# AN INVESTIGATION OF THE IMPACT OFBUILDING ENVELOPE CONSTRUCTION MATERIALS ON THE THERMAL PERFORMANCE OFRESIDENTIAL HOUSES IN BENGHAZI-LIBYA

**Awad S. Bodalal**

Mechanical Engineering Department
Garyounis University Benghazi Libya
E-mail: drawadbodalal@hotmail.com

**الملخص**

يهدف هذا البحث إلى دراسة التأثير الحراري للمواد الإنشائية الداخلة في بناء الظرف الخارجي لنموذجين من المباني السكنية الواقعة في مدينة بنغازي وتقيم مساهمة المكونات الأساسية للظرف الخارجي (الجدران والنوافذ والأسقف) في كمية الحرارة المكتسبة أو المفقودة من المبنى. حيث قدم هذا البحث نتيجة محاكاة نظرية لثلاثة بدائل لمواد بناء تستخدم في بناء الظرف الخارجي للمبنى لتصميمين من المباني السكنية في البيئة الليبية. البديل الأول يفترض أن الظرف الخارجي للمبنى يتألف من طبقة من الملاط الداخلي بسمك 12 مم متبوعا بطوب إسمنتي مجوف بسمك 200 مم ثم طبقة من الملاط الخارجي بسمك 12 مم. وهو نمط البناء الشائع في الجماهيرية وبالتالي تم استخدامه كمقياس لمقارنة أداء البديلين الآخرين. البديل الثاني يفترض أن الظرف الخارجي للمبنى يتألف من طبقة من الملاط الداخلي بسمك 12 مم متبوعا بطوب إسمنتي مجوف بسمك 150 مم وفراغ بسمك 50 مم، وطوب إسمنتي مجوف بسمك 100 مم ثم طبقة من الملاط الخارجي بسمك 12 مم. البديل الثالث يفترض أن الظرف الخارجي للمبنى يتألف من طبقة من الملاط الداخلي بسمك 12 مم، طوب إسمنتي مجوف بسمك 250 مم، مادة عازلة من الاسمنت والبرلايت بسمك 25 مم وطبقة من المواد المستخدمة في التشطيب الخارجي بسمك 4 مم. تم استخدام البرنامج الهندسي المعروف (Cymap) في دراسة تقييم الأداء الحراري لهذه البدائل ومقارنة هذا الأداء بالمعايير والمقاييس العالمية المنصوح بها في الكفاءة الحرارية للمباني. أظهرت نتائج المحاكاة الحرارية أن الأداء الحراري للبديل الأول وهو النمط الشائع في بناء البيت الليبي هو الأقل كفاءة حرارية وان البديل الثالث هو الأكثر كفاءة حرارية والأكثر اقتصادية في استهلاك الطاقة وبالتالي هو الأكثر ملائمة للبيئة الليبية. كذلك كانت مساهمة المكونات الأساسية للظرف الخارجي للمبنى المتمثلة في النوافذ و الجدران و الأسقف هي 20%، 70%، 10% على التوالي من الحمل الحراري الكلي المنتقل عبر الظرف الخارجي للمبنى.

**ABSTRACT**

This study is aimed at the investigation of the impact of the building envelope construction materials on the thermal performance of two different designs of residential buildings in Benghazi Libya. Three different scenarios of building envelope construction materials were simulated. The first scenario (called reference scenario), which is widely used in building in Libya, consisted of 12 mm layer of cement plaster followed by a 200 mm hollow cement block and a 12 mm layer of cement plaster. The second scenario consisted of 12 mm cement plaster, 150 mm hollow cement block, 50 mm air gap, 100 mm hollow cement black, and a 12 mm layer of cement plaster. Finally, the third scenario of the building envelope assumes that it consisted of 12 mm layer of cement plaster followed by 250 mm hollow cement block and a 25 mm decorative color layer functioning as insulation (mixture of cement and perlite) known as Stucco. A commercial software (Cymap) is used to simulate the thermal performance of the three alternatives scenarios. The contribution of walls windows, and roofs in the total heat loss/gain from the building is assessed. The total energy consumed in the building (in cooling and heating) is calculated in monthly and annual basis. The results of this study reveals that the reference scenario, which is commonly use in Libya, is the worst among the three scenarios and the walls, windows and roofs contribute by about 70%, 20% and 10% from the total building fabric load respectively.

**KEYWORDS:** Building thermal insulation; Building envelope; Building energy efficiency; Thermal load calculation; Fabric (transmission) load; Residential Envelope Transmittance Value (RETV); budget cost method.

## INTRODUCTION

Occupied buildings have always been designed to keep people comfortable. Energy concerns in both official as well as public level have changed recently. Previous studies have revealed that a great amount of world energy demand is connected to the building environment. For instance, in 2008, buildings in Libya (residential and commercial) consumed about 45% from the total electrical energy produced in the country [1]. A considerable amount of this percentage is consumed by cooling and heating equipment. Also, there is a direct proportion between the increased $CO_2$ discharge to the outer atmosphere and the energy demand in general, and the energy consumed in building, in particular [2]. In an age of increased environmental awareness and increased fuel prices, nations have begun placing increased emphasis on the amount of energy consumed by buildings. One of the main methods to achieve an optimum thermal performance is to insulate the building envelope by applying appropriate insulation materials which leads to increasing the energy efficiency of the building as well as reducing the running cost [3,4].

In light of the conditions of the Libyan environment, and in order to achieve the thermal comfort criteria, the buildings in Libya require heating in the winter and cooling in the summer. The heating and cooling loads are greatly influenced by the size, type, function as well as the thermal properties of the building materials especially those used in the exterior construction of the building. Obviously, a greater load requires a larger HVAC system in order to achieve thermal comfort criteria. This will directly increase the initial and operational investments as well as the energy consumed in the operation of the system. Therefore, reducing the energy use for space cooling and heating in building is a key measure to energy conservation and environmental protection in Libya.

