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Thermal and Financial Comparison Study on Different Configurations of Cement Block Walls in Libya

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ABSTRACT
The use of cement block for the walls in the buildings is widely common in Libya. The 200mm cement block is the most common used type, but, it has many drawbacks such as it is low R-value which is reflecting on the cooling and heating loads of the building and increases the cost of cooling and heating in the summer time and winter time respectively. In this paper, three proposed configurations of cement block are introduced, investigated and classified based on the R-value, U-value and thermal loads by using of the database of the meteoblue website and Hourly Analysis Program (HAP) as a calculation tool.
Results reveal that the 2nd scenario has the highest R-value and lowest thermal loads then the 3rd scenario while the 1st scenario has the worst thermal characteristics. In general, it can be said, that the increase of the insulation leads to enhancement of the R-value, therefore, the thermal characteristics have better values. A 4th scenario is made to have the same R-value of the 2nd scenario but with different combination of the blocks and polystyrene. Financially, the comparison between 2nd and 4th showed that the 2nd scenario has lower capital cost than the 4th scenario.
Keywords: *cement block, heating and cooling loads, HAP software, climate conditions.*

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I. INTRODUCTION

There are many products that can be used to weatherize and insulate buildings. The main objective when insulating is to create an energy-retaining envelope, one that will contain and put to best use the heat/cooling produced by the building's heating/cooling unit. To achieve this, it is needed to use different materials, each in an appropriate location. One of those materials is the expanded polystyrene (EPS). Insulated concrete form (ICF) panels are structural wall panels made out of poured concrete core in interlocked expanded polystyrene (EPS) that hold the concrete together during curing operation. The EPS are stay-in-place permanently as a part of a wall panel where EPS provides thermal insulation to the building and reinforced concrete affords a structural system to the building [1].

The flow rate of heat through a building product is known as the U-value. The U-value (or U-factor) is a measure of the flow of heat (thermal transmittance) through a material, given a difference in temperature on either side. Since the U-value is a measurement of heat flow, the lower the U-value, the more slowly does the material transfer heat in and out of the home. The U-value typically is used in expressing overall thermal conductance, since it is a measurement of the rate of heat flow through the complete heat barrier, from room air to outside air. The lower the U-value, the better is the insulating value. U-value is the customary unit used by the fenestration industry to quantify conducted heat gain or loss. With other building materials, such as insulation, roofing, and flooring materials, the R-value which represents the total thermal resistance of the walls is frequently used for conducted heat gain or loss [2].

In this study, a thermal comparison between three scenarios will take place taking into account the weather conditions of two cities in the State of Libya. Also, a financial comparison between two scenarios that have the same thermal insulation value will be achieved.

II. THEORETICAL ANALYSIS

In this work, three scenarios of walls of a building will be introduced and studied as follows:

i) The walls are of conventional cement blocks with a thickness of 200 mm, as shown in Figure 1a.

ii) The walls are made of conventional block with a thickness of 200 mm and integrated with 60 mm of expanded polystyrene, as shown in Figure 1b.

iii) The walls are made of three layers including, two layers (internal and external) of 100 mm conventional cement block and, between these two layers, a layer of 30 mm of expanded polystyrene, see Figure 1c.

In all these three scenarios, the total thickness is taken to be close of the value of 200 mm which should be the same for the beam under the walls, note that the third scenario's thickness is exactly 230 mm.

