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Analysis on thermal performance for increasing energy efficiency: A case study for Tripoli-Libya, using Ecotect®

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Abstract: Recently, the significant increase in energy consumption to provide thermal comfort in Libyan buildings, has increased the dependence on mechanical systems and non-renewable resources. Therefore, there have been efforts, particularly by the governmental authorities, to search for solutions to improve buildings in terms of their thermal performances, in order to reduce high energy consumptions.

The aim of this research is to analyze and determine certain passive design strategies for residential buildings in Tripoli-Libya, by using the analysis program Autodesk Ecotect®, to reduce energy consumptions and provide thermal comfort. By the use of this program, issues such as; best possible orientation, loads of heating and cooling, thermal mass, along with the direct effects of building materials and the importance of window sizes on thermal comfort were analyzed, based on the designed typical Libyan residential building model.

The results of the study were analyzed and guidelines were developed to enhance the energy performance of residential buildings in Libya. The findings of this study show that the proper orientation of the building and effective use of insulation materials can provide a 60% increase in thermal performance. Moreover, the results of evaluation on thermal comfort level by using the PMV method showed that, together with the necessary adjustments, the building would provide thermal comfort for its users.

تحليل الأداء الحراري لزيادة كفاءة الطاقة: دراسة حالة طرابلس ليبيا باستخدام Ecotect®

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ملخص: في الآونة الأخيرة ، أدت الزيادة الكبيرة في استهلاك الطاقة لتوفير الراحة الحرارية في المباني الليبية ، إلى زيادة الاعتماد على الأنظمة الميكانيكية والموارد غير المتجددة. لذلك ، كانت هناك جهود ، خاصة من قبل الجهات الحكومية ، للبحث عن حلول لتحسين المباني من حيث أدائها الحراري ، من أجل تقليل استهلاك الطاقة العالية.

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الهدف من هذا البحث هو تحليل وتحديد بعض استراتيجيات التصميم السلبي للمباني السكنية في طرابلس-ليبيا ، باستخدام برنامج التحليل ®Autodesk Ecotect ، لتقليل استهلاك الطاقة وتوفير الراحة الحرارية. باستخدام هذا البرنامج تمّا معالجة بعض قضايا مثل ؛ تم تحليل أفضل توجيه ممكن ، و دراسة أحمال التدفئة والتبريد ، والكتلة الحرارية ، إلى جانب التأثيرات المباشرة لمواد البناء وأهمية أحجام النوافذ على الراحة الحرارية ، بناءً على نموذج المبنى السكني الليبي النموذجي المصمم.

تم تحليل نتائج الدراسة ووضعت أدلة إرشادية لتحسين أداء الطاقة في المباني السكنية في ليبيا. تظهر نتائج هذه الدراسة أن التوجيه الصحيح للمبنى والاستخدام الفعال لمواد العزل يمكن أن يوفر زيادة بنسبة 60 ٪ في الأداء الحراري. علاوة على ذلك ، أظهرت نتائج التقييم على مستوى الراحة الحرارية باستخدام طريقة PMV ، إلى جانب التعديلات اللازمة ، أن المبنى سيوفر الراحة الحرارية لمستخدميه.

Keywords: ***Ecotect, Energy Efficiency, Passive Design Strategies, Residential Buildings, Tripoli.***

1. INTRODUCTION

Energy is one of the main necessities of everyday life in civilized societies. However, rapid industrial development which increases the global energy demand constantly (Suzer, 2015), leads to the increase in electricity production costs. Therefore, as to mitigating environmental impacts and providing economic savings, effective energy conservation is required at a global scale.

As to the energy consumption in Libyan buildings, mostly electricity is consumed for cooling and heating purposes for the extreme seasonal temperature variations (IEA Country Energy Statistics, 2009). Moreover, the issue of global warming is increasing the temperatures especially during summer seasons, which leads to the increase in energy needs (Morrissey and Justus, 2000). The problem is that the increase in energy consumption in the buildings for purposes of cooling and heating in Libya has increased the dependence on mechanical systems to provide thermal comfort. Even though Libya is one of the rich countries in renewable energy resources such as wind and solar power (General Electric, 2008), the load of electricity in the country gradually increases every year. With increasing demand for cooling, air conditioning consumes a significant amount of energy, and the generated electricity only fulfills 50-70% of the population needs (General Electric, 2012). It should be noted that, one of the main objectives of architectural design is to provide thermal comfort for the occupants of a building, while reducing its energy consumption rates.