As is known, the better the thermal properties (especially thermal conductivity) of the external building construction materials, the more energy efficient it is. In Libya, some of the most commonly used construction materials for building envelope are the cement brick as the principle substance, plus two cement plaster layers as internal and external finishing layers. Cement bricks and reinforced concrete are well known for being easy to construct and for having high durability. This has led to their dominance in construction in Libya. However, they also have some disadvantages especially in regards to their thermal properties, namely its high thermal conductivity. Therefore, buildings made of such construction materials are usually uncomfortable for its occupant unless an air-conditioning system is heavily employed. Figure (1) shows a typical building in Libya along with cross sectional view of the external wall. As we can see, it is simple a block of concrete since all wall as well as roofs are not thermally insulated and this leads to dramatic increases in the thermal load.

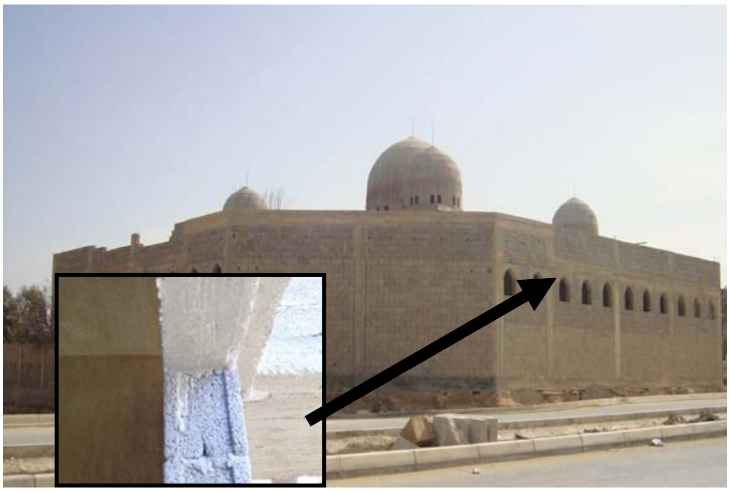


**Figure1: A typical building envelope used in Libya**

The aim of this paper is to investigate the impact of the building envelope construction materials on the thermal performance of two different designs of residential buildings in Benghazi Libya. A commercial software (Cymap) was employed to simulate the thermal performance of the three alternatives scenarios. The contribution of the individual building envelope component namely the walls the windows and the roofs in the total heat loss/gain from the building will be evaluated. Finally, the total energy consumed in the building (in cooling and heating) is calculated in monthly and annual basis.

It is hoped that the results of this study and its findings will rise the awareness and highlight the importance of the thermal properties of building envelope construction materials as a key factor for reducing the energy use for space cooling and heating in buildings.

## PREVIOUS STUDIES

In literature, there are many studies directed toward the energy conservation in the buildings. This review is not intended to be extensive but, rather to show clearly conclusions of the previous researchers regarding the effect of some environmental parameters on the energy consumed in the buildings and also the effect of some thermal properties of building materials, namely the thermal conductivity on the heat lost/gain through the building envelope. Hasan (1999) [5] used life cycle cost analysis to determine optimum insulation thicknesses. The results showed that for rock wool as an insulation, 10 years is the saving life time with 21$/m$^2$. He reported payback periods of 1-1.7 years for rock wool and 1.3-2.3 years for polystyrene insulation depending on the type the wall structure. Comakli and Yuksel (2003) [6] investigate the effect of insulation thickness on the energy used in the building. He optimized the thickness of the insulation when coal is used as a fuel. Al-Sallal (2003) [7] studied the usages of polystyrene and fibreglass as insulations in warm and cold climates. He found that the payback period in cold climates is shorter than that in warm climates. The selection and optimization of the insulation layer formed the frame work of Al-Khawaja and et. al. (2004) [8]. He found that the position of the insulation layer play an important role in the overall performance of the insulated wall. Ozkahraman and Bolatturk (2006) [9] investigate the effect of using tuff stone as external building materials on the thermal behaviour of the building in cold climates. He conclude that a considerable energy saving can be achieved by using this type of stone as an outer finishing layer. In a study conducted by Sisman et. al. (2007) [10] aimed to investigate the impact of applying insulation layer to ceiling and walls of residential house in Turkey, it was shown that considerable energy saving can be achieved by insulation of the outer envelope of the building. He also proposed a correlation of optimum insulation thickness in terms of degree day.

In general, two important conclusions can be drawn from the above review. Firstly, all the previous studies have concluded that, thermal properties of the building envelope play a vital role in the energy saving in the buildings. Secondly, most of the previous studies concentrated on the usages of insulation materials as part of building walls and less attention is given to the other building envelop components namely windows and roofs. This paper will address the effect of the three building envelop components and the contribution of each one on the total heat gain/loss from the buildings.

## DESCRIPTION OF THE SIMULATED CASES

Before describing the cases that intended to be simulated, it is worthwhile to give some definition of some key terms used in this study as well as a list of the assumptions upon which this simulation is based.

### (i) Definitions and Key Assumptions

First, the term “Design” denotes the different floor plans used in this study. For instant, Design-I refers to diagram V1-a and Design-II refers to diagram V2-a (See Figure (2)). It is noteworthy that the floor areas for the first and second design are 190.76 $m^2$ and 157.89 $m^2$ respectively. Also, the window areas in Design-I is 18.36 $m^2$ and Design-II is 21.8 $m^2$. Secondly, the term “Scenario” is used to represent the different external wall constructions that were considered in this paper. Later, the composition of the different scenarios will be given along with the calculation of their individual U-values.