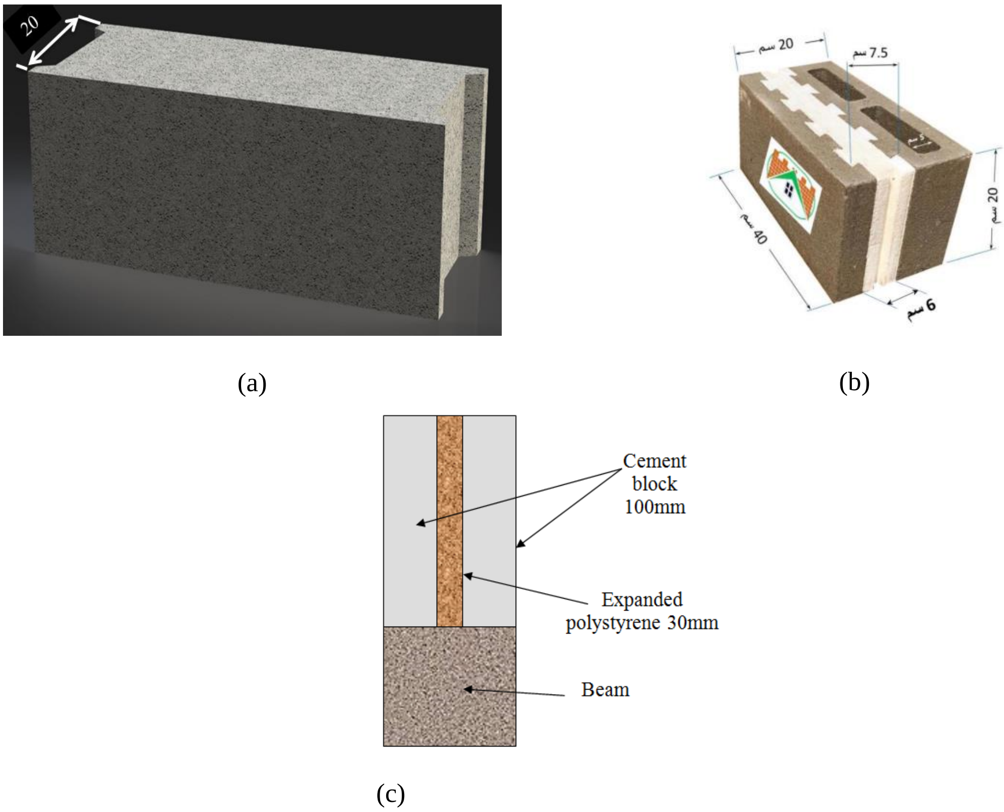

Figure 1. Three scenarios of proposed wall, a) 200mm cement block, b) 200mm cement block with 60mm polystyrene and c) two 100mm cement block with a layer of 30mm polystyrene.

The comparison between the thermal performances of each scenario will be done according to the U-value and the cooling load of the air-conditioning system. The calculation is achieved by means of commercial software called Hourly Analysis Program (HAP).
The heat flux passes throw the wall by conduction is found by applying Fourier equation as follows:

$$q'' = \frac{k}{x} * \Delta T \tag{1}$$

where q'' is the heat flux in W/m^2 , k is thermal conductivity (W/m^2.K), x is the wall thickness in metres, and ΔT is the temperature difference between the inside and outside faces of the wall in Kelvins or degree Celsius .
The heat-transfer rate may be considered as a flow, and the combination of thermal conductivity, thickness of material, and area as a resistance to this flow. The temperature is the potential, or driving, function for the heat flow, and the Fourier equation may be written as:

$$q = \frac{\Delta T_{overall}}{\sum R_{th}} \tag{2}$$

where the term $\sum R_{th}$ is the **R-value** which is the summation of the series thermal resistances , and for single resistance it equals to (*k/x*). The unit of the thermal resistance is (m^2. K/W).
the overall heat transfer coefficient, U-value, is defined as shown in the equation:

$$U = \frac{1}{\sum R_{th}} \tag{3}$$

The unit of the U-value is (W/ m^2. K).

2.1 Hourly Analysis Program (HAP)

HAP is a computer tool which assists engineers in designing HVAC systems for commercial buildings. HAP is two tools in one; firstly, it is a tool for estimating loads and designing systems. Secondly, it is a tool for simulating energy use and calculating energy costs. HAP estimates design cooling and heating loads for commercial buildings in order to determine required sizes for HVAC system components. Ultimately, the program provides information needed for selecting and specifying equipment [3]. Specifically, the program performs the following tasks:

- Calculates design cooling and heating loads for spaces, zones, and coils in the HVAC system.
- Determines required airflow rates for spaces, zones and the system.
- Sizes cooling and heating coils.
- Sizes air circulation fans.
- Sizes chillers and boilers.