Recently, buildings in Libya have needed excessive cooling units in order to maintain thermal comfort at a desirable level (IEA Country Energy Statistics, 2009). Therefore, the Libyan citizens have not been paying energy bills, with Continuous blackouts in Libya, the authorities have been trying to find cost-effective solutions to improve buildings in terms of their thermal performances and provide energy efficiency. It is believed that this fact proves the importance and the necessity of the research topic. Therefore, this study aims to examine certain factors of passive design strategies namely; suitable orientation, building materials and window sizes, together with the PMV value, by analyzing the heat gains and losses through the fabric of a modeled building, to provide thermal comfort for the users of residential buildings in Tripoli, Libya.

Tripoli, which is the Libyan capital, is located in the North-Western Libya on the coast of the Mediterranean Sea at coordinates; 32° 52' N, 13° 10' E. Its altitude is 9 m above the sea level, and the city occupies a total land area of 400 km^2 (Alsharif and Pradhan, 2014). Tripoli represents the coastal area of Libya as shown in Figure1. Its climate is relatively mild even in the summer seasons, however on some days the temperature may reach 40° C with quite high humidity, especially in months July and August. During the winters, this region mostly gets precipitation with low temperatures at nights, while the average temperature is 15 °C in the spring season (Elwefati, 2007), (kalifa and Alagt, 2018).

Climate data of the city of Tripoli provided input for the environmental analysis software program, Autodesk Ecotect®, which was used for the analysis of this study.

Figure (1). Geographical location of Tripoli, Libya, ('Geographical Location', 2013).

2. METHODOLOGY

Based on the objectives of the study, to analyze certain passive design strategies for Tripoli, Libya, a residential building model with an area of 110 m² was designed in Autodesk AutoCAD®2017 software program. The building was designed as one of the communism types of residential buildings constructed in Libya (Awen, Sheta, & EL-Maidawy, 2020), (Omar, 2003), (Fig. 2). After that, the 3D model was exported to Autodesk Ecotect®2011 software program for the analysis part of the study (Fig. 3).

Autodesk Ecotect® is the most comprehensive and innovative building analysis software on the market today. It features a designer-friendly 3D modeling interface fully integrated with a wide range of performance analysis and simulation functions. http://www.autodesk.com

What really sets Ecotect apart is the visual nature of calculation feedback and its support for very early stage conceptual design as well as final design validation. Designers can start generating vital performance-related design information before the building form has even been developed. You can start with a detailed climatic analysis to calculate the potential effectiveness of various passive design techniques or to optimize the use of available solar, light and wind resources. You can then move on to test these ideas on some simple sketch models before gradually developing up the final design. Similarly, many researchers have used this software to evaluate the required design configurations in their studies as: (Wang et al., 2011), (Marsh, 2003), (Sadafi et al., 2011).

Autodesk AutoCAD®2017 software program, It is computer – aided drawing and design program that supports the creation of 2D and 3D graphics.

Description the building:

The residential model designed for the study is a single-storey building containing a living room, a kitchen, two bedrooms, a bathroom, a WC and guest room, all located around a central hall that connects these spaces. The designed residence can accommodate six, to a maximum of eight users Figure 2.

The windows of the building are placed on all facades to increase the natural ventilation and access of natural light into the building. The areas of all the windows are 120 cm² except the one in the living room, which has a larger area. By using the climatic data together with the latitude and longitude data of the city of Tripoli, and by examining the heating and cooling loads of the building in Ecotect program, issues such as; the best orientation, thermal mass, building materials and window size in the living room were analyzed.

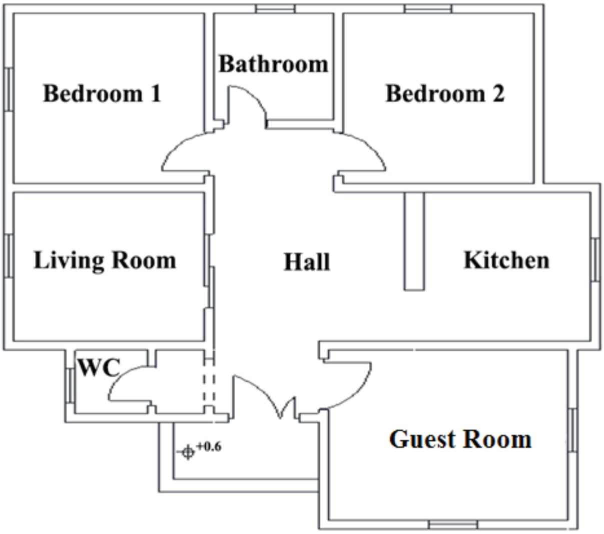

Figure (2). Floor plan of the residential building model.