Based on the information available on the designs, the following assumptions were made in this simulation:

- The building is facing south (to assume the worst case scenario load)
- The environmental and meteorological data were given for the case of Benghazi-Libya
- Gypsum was used as the outer decorative layer in the third scenario
- The cost of energy was made to be the local expense of electricity (0.05 L.D./kW hr)
- The value of thermal conductivity (*k*) was taken from Holman J. P. (1981)
- All other input parameters used in the software are based on ASHRAE standard

**(ii) Description of the Two Designs**

The simulated cases are two residential houses located in Benghazi Libya (Latitude $32^0$.45”). All other important information about the two designs is summarized in the table below.

| Design | Floor Area ($m^2$) | Fenestration Surface Area ($m^2$) | Opaque Surface Area ($m^2$) |
|---|---|---|---|
| I | 190.76 | 21.18 | 174.32 |
| II | 157.89 | 18.36 | 226.87 |

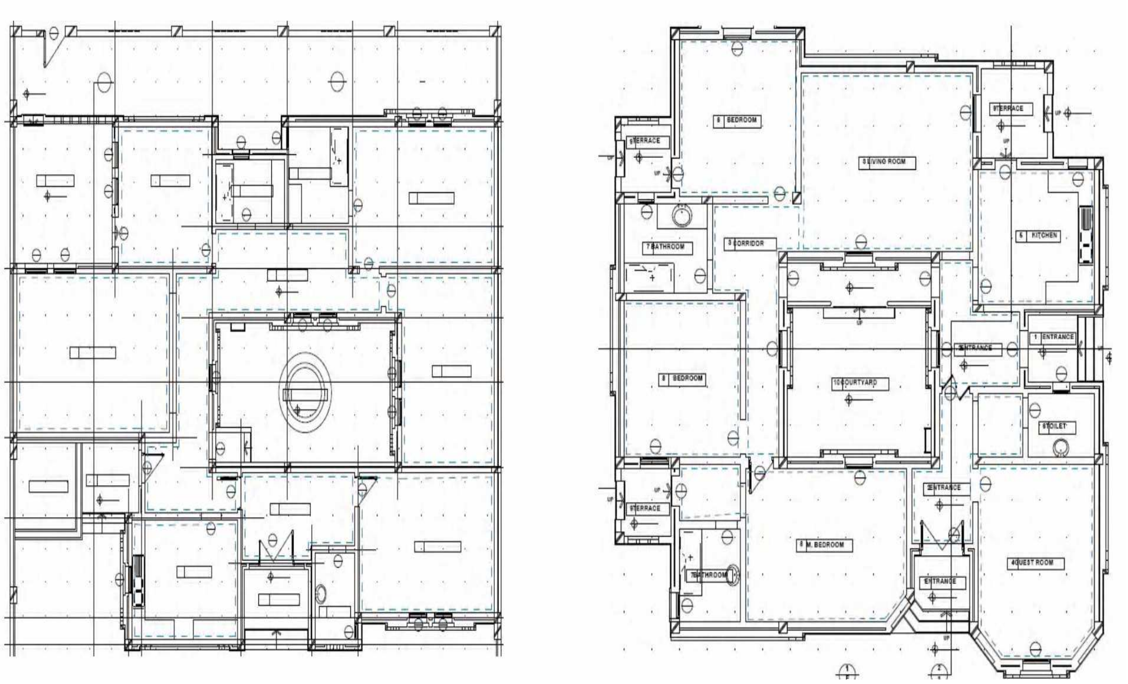


**Figure 2: Floor plan of the simulated cases for Design-1 (left) and Design-2 (right)**

**(iii) Proposed Scenarios of the Envelope Components**

This section will describe the structure of the three wall scenarios as well as the other envelope components. The table below (Table (1)) gives detailed descriptions of all components that were investigated in this study.

**(iv)The Overall Heat Transfer Coefficient (U-Value) Calculations**

As mentioned above, in this study the simulation process will be performed via a commercially available software namely Cymap. One of the key input parameters is the overall heat transfer coefficient (*U*). This section will describe in detail the method that was used to evaluate the *U*-values that were used in this study. Table (2) below summarizes the materials that were used in the construction of the building envelope as well as their particular thermal parameters [11] [14]. The subsections (**a, b, c** and **d**) are devoted to the details of the calculation procedure for the walls, roofs, windows and floors of the three given scenarios respectively.

**Table 1: Description of the building envelope Components used in the simulations**

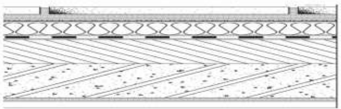
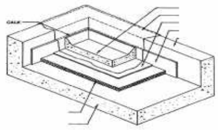
| Envelope component | Cross sectional | | Description |
|---|---|---|---|
| Wall | Scenario-I |  | * Plaster (12 mm Thick), * Hollow concrete block (HCB) 200 mm, * Plaster (12 mm Thick) |
| | Scenario-II |  | * Plaster (12 mm Thick), * Hollow concrete block (HCB) 100 mm, * Air-gap of 50 mm, * Hollow concrete block (HCB) 150 mm, * Plaster (12 mm Thick) |
| | Scenario-III |  | * Decorative colour layer (4 mm) (***Stucco***), * Mixture of cement + perlite (insulation) (25 mm), * Hollow concrete block (HCB) 250 mm , * Plaster (12 mm Thick) |
| Roof |  | | * Cement Mortar Tile , * Cement Mortar, * Sand Bed, * Heat Insulation, * Water Proofing, * Plain Conc. Sab * Reinforced Conc. Slab |
| Floor |  | | * Terrazzo Tile [k=1.73] (L=15mm),* Cement Mortar [k=1.73] (L=20 mm) * Sand Bed [k=0.35] (L=60 mm) * Plain Conc. Slab [k=1.8] (L=100 mm) * Water Proofing [k=0.0648] (L=40 mm) * Plain Conc. Slab [k=1.8] (L=100 mm) |
| Windows |  | | * Single Clear 6 mm glazing |