HAP's calculation method is made according to the ASHRAE's standards. Moreover, it runs detailed 8760 hour-by-hour simulation for energy analysis purpose.

III. RESULTS AND DISCUSSIONS

3.1 The overall coefficient value (U-value) and thermal resistance value (R-value)

By applying the HAP software to calculate the U-value and R-value for the three scenarios, results come as showing in Table 1 to 3.

From Table 1 to 3, it is clear that the 2nd scenario has the higher value of the thermal resistance with an R-value of 2.09 (m^2.K)/W. The 3rd scenario's R-value is about 1.31 (m^2.K)/W which is about 30% less than the second scenario. While, the lowest R-value among the three proposed scenarios is conducted by the 1st scenario with an R-value of about 0.459 (m^2.K)/W. Comparing with the 2nd scenario, the 1st scenario is slightly more than three-quarters less. For the U-value, by using equation (3), the U-value of the 2nd scenario has the lowest value of 0.478 (W/ m^2. K), while, the U-value of the 3rd scenario is 0.763 (W/ m^2. K). The highest U-value is 2.18 (W/ m^2. K) for the 1st scenario.

Table 1. Wall Layers Details (Inside to Outside) of the first scenario

Layers	Thickness mm	Density kg/m³	Specific Ht. kJ / (kg - °K)	R-Value (m²-°K)/W	Weight kg/m²
Inside surface resistance	0.000	0.0	0.00	0.12064	0.0
203mm common brick	203.200	1250	0.84	0.27954	250.0
Outside surface resistance	0.000	0.0	0.00	0.05864	0.0
Totals	**203.200**	**-**		**0.45882**	**250.0**

Table 2. Wall Layers Details (Inside to Outside) of the second scenario

Layers	Thickness mm	Density kg/m³	Specific Ht. kJ / (kg - °K)	R-Value (m²-°K)/W	Weight kg/m²
Inside surface resistance	0.000	0.0	0.00	0.12064	0.0
203mm common brick	43.000	1250	0.84	0.05915	53.75
Expanded polystyrene	60.000	20.0	1.50	1.71400	1.2
102mm common brick	100.000	1250	0.84	0.13757	125.0
Outside surface resistance	0.000	0.0	0.00	0.05864	0.0
Totals	**203.000**	**-**		**2.09**	**190.0**

Table 3. Wall Layers Details (Inside to Outside) of the third scenario

Layers	Thickness mm	Density kg/m³	Specific Ht. kJ / (kg - °K)	R-Value (m²-°K)/W	Weight kg/m²
Inside surface resistance	0.000	0.0	0.00	0.12064	0.0
102mm common brick	100.000	1250	0.84	0.13757	125
Expanded polystyrene	30.000	20.0	1.50	0.8570	0.6
102mm common brick	100.000	1250	0.84	0.13757	125
Outside surface resistance	0.000	0.0	0.00	0.05864	0.0
Totals	**230.000**	**-**		**1.31142**	**250.6**

To sum up, from the Tables 1 to 3, it is clear that the 2nd scenario has the best R-value and lowest U-value with a clear difference with the two other scenarios as seen in Figure 2. In addition, the 2nd scenario has a privilege over the third scenario because it has lower thickness and less weight/square area which may affect the design conditions and cost considerations.