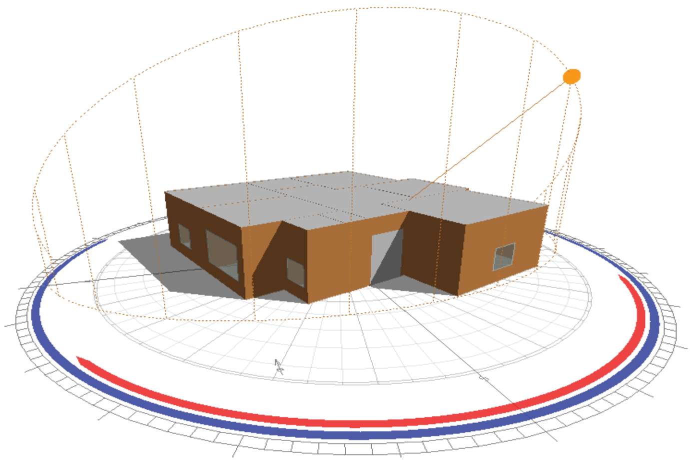

Figure (3). 3D view of the residential building model showing the sun path.

3. FINDINGS

Thermal Properties

Firstly, the weather data was selected for Tripoli, Libya, from the weather library of the program. In Ecotect, based on the designed model, the interior spaces are assigned as *zones*, for thermal analyses purposes.

The residential model designed for the study had eight thermal zones, namely;

1. Living Room
2. Kitchen
3. Bedroom 1
4. Bedroom 2
5. Guest room
6. Bathroom
7. WC
8. Hall

Table 1 shows the thermal properties and specifications for the building.

Table (1). Thermal properties and specifications for the residential building model.

Definition	Identification
The maximum number of people who will occupy the zones	8 users
The type of system used in the zones	Passive system
Highest desirable temperature	25° C (Elwefati, 2007)
Lowest desirable temperature	15° C (Elwefati, 2007)

Best Orientation

Givoni (1991) states that, with walls sufficiently insulated at the exterior and effectively shaded windows, changes in internal temperature regarding the orientation may be minor. However, the results of our analysis pointed out that there is a direct and very strong relationship between the orientation of the building and the energy consumed to maintain comfortable thermal conditions. In our case, the orientation was found to be more important in terms of controlling solar radiation, as well as wind directions and thus natural ventilation, as passive design strategies. Therefore, before further analyses on thermal comfort data, the best orientation for the case study building to be located in Tripoli, Libya was found out. Based on the latitude and longitude data for the mentioned region, the results showed that the best orientation for the building was 162.5° North and 17.5° South. Therefore, it was found that, the entrance of the building should be located at South-South-East. Figure 4 and Figure 5 shows the best orientation for the model. Based on this result this strategies aim to maximize the potential for solar collection through the orient of the longest side of building to face south.

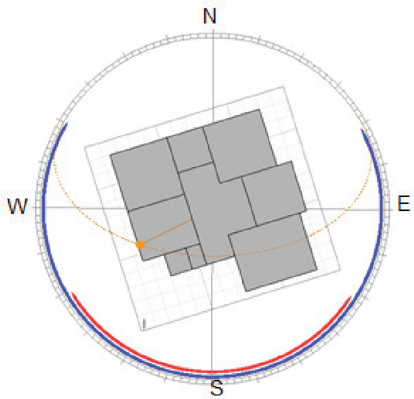

Figure (4). The best orientation for the residential building model.

Material Use

Regarding the analysis on the effects of used materials on thermal comfort and energy efficiency, firstly, the type of the materials used in the model was chosen as the one type of traditional material assemblies commonly constructed in Libya (Awen, Sheta, & EL-Maidawy, 2020). This material assembly was assigned as Alternative 1, and its specifications were calculated and noted down. After that, the materials were changed, and the second assembly was assigned as Alternative 2.Tables2 and3, show the thermal properties of the materials used in both alternatives. Both the material are with U-Valum (U-Valum is the thermal transmittance is the current thermal passing in square meters one of the element, structural, is the knowledge of the value of the transitional thermal necessary to judge the quality and efficiency of the thermal insulation elements of the different(wall and ceilings). And the more decreased the value of the transitional thermal, increased capacity of the thermal insulation and rose rate savings in thermal energy lost through the parts of the building).