**Table 2: Materials used in constructing the building envelope of the simulated cases [11, 14, 15].**

| Material | Conductivity $k$ (W/mK°) | Thickness $L$ (mm) | Resistance $R$ (m$^2$K°/W) |
|---|---|---|---|
| Plaster | 1.2 | 12 | 0.01 |
| Hollow Concrete Block | 0.9 | 100 | 0.11 |
| | | 150 | 0.16 |
| | | 200 | 0.22 |
| | | 250 | 0.27 |
| Perlite + Cement Mixture | 0.31 | 25 | 0.07 |
| Decorative Layer (Stucco) | 1.39 | 4 | 0.002 |
| Cement Mortar | 1.73 | 20 | 0.01 |
| Terrazzo Tiles | 1.73 | 15 | 0.008 |
| Sand Bed | 0.35 | 40 | 0.11 |
| | | 60 | 0.17 |
| Water Proofing (EPDM) | 0.06 | 40 | 0.61 |
| Plain Concrete Slab | 1.75 | 100 | 0.05 |
| Heat Insulation | 0.025 | 50 | 2 |
| Reinforced Concrete Slab | 1.9 | 100 | 0.05 |

**(a) The overall heat transfer coefficient calculations for the walls**

*** Scenario I "Reference Case"**

$$\because U = \frac{1}{\sum R_{th}} = \frac{1}{R_o + R_1 + R_2 + R_3 + R_i}$$ where $R_0$ and $R_i$ Outside and Inside air film resistance

$R_o = 0.0444$ m$^2$K$^o$/W and $R_i = 0.12$ m$^2$K$^o$/W

$R_1 = L_1 / K_1 = 0.012/1.2 = 0.01$ m$^2$K$^o$/W (for 12 mm thick plaster outside)

$R_2 = L_2 / K_2 = 0.2/0.9 = 0.22$ m$^2$K$^o$/W (for 200 mm thick hollow concrete block)

$R_3 = L_3 / K_3 = 0.012/1.2 = 0.01$ m$^2$K$^o$/W (for 12 mm thick plaster inside)

$$\therefore U = \frac{1}{0.04 + 0.01 + 0.22 + 0.01 + 0.12} = 2.46 \text{ W/m}^2\text{K}^o$$

*** Scenario II**

The U-value may be calculated in a manner similar to Scenario-I.

$$\therefore U = \frac{1}{0.04 + 0.01 + 0.11 + 0.17 + 0.16 + 0.01 + 0.12} = 2.05 \text{ W/m}^2\text{K}^o$$

*** Scenario III**

The U-value may be calculated in a manner similar to Scenario-I.

$$\therefore U = \frac{1}{0.04 + 0.002 + 0.07 + 0.27 + 0.01 + 0.12} = 1.88 \text{ W/m}^2\text{K}^o$$

**(b) The Overall Heat Transfer Coefficient Calculations for the Glass Windows**

| | Summer | Winter | Adopted Value |
|---|---|---|---|
| $U$ (W/m$^2$K$^o$) | 5.9 | 6.2 | 6.02 |

**(c) The Overall Heat Transfer Coefficient Calculations for the Roofing**

Following similar procedures to the above, we can calculate the U-value for the roof.

$$\therefore U = \frac{1}{0.04+0.008+0.01+0.1+2.0+0.61+0.04+0.05+0.12} = 0.33 \text{ W/m}^2\text{K}^o$$

**(d) The Overall Heat Transfer Coefficient Calculations for the Flooring**

Following similar procedures to the above, we can calculate the U-value for the roof.

$$\therefore U = \frac{1}{0.12 + 0.00 + 0.01 + 0.17 + 0.0.05 + 0.61 + 0.05} = 0.95 \text{ W/m}^2\text{K}^o$$

Table (3) below summarizes the results of the calculations performed above of all *U*-values forming the different components of the building envelopes under consideration.

**Table 3: Summary of the calculated U-values**

| Element | (*U*) Value for Scenario-I (W/m² K°) | (*U*) Value for Scenario-II (W/m² K°) | (*U*) Value for Scenario-III (W/m² K°) |
|---|---|---|---|
| External Wall | 2.46 | 2.05 | 1.88 |
| Roof | 0.33 | 0.33 | 0.33 |
| Floor | 0.95 | 0.95 | 0.95 |
| Windows | 6.02 | 6.02 | 6.02 |

## RESULTS AND COMPARISONS OF THE SIMULATED CASES

This section is devoted to the demonstration of the thermal loads as well as the energy consumption of each design, relative to one another. Table (4) gives a comparison between the two designs and the three scenarios in terms of Heating and Cooling loads as well as the energy consumption. The cooling load is calculated for the peak month (June) and the heating load was found using the average value of the heating months load.

It may appear to the reader that the values for Design-2 are lower than those for Design-1. This is largely due to the fact that the floor area of Design-2 (157.89 $m^2$) is less than the area of Design 1 (190.76 $m^2$). Another stark contrast between the two designs is the ratio between the opaque walls and the fenestrations. Design 1 has a fenestration area of 21.8 $m^2$ while Design 2 has a fenestration area of 18.36 $m^2$.

Using Cymap (Building Environment Software), simulations were run and comparisons were made between the designs and scenarios. One of the comparative parameters was the energy consumption per month (in Libyan Dinars). For the sake of brevity, only one set of the graphical comparisons will be placed in this paper. It is noteworthy to mention that the energy calculations were done on a 24 hour basis which is summarized in Table (5).

