 2000; Johansson, 2006).

The energy sector plays a vital role in the socio-economic development of any country (Al-Yousfi, 2004). More than 20% of the population in Arab regions suffer from the lack of electrical energy supplies; and almost the same percentage suffer from epileptic supply of electric power (UN-ESCWA, 2006; Al-Yousfi, 2004; Fattouh and El-Katiri, 2012; Abdul Gelil, 2008). Yemen is one of Arab world countries with the poorest energy services particularly in the field of electricity access (Fattouh and El-Katiri, 2012). According to Yemeni government report published in (2005), it was reported that the beneficiaries of the electricity power are about 36% of total population in the year 2004; and about 39.6% in years 2009 and 2010 (W B, 2013). In Hadhramout state, energy consumption increased rapidly to reach about 278.25 GW/H in 2010 from 140.07 GW/H in 2001with a growth rate of about 11% per annum. Yemen still needs to increase electric power generation to meet needs which means increase in air pollution and CO_2 emissions. Thus, any successful energy-efficiency building design will also have a significant impact in reducing the negative impact on the environment.

Thus, it is certain that the results of this study will significantly help in understanding and promoting the use of passive cooling techniques, suggest recommendations for methods in improving the indoor environment, and consequently contributing to eliminate or reduce the reliance on active cooling mechanical system.

1.5 RESEARCH QUESTIONS

The research questions of this study are as follows:

1- What is the indoor and outdoor thermal condition during summer and winter in traditional and modern mud brick houses in hot and dry climate of Wadi Hadhramout? Is it within the thermal comfort zone?
2- How do the building envelope elements affect the indoor condition; and how does each element affect indoor air temperature in hot and dry climate?
3- Is the existing wall and roof thickness effective; and what is the effective wall and roof thickness?
4- What is the important element of envelope design which has good contribution in enhancing indoor thermal condition?
5- What is the new building envelope design which improves the indoor air temperature in hot and dry climate? Is it achieving comfortable indoor condition?

1.6 OBJECTIVES OF THE STUDY

The main objectives of this study are to evaluate thermal features of the house envelope and identify the appropriate methods and means of building envelope elements to reduce indoor air temperature of hot and dry climate in Tarim, to ensure thermal comfort level of the users and minimise energy consumption. So the objectives of the study are:

1- To investigate the existing building envelope elements which affect the indoor air temperature and thermal comfort of residential buildings.

2- To suggest appropriate methods as a recommendation for building envelope design which reduces indoor air temperature by passive cooling techniques in hot and dry climate.

1.7 RESEARCH FRAMEWORK

Before starting any research it is essential to draw a clear plan describing the steps and methods that will be followed to conduct this research correctly. The research framework of this study (Figure 1.8) can be summarised and organised into three main phases namely: literature review, research methodology and analysis. The first step contains two parts; the first one is the definition and collecting of sufficient information and resources such as books, journals and theses related to the research subject in order to know the background, problems, objective and research questions, and in the end drawing a clear framework on how to accomplish this research. The second part is the identification of the climate in the study area; and then, definition of keywords will be reviewed followed by previous research and studies in similar contexts of this study especially on the impact of building envelope elements on indoor thermal condition. Finally, the indoor thermal comfort and the previous studies in this context will be reviewed.

The second phase is research methodology which consists of the methodology of survey, simulation and case study. The first step (methodology of survey) will cover the methodology of data collection from the fieldwork, methodology diagram, checklist factors and equipments to be used. However, the second step is the simulation which consists of a review of building simulation software and selection of software. Model will be calibrated by the real measurements from the field. Modifications that will be made to the building envelope elements will also be