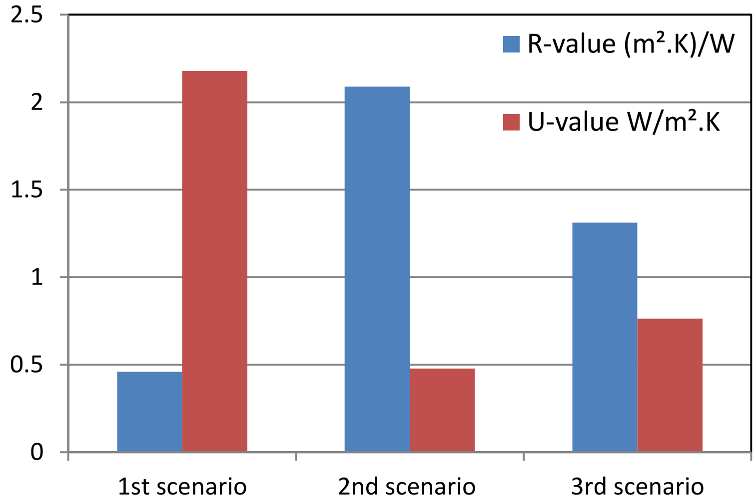

Figure 2. The R-value and U-value of the proposed scenarios

3.2 Thermal loads calculations

In this section, the cooling and heating loads resulting from the walls of a building of dimensions of 6m*6m*3m will be calculated and discussed for the climate conditions of the city of Benghazi, which is located in the north-eastern of Libya at coordinates (32.1194° N, 20.0868° E), and city of Sebha, which is located in the south-western of Libya at coordinates (27.0365° N, 14.4290° E). For each city, the three wall scenarios proposed previously will be considered, therefore, the results will include six different values of the thermal loads.

3.2.1. Thermal loads of Benghazi-location-building

The following tables show the cooling loads of a building in a city of Benghazi by applying the three proposed scenarios on it. The calculation is done by assuming that there are no heat losses from the roof or the ground and the only way for the heat to flow in or out of the building is the walls in order to check the effect of the various proposed wall configurations on the thermal loads.

The climate conditions are taken from the database of the website meteoblue [4]. The meteoblue weather diagrams are conducted on 30 years of hourly climate model simulations and accessible for each place globally. They give good indications of typical climate patterns and expected conditions. Accordingly the weather conditions of Benghazi city is considered that the average ambient temperature in the summer time is 37 °C and in the winter time is 8 °C. It should be taking into account that the indoor design temperature is 24 °C . From Table 4, it can be noted that thermal loads regardless cooling or heating are the lowest in the case of the 2nd scenario which can be justified because of the lowest U-value. In the second place, came the 3rd scenario then the 1st scenario. In addition, Table 4 gives the percentage reduction of applying 2nd or 3rd scenarios based on the 1st scenario.

Table 4. Thermal loads of Benghazi-location-building

Scenario no.	Cooling Load (W)	Heating Load (W)	% Reduction Based on 1st Scenario
1st	2040.48	2511.36	00.00
2nd	447.85	551.20	78.05
3rd	713.73	878.44	65.02

3.2.2. Thermal loads of Sebha-location-building

By applying same assumption in the previous section but on the climate conditions of the city of Sebha [5], which is non-costal city. Therefore, the average ambient temperature in the summer time is 43 °C and in the winter time is 5 °C. the following table has been found.

Table 5. Thermal loads of Sebha-location-building

Scenario no.	Cooling Load (W)	Heating Load (W)	% Reduction Based on 1st Scenario
1st	2982.24	2982.24	0.00
2nd	654.55	654.55	78.05
3rd	1043.14	1043.14	65.02

Same trend of reduction in the thermal loads of Benghazi-location-building happens with the Sebha-location-building, where, the 2nd scenario has the lowest heating and cooling values then came the 3rd scenario. Also from Table 5 can be noted that the heating and cooling loads for each scenario has the same value because the indoor temperature along the year should be 24 °C which lay in the half way between 43°C, in the summer time, and 5°C, in the winter time which makes the temperature difference is the same in both cases. Therefore, the value of the cooling load and heating load for each scenario is the same.

3.3 Cost calculations and comparing between two configurations

As can be seen from the abovementioned sections, the 2nd scenario showed the best characteristics of the thermal insulation but it is needed to compare this scenario with the configuration of 150mm-cement-block and 200mm-cement-block and integrated with 50mm of polystyrene which may have the same thermal characteristics of the second scenario. The R-value of this alternate (4th scenario) is calculated in Table 6.