**Table 4: Comparison of the thermal performance and energy efficiency of the different scenarios (Design-1)**

| | | Design-1 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Scenarios | | | | | | | | |
| | | I | | | II | | | III | | |
| | | Walls | Windows | Roof | Walls | Windows | Roof | Walls | Windows | Roof |
| Fabric Cooling Load (KW) | | 10.25 | 2.70 | 1.38 | 9.54 | 2.64 | 1.28 | 9.16 | 2.70 | 1.25 |
| Heating load (KW) | | 7.88 | 2.23 | 1.16 | 7.15 | 2.11 | 1.02 | 6.80 | 1.91 | 1.01 |
| Energy Consumption | GJ | 180 | | | 173 | | | 170 | | |
| | Cost (LD) | 2495 | | | 2394 | | | 2349 | | |

**Table 5: Comparison of the thermal performance and energy efficiency of the different scenarios (Design-2)**

| | | Design-2 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Scenarios | | | | | | | | |
| | | I | | | II | | | III | | |
| | | Walls | Windows | Roof | Walls | Windows | Roof | Walls | Windows | Roof |
| Fabric Cooling Load (KW) | | 8.48 | 2.51 | 1.25 | 7.77 | 2.31 | 1.16 | 7.57 | 2.16 | 1.10 |
| Heating load (KW) | | 6.43 | 1.80 | 0.95 | 5.80 | 1.70 | 0.81 | 5.50 | 1.51 | 0.80 |
| Energy Consumption | GJ | 155 | | | 150 | | | 146 | | |
| | Cost (LD) | 2162 | | | 2071 | | | 2031 | | |