Table (2). Thermal properties of Materials: Alternative 1.{ Ecotect library}

Material descriptions	**U- Value (W/m^2 K)**	**Admittance (W/m^2 K)**
Floor: 100 mm thick concrete slab on ground plus ceramic tiles	0.880	6.100
Wall: 100 mm concrete block with 10 mm plaster on each side	1.800	3.360
Ceiling: 10 mm suspended plaster board ceiling on 200 mm joists as air gap with no insulation	4.320	3.980
Window: Single pane of glass with aluminum frame (No thermal break)	6.000	6.000
Door: 40 mm thick solid pine timber door	2.310	3.540

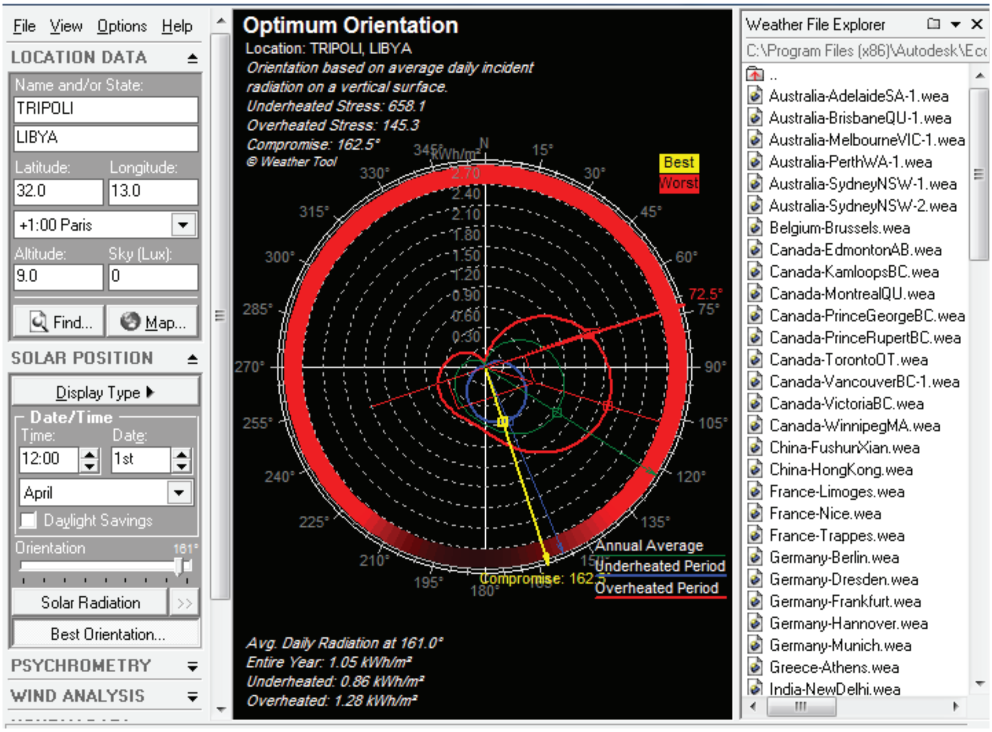

Figure (5). The best orientation for the residential building model from the Ecotect program

Table (3). Thermal properties of Materials: Alternative 2. { Ecotect library}

Material description	U- Value (W/m² K)	Admittance (W/m² K)
Floor: 100 mm thick concrete slab on ground plus carpet and underlay	0.920	6.00
Wall: 70 mm limestone, 130 mm concrete cinder block, 30 mm polystyrene general purpose, 20 mm plaster	0.580	5.920
Ceiling: 10 mm suspended plaster board ceiling, plus 50 mm insulation, with remainder [150 mm] joists as air gap	0.500	0.900
Windows: Double glazed with timber frame.	2.900	2.900
Door: 40 mm thick solid core pine timber door	2.310	3.540

Total Energy Use

Firstly, the total amount of energy use throughout the year was calculated for Alternative 1 (Figure 6). It was seen that during the months of January, February, March and April, there is no need for cooling energy. The energy for heating is stabilized during the summer months, June, July, and August, as well as in September. On the other hand, it was observed that, the need for cooling energy increases during the summer months and this need highly exceeds the need for heating energy during winter months (Figure 6).