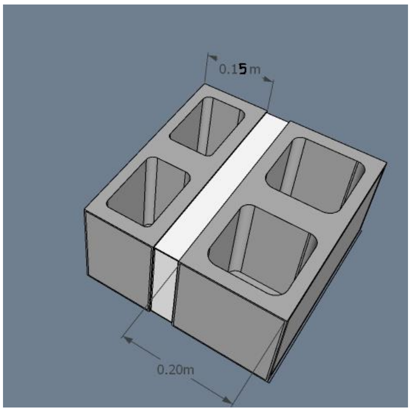

Figure 3. The fourth scenario including double different cement block with a layer of 50mm polystyrene

Table 6. R-value calculations of 4th scenario

Layers	Thickness mm	Density kg/m³	Specific Ht. kJ / (kg - °K)	R-Value (m²-°K)/W
Inside surface resistance	0.000	0.0	0.00	0.12064
203mm common brick	200.000	1250	0.84	0.27954
Expanded polystyrene	50.000	20.0	1.50	1.42833
150mm common brick	150.000	1250	0.84	0.20655
Outside surface resistance	0.000	0.0	0.00	0.05864
Totals	**400.000**	-		**2.0937**

From Table 6, the R-value for this combination is 2.0937 m^2.K/W. Because the R-value of the last combination is very close value of the 2nd scenario; therefore, the financial comparison will be done in this section between the 2nd scenario and this 4th scenario.

In the financial comparison some prices and standards should be fixed in the two scenarios such as the price of the cement bag (50kg) is taken as 16 LD/bag, and the 100kg of reinforced steal is taken as 450 LD/100kg. Also, the prices are taken from the local market as an average value. In addition the 1 cubic metre of reinforced concrete should contain 350 kg of the cement and 100 kg of reinforced steal. Finally, the tie beam cross sectional area is taken 20cm*40cm for the 2nd scenario and 35cm*40cm for the 4th scenario.

Table 7. Financial comparison between 2nd and 4th scenarios.

item	2nd scenario	4th scenario
1m² of block Price*	5.5 LD*12.5 piece/m²= **68.75 LD/m²**	3.2 LD*12.5 piece/m²= **40 LD/m²**
Manpower price*	**9 LD/m²**	**18 LD/m²**
Insulation price*	**0 LD/m²**	**30 LD/m²**
Mortar price**	**2 LD/m²**	**4 LD/m²**
Reinforced tie beam**	(120 LD/m)/3m(height)=**40 LD/m²**	(240 LD/m)/3m(height)=**80 LD/m²**
Total	**119.75 LD/m²**	**172 LD/m²**

Form Table 7, it is clear that the 2nd scenario has lower cost than the 4th scenario to fulfil the same amount of thermal insulation (same U-value). It is noticeable that the increase in cost per metre in the 4th scenario over the

2nd scenario is about 43.63%. From the architectural viewpoint, the difference between the 2nd and 4th scenarios is 40 cm in length and 40 cm in width.

IV. CONCLUSIONS

In this paper, a thermal comparison between three scenarios of walls are considered and investigated based on their R-value and the thermal loads by using HAP software and the database of the website meteoblue.

According to the calculations done in the study, it is concluded that the 2nd scenario has the lowest U-value and highest R-value, therefore, it has the minimum values of cooling and heating loads among the other scenarios regardless the climate conditions of the place that building exist in.

In the second place, the 3rd scenario has a U-value less than the 1st scenario and higher than the 2nd scenario. Reflecting to this result, the cooling and heating loads for the 3rd scenario are in between the two other scenarios. But, the reduction percentage based on the 1st scenario is high and close to the 2nd scenario. On the other hand, comparing between the 2nd and 3rd scenarios it is clear that the 2nd scenario (thickness 200mm) has thinner dimension than the 3rd scenario which makes the foundation beam thinner and, therefore, the cost and the weight smaller.

A 4th scenario is made to have the same R-value of the 2nd scenario but with different combination and dimensions of the blocks and polystyrene. The Financial comparison between 2nd and 4th presented that the 2nd scenario has lower capital cost than the 4th scenario. Where, the increase in the 4th scenario over the 2nd scenario is about 43.63%.

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