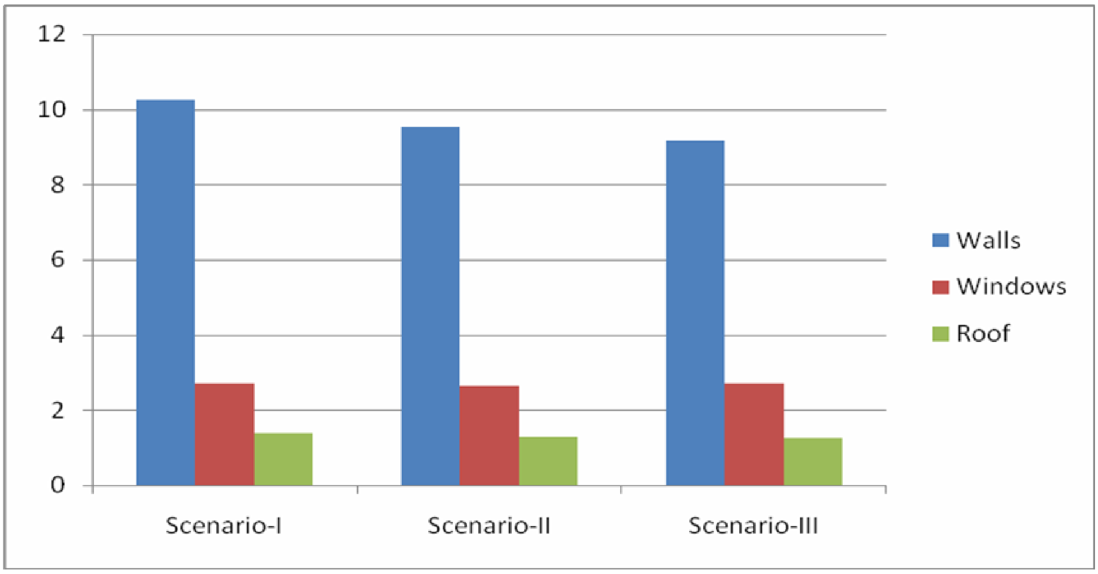



**Figure 3: Comparison of the Fabric Cooling the 3 Scenarios (Design-1)**

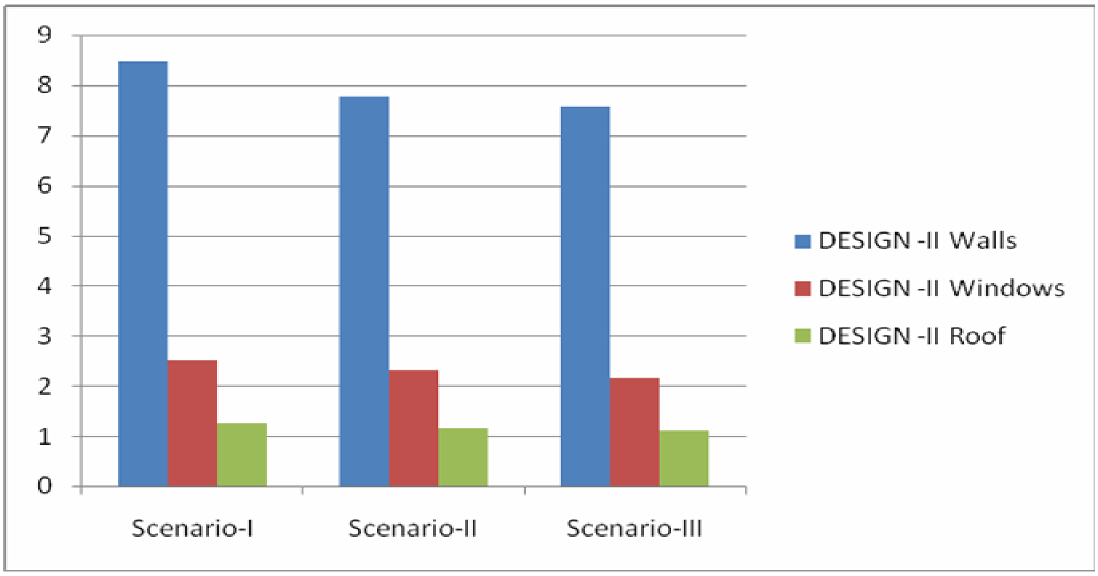
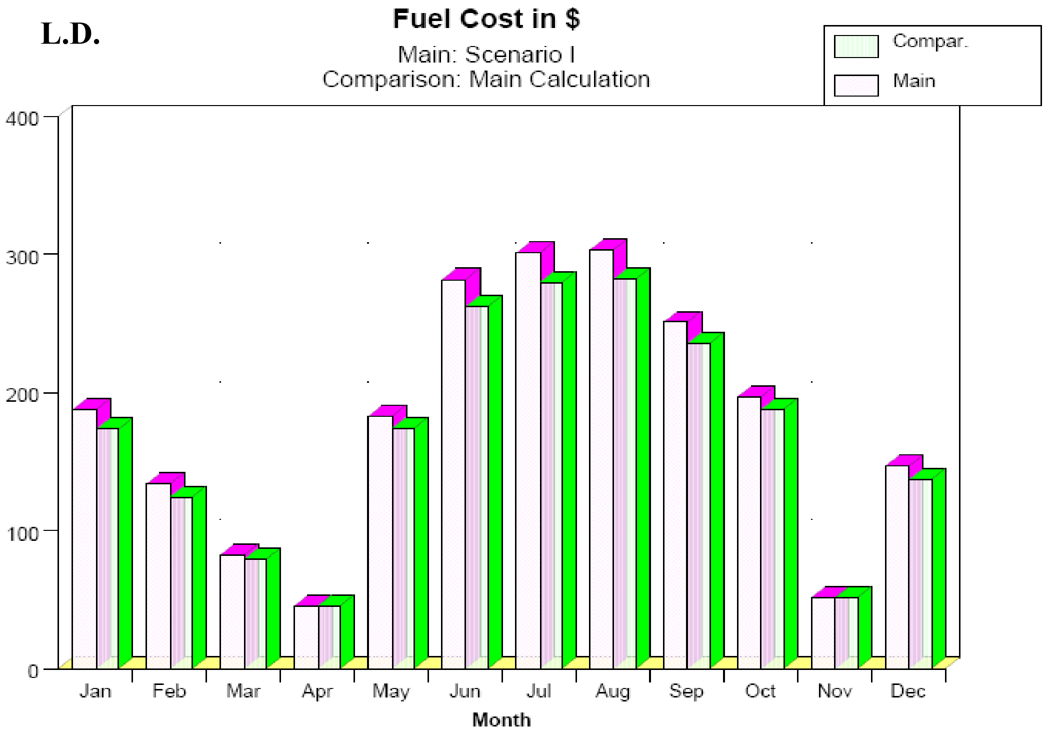



**Figure 4: Comparison of the Fabric Cooling the 3 Scenarios (Design-2)**



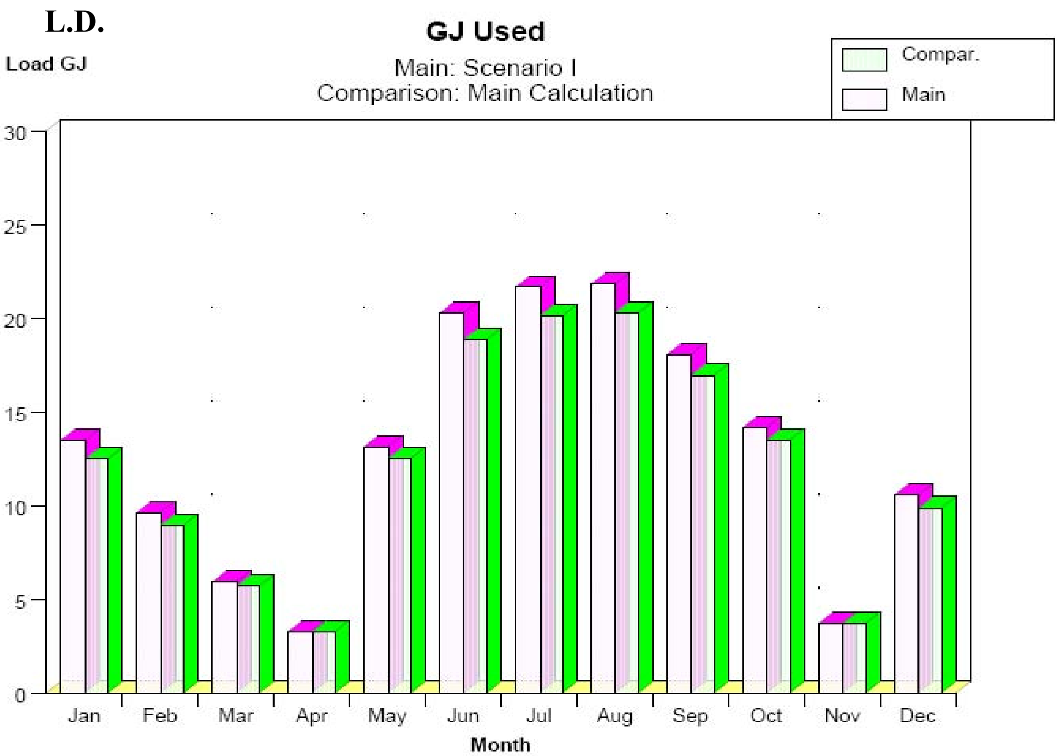




**Figure 5: Comparisons of energy consumption and cost between Scenario-I and Scenario-II in Design-II**

## Building Envelop Reference Criteria

The three scenarios and two designs were put through tests in terms of the conformity to the international standards for the sake of energy conservation and thermal efficiency. The main focus of this section will be on the two methods usually used for the thermal evaluation of the buildings namely the Budget Cost Method (BCM) and the Residential Envelope Transmittance Value (RETV) Method.