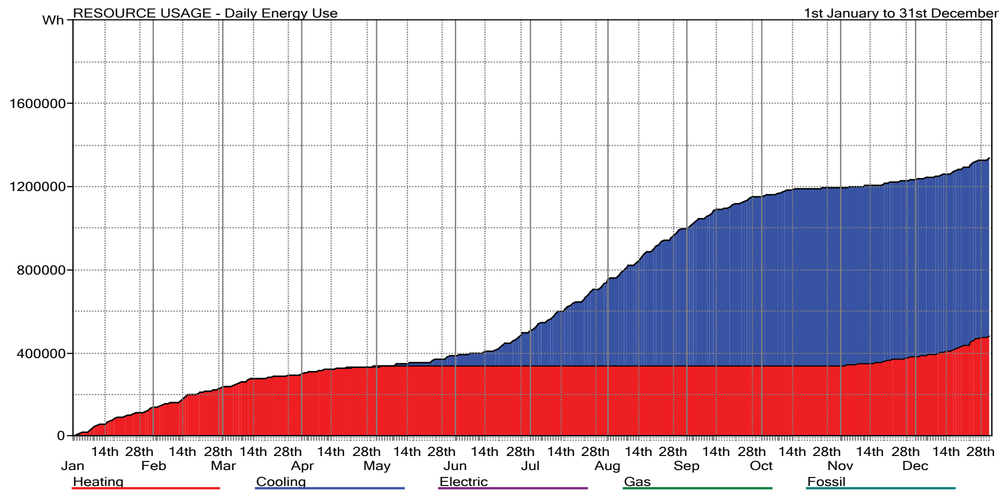

Figure (6). Total energy use during the year.

Thermal Conditions

The period for the thermal comfort conditions analysis in our study included three months, namely; March, June, and December. These three months showed some variations in climatic conditions and were perceivable during a year. The mentioned time span was found to be helpful to calculate the Predicted Mean Vote (PMV) values.

PMV uses a scale to predict thermal sensation votes on a seven-point scale (Hot: 3, Warm: 2, Slightly warm: 1, Neutral: 0, Slightly cool: -1, Cool: -2, Cold: -3). Zero is the neutral point, representing the comfort state, the positive values indicate an uncomfortable feeling due to a hot sensation, and the negative values indicate an uncomfortable feeling due to a cold sensation)Elaiab, 2014). The major limitation of the PMV model is the explicit constraint of skin temperature and evaporative heat loss for comfort sensation at a given activity level.

The PMV calculations included the hours; 9 am, 12 pm, 3 pm and 6 pm. The Ecotect software program used three comfort condition indicators, which were; Uncomfortable, Almost Comfortable and Comfortable. According to our results, generally the PMV values ranged from -2.77 to +1.28. The maximum PMV value (+1.28) was observed in June at 3 pm, and the minimum PMV value (-2.77) was in December at 9 am and 12 pm. Table 4 shows the summary of thermal comfort conditions according to the PMV variations in all thermal zones of the building, for material assemblies; Alternative 1 and Alternative 2.

Table (4). Summary of thermal comfort conditions for material assemblies Alternative 1 and Alternative 2.

Month	Comfort condition	PMV result (Alternative 1)	PMV result (Alternative 2)
March: 9:00 am to 6:00 pm.	Almost comfortable	-1.41 / -1.75	-1.27 / -1.38
June: 9:00 am to 6:00 pm.	Comfortable	+1.28/ 0.86	0.92 / 0.99
December:9:00 am to 6:00 pm	Uncomfortable	-2.70/ -2.77	-2.31/ -2.61

When the materials were entered as given in Table 2 (Alternative 1), the simulation results showed that the thermal performance of the building was not satisfactory. The calculations for the whole year showed that the building gained excessive heat during the summer months and lost excessively in the winter season. These results showed that the selected materials were not useful to provide thermal comfort inside the building. By assessing the air temperatures inside and outside the building, it was conveyed that a high amount of heat flow through the fabric took place. On the other hand, it was seen that the percentage for heat losses were as high as 83.3%, in Alternative 1. Therefore, the simulation results pointed out that the thermal conditions of Alternative 1 was not comfortable. However, when the materials were selected as in Alternative 2 (Table 3), the results differed, showing significant changes in the amounts of heat gains and losses, and the thermal conditions were regarded as satisfactory. Table 5 shows the heat losses and gains for the designed residential building model, according to both material assembly alternatives.

Table (5).Comparison between heat losses and gains, for Alternatives 1 and 2.