### 1-Budget Cost Method (BCM)

This standard is used to set a maximum value of energy per unit floor area. The standard is set at 35 BTU/hr/ft$^2$ or 0.11 kW/m$^2$. The following depicts the compliance of the wall structures with the standard:

In the case of Design-1, since the floor area is 190.76 m$^2$, then the building thermal load should not exceed 20.98 kW

Standard BCM value = 190.76 x 0.11 = 20.98 kW (maximum)

Similarly, in the case of Design- 2, since the floor area is 157.89 m$^2$, then the building thermal load should not exceed 17.36 kW

Standard BCM value = 157.89 x 0.11 = 17.36 kW (maximum)

**Table 6: Comparison of maximum allowable (BCM) values with calculated loads**

| Design No. | Scenario No. | Standard BCM values (KW) | Calculated Value (KW) | Compliance |
|---|---|---|---|---|
| Design-1 | Scenario I | 20.98 | 21.4 | **FAILED** |
| | Scenario II | | 19.9 | PASSED |
| | Scenario III | | 19.2 | PASSED |
| Design-2 | Scenario I | 17.36 | 17.9 | **FAILED** |
| | Scenario II | | 16.5 | PASSED |
| | Scenario III | | 15.9 | PASSED |

According to Table (6), the first scenario in both designs failed to comply with the Budget Cost Method, whereas the all other scenarios were within range and hence may be considered thermally efficient.

### 2-Residential Envelope Transmittance Value (RETV) Method

This is a standard that is a specialized form of Overall Thermal Transfer Value (OTTV) calculation. It is specifically designed for residential dwellings. The OTTV requirement does not apply to non air-conditioned buildings such as residential buildings that are designed to be naturally ventilated. However, as it becomes increasingly common for residential buildings to be air-conditioned, there is a need to regulate the design of their envelopes so that heat gain or lost into the interior spaces and hence air-conditioning energy used can be minimised.

Based on the results of previous specialized studies, the OTTV concept was extended in 2008 to cover residential buildings [12]. As the air conditioners in residential buildings are usually turned on in the night, the envelope thermal performance standard for residential buildings is given the name Residential Envelope Transmittance Value (RETV) so as to differentiate it from OTTV, which is meant for buildings that operate the air-conditioning system during the day. Based on this method, a value of 25 W/m$^2$ has been recognized as the maximum limit in evaluating the building envelope thermal performance [13].

*** General Equation**

$$RETV = 3.4(A_w \times U_w)/A_o + 1.3(A_f \times U_f)/A_o + 58.6(A_f \times SC_f) \times CF/A_o$$

Where:

**$A_w$:** Area of opaque walls (m$^2$)
**$U_w$:** U-value of opaque wall (W/m$^2$.K)
**$A_o$:** Area of external walls (m$^2$)
**$A_f$:** Area of fenestration (m$^2$)
**$U_f$:** U-value of fenestration (W/m$^2$.K)
**$SC_f$:** Shade Coefficient of fenestrations
**CF:** Correction Factor

*** The overall RETV value**

$$RETV(overall) = \frac{(A_{o1} * RETV_1) + (A_{o2} * RETV_2) + ... + (A_{on} * RETV_n)}{(A_{o1} + A_{o2} + ... + A_{on})}$$

The following tables (7 and 8) will summarize the result of the RETV calculation for the two designs and each of their 3 scenarios:

**Table 7: RETV values for Design-I of the three scenarios**

| Design-1 | | | | | Scenario-I | | Scenario-II | | Scenario-III | |
|---|---|---|---|---|---|---|---|---|---|---|
| Façade | Area m$^2$ | Opaque Area m$^2$ | Area of Fenestration m$^2$ | U fenestration (W/m$^2$K$^o$) | U wall (W/m$^2$K$^o$) | RETV (W/m$^2$) | U wall (W/m$^2$K$^o$) | RETV (W/m$^2$) | U wall (W/m$^2$K$^o$) | RETV (W/m$^2$) |
| South | 90.7 | 85.26 | 5.44 | 6.02 | 2.46 | 11.35 | 2.05 | 10.06 | 1.88 | 9.53 |
| North | 66.7 | 60.46 | 6.24 | 6.02 | 2.46 | 12.86 | 2.05 | 11.61 | 1.88 | 11.10 |
| West | 19 | 11.42 | 7.58 | 6.02 | 2.46 | **37.60** | 2.05 | **36.78** | 1.88 | **36.44** |
| East | 19.1 | 17.18 | 1.92 | 6.02 | 2.46 | 15.26 | 2.05 | 14.02 | 1.88 | 13.51 |
| Overall (RETV) | | | | | 14.8075 | | 13.5780 | | 13.0726 | |

**Table 8: RETV values for Design-II of the three scenarios**

| Design-2 | | | | | Scenario-I | | Scenario-II | | Scenario-III | |
|---|---|---|---|---|---|---|---|---|---|---|
| Façade | Area m$^2$ | Opaque Area m$^2$ | Area of Fenestration m$^2$ | U fenestration (W/m$^2$K$^o$) | U wall (W/m$^2$K$^o$) | RETV (W/m$^2$) | U wall (W/m$^2$K$^o$) | RETV (W/m$^2$) | U wall (W/m$^2$K$^o$) | RETV (W/m$^2$) |
| South | 63.498 | 57.57 | 5.92 | 6.02 | 2.46 | 13.01 | 2.05 | 11.76 | 1.88 | 11.25 |
| North | 67.8 | 62.8 | 5 | 6.02 | 2.46 | 11.91 | 2.05 | 10.63 | 1.88 | 10.11 |
| West | 66.9 | 62.58 | 4.32 | 6.02 | 2.46 | 13.10 | 2.05 | 11.81 | 1.88 | 11.28 |
| East | 47.1 | 43.98 | 3.12 | 6.02 | 2.46 | 12.91 | 2.05 | 11.62 | 1.88 | 11.09 |
| Overall (RETV) | | | | | 12.71 | | 11.44 | | 10.91 | |

A point that may be noted in the RETV comparison is that the West wall has the highest value in all the scenarios of Design-I even though the overall RETV value complies with the standard (25 W/m$^2$). This is largely due to the fact that the walls on that side have a relatively high window to wall ratio. Therefore, this may place emphasis on the importance of window allocation in the design phase of construction.

As for Design-II, all of its walls' values are within the range of the RETV and its overall values are lower than their counterparts in Design-I. In particular, Design-II Scenario-III proved to be the most efficient of all the scenarios in terms of RETV.

**Contribution of the Building Envelope individual Components**

The results of this study reveal that the reference scenario, which is commonly used in Libya, is the worst among the three scenarios. Also the analysis of the energy report form the simulations showed that the walls, windows and roofs contribute by 70%, 20% and 10% from the total building fabric load respectively. This founding highlights the importance of the thermal properties of the building envelope construction materials in general and the materials used for the walls in particular. A considerable amount of energy consumed in the buildings can be saved (and hence protecting our environment) if thermally efficient building materials were used in constructing the walls. More attention should be paid to walls insulation (especially in countries like Libya where the demand for building cooling and heating are high) if we need to reduce the energy consumed in the building and save the environment.

## Conclusions and Recommendations

In this study, a simulation was made of the energy consumption of three different scenarios with two designs and a thermally efficient design was determined. The effect of the external wall construction on the thermal performance was observed in a large residential construction project in Sulug-Libya. The following conclusions and recommendations were reached:

### CONCLUSIONS

- As can be deduced from the results of the various calculations, in addition to referencing the standards, Scenario 3 is the most energy efficient construction. However, the contractor has to take into account other factors (such as execution time) into the big picture. From a thermal efficiency point of view, Scenario 3 is the best wall proposal.
- Another deduction that can be reached is that the values of the results for Design 2 are lower and more efficient than Design 1. This is attributed mainly to the lower floor area but as well to the fact that there are less exterior windows. Design 1 has 13.464 $m^2$ of external windows whereas Design 2 has only 10.284 $m^2$.
- Even though Scenario-I (Reference Case) is the most widely used external wall in Libya, it is the least thermally efficient and consumes the most energy.
- The windows play a major role in the determination of the overall energy efficiency of a building, especially the window to wall ratio. Therefore, designers must pay very close attention to the location of windows of buildings in hot environments.

### RECOMMENDATIONS

- Thermally insulating materials should be used in the construction of the external walls or at least different materials should be employed in order to improve the thermal performance of the currently popular wall construction (Scenario-I).

- Large external window areas should be avoided or alternatively, double glazed windows should be used.
- The building should be oriented in such a way that it receives minimal heat gain in the summer and maximum in the winter.
- The area around the building should be modified in such a way to minimize heat gains or loss. Shade (for example, from trees) could decrease the solar heat gains.
- Broadening of building research with emphasis on the introduction of low-cost high-thermal-performance materials into the local market.

**REFERENCES**


[1] Electricity General Company Annual Report (2008) Libya (S.P.L.A.J) "In Arabic"

[2] Aribi, H. Bashir "The Importance of Building Thermal Insulation for Energy Saving and Environmental pollution "Presented in the 25th Arabic Engineering Conference Tripoli, Libya (2009)

[3] Bolatturk, Ali, " Determination of optimum Insulation Thickness for Building Walls With Respect to Various Fuels and Climate Zones in Turkey" Journal of Applied Thermal Engineering Vol. 26 pp.1301-1309 (2006).

[4] Yildiz, A., Gurlek, M., Ozbalta, N. "Economical and Environmental Analysis of Thermal Insulation Thickness in Buildings "Journal of Thermal Science and Technology Vol. 28 pp. 25-34 (2008).

[5] Hasan, A., "Optimizing Insulation Thickness for Buildings Using Life Cycle Cost" Applied Energy Vol. (63) No. 2 pp.115-124 (1999).[6] Comakli, K., Yuksel, B., "Optimum Insulation Thickness of External Walls for Energy Saving" Applied Thermal Energy Vol. (23) No. 4 pp. 473-479 (2003).

[7] Al-Sallal, K. A., "Comparison between Polystyrene and Fiberglass Roof Insulation in Warm and Cold Climates" Renewable Energy Vol. (28) No. 4 pp. 603-611 (2003).

[8] Al-Khawaja, M., J., "Determination and Selecting the Optimum Thickness of Insulation for Buildings in Hot Countries by Accounting for Solar Radiation" Applied Thermal Engineering" Vol. (17) No. 18 pp.2601-2610 (2004)

[9] Ozkahraman, H. T., Bolatturk, A., "The Use of Tuff Stone Cladding in Building for Energy Conservation" Construction and Building Materials Vol. (20) No. 7 pp.435-440 (2006)

[10] Sisman, N., Kahya, E., Aras N., "Determination of Optimum Insulation Thicknesses of the External Walls and Roof for Turkey's Different Degree Day Regions" Energy Policy Vol. (35) pp. 5151-5155 (2007).

[11] ASHRAE Standard

[12] Code on Thermal Performance Envelope (RETV) Building and Construction Authority (2007), Singapore.

[13] Hui, S. C. M., "Overall thermal transfer value (OTTV). How to improve its control in Hong Kong," Proc. Of the one-day Symposium on Building Energy and Environment, Kowloon, Hong Kong, HKIE BS Division /CIBSE/ ASHRAE/PolyU, 1997, pp 12-1 to 12-11.

[14] Holman, J.P. "Heat Transfer" 5th ed. McGraw-Hill (1981), pp 24-48.

[15] www.engineeringtoolbox.com