Category	Losses		Gains	
	Alternative 1	Alternative 2	Alternative 1	Alternative 2
Fabric	83.3%	33.4%	7.3%	2.0%
Sol – Air	0.0%	0.0%	56.3%	10.0%
Solar	0.0%	0.0%	8.2%	10.9%
Ventilation	10.1%	47.0%	0.9%	2.9%
Internal	0.0%	0.0%	22.3%	71.3%
Inter – Zonal	6.6%	19.6%	5.0%	3.0%

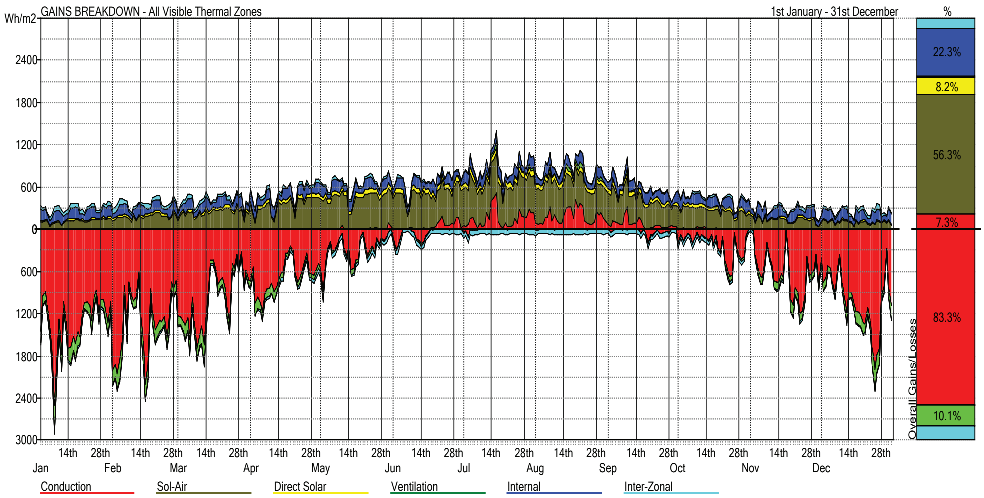

Figure (7). Heat gains and losses when using the materials mentioned as Alternative 1.

When the materials were changed to Alternative 2, the reduction in the heat losses during the year showed that significant heat flows occurred through the windows in Alternative 1. In naturally ventilated buildings, the thermal effects of ventilation openings and infiltration, lead to drastic reductions in interior temperatures, especially during morning hours.

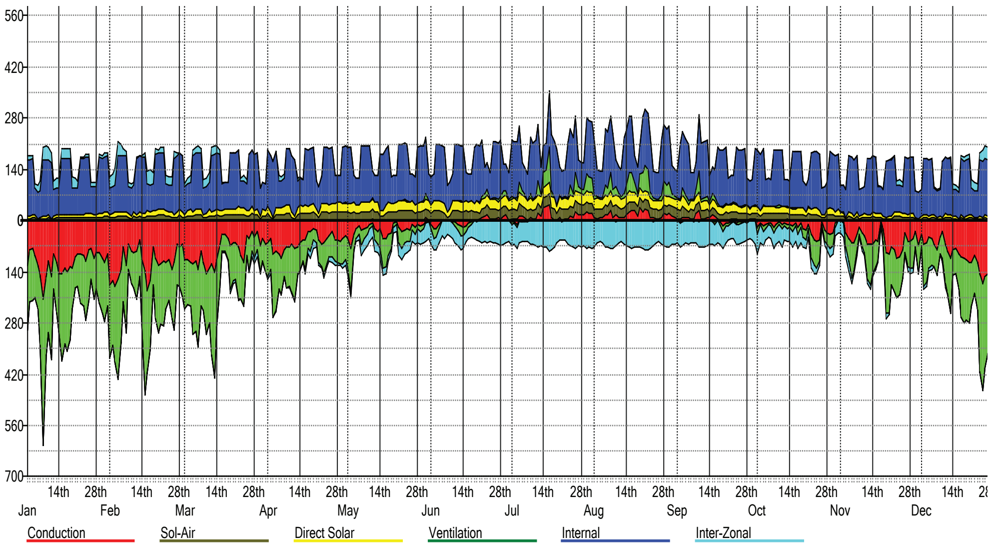

Figure (8). Heat gains and losses after changing materials to Alternative 2.

Measuring the Loads of Heating and Cooling

While measuring the loads of heating and cooling for the whole year it was seen that, when the materials were changed to Alternative 2, the loads were significantly decreased. However, the results also showed that there was still the need for heating and cooling in some months of the year. Figures 9 and 10 show the significant decrease in the loads of heating and cooling, when the material swere changed to Alternative 2. These results pointed out the importance of insulation properties of materials and their ability to provide thermal comfort for the occupants inside the building.

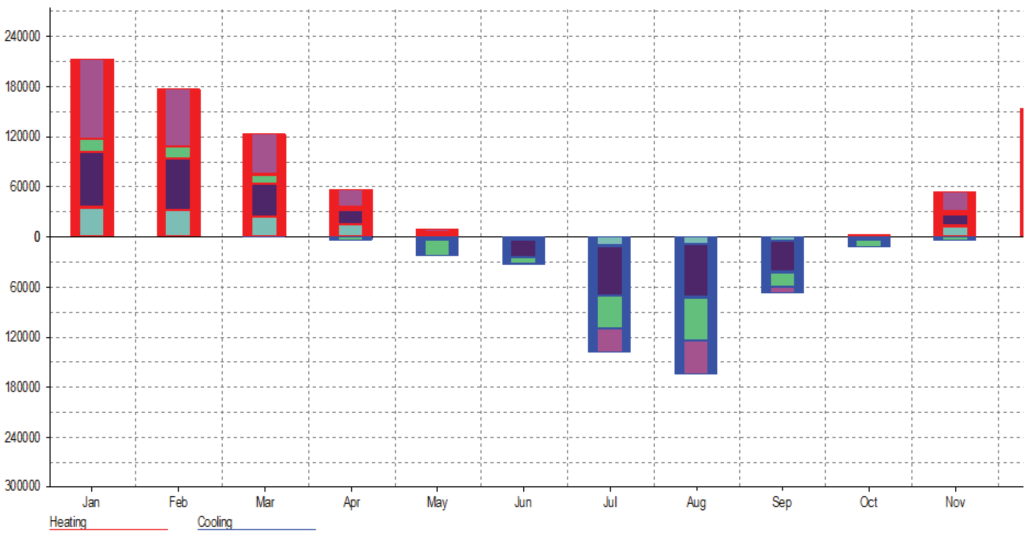

Figure (9). Loads of heating and cooling for Alternative 1.

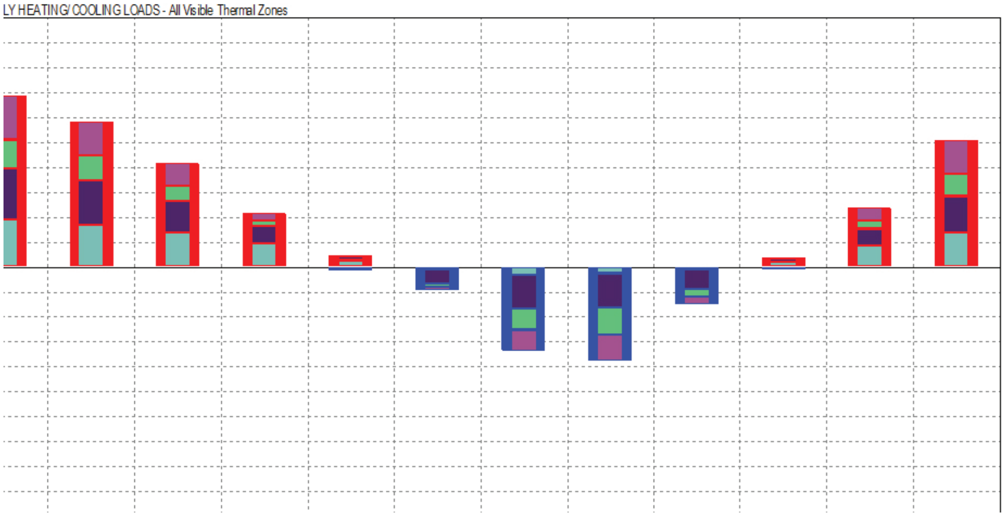

Figure (10). Loads of heating and cooling for Alternative 2.

Window Size

The windows are important passive design elements, as they control the amount of daylight and ventilation access to the building (Khan, Su and Riffat, 2008). Moreover, they also control the solar gains in a building. Thus, the window size is an essential part of the passive design of buildings. When the window size is increased, the amount of ventilation is higher, however, this can also lead to high heat gains inside the building (Ahsan, 2009). While deciding on the window size, the climate and the suitable orientation of the window are crucial factors. Large openings are preferable in hot climates for increasing natural ventilation, however, they must be shaded well, such as by trees or artificial shading devices for avoiding excessive solar heat gains (Limb, 1994). Therefore, using relatively small windows with the correct orientation can be considered as a good strategy as well.

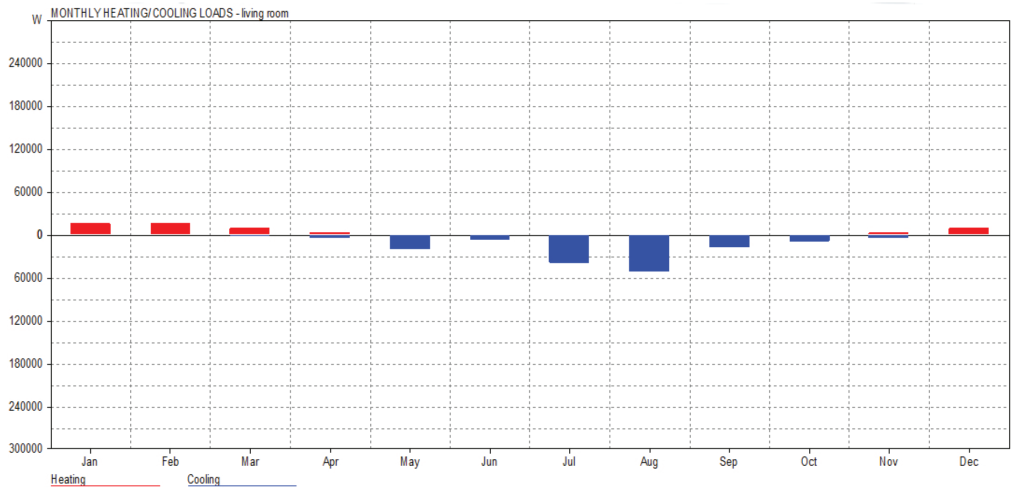

Figure (11). Heating and cooling loads of the living room with 100 cm by 120 cm window size

As to the window size for the living room, it was changed from 100 cm by 120 cm, to 200 cm by250 cm, considering good ventilation would be needed, since it is a frequently used space. As seen in Figures 11 and 12, when the window size was increased, together with the heat gains and losses, the loads of heating and cooling increased as well. However, as stated above, in order to benefit from windows while avoiding their disadvantages, other passive design strategies must be applied as well, such as, correct orientation and, external and internal shading devices.

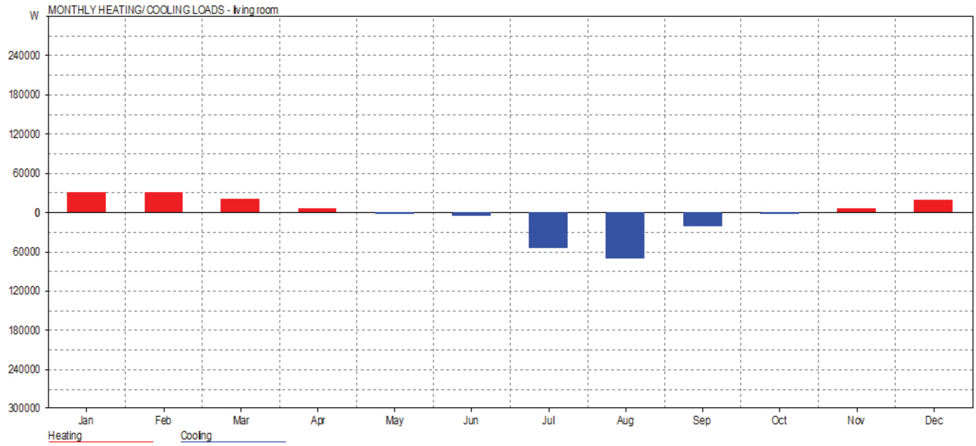

Figure (12). Heating and cooling loads of the living room with 200 cm by 250 cm window size

Thermal Comfort with Respect to Hours

The thermal conditions of the individual zones of the building with respect to the hours of the day were also calculated and examined. The calculations were conducted for three months of the year, namely; March, June, and December. The results clarified that the residential building would be comfortable for its users, even in months with higher heat gains and losses.

After changing the building materials to Alternative 2 and increasing the window size, the findings revealed temperature changes in the living room. The temperatures showed a state of thermal comfort during the summer season, yet, they changed slightly in March during morning hours, from 8 am to 11 am. However, this was not considered as a drawback, as they decreased during the sleep hours and increased until they became moderate from 9 am to 10 pm. These results were very close to the results taken for December.

Bedroom 2 had moderate temperatures in March, from 12 pm to 11 pm, and they decreased during the sleep hours, from 12 am to 11 am. Moreover, in summer, the space was thermally comfortable and in December, the results were satisfactory during sleep hours.

Even though the main aim of the study does not entail promoting a specific design for a residential building; based on the conducted study, certain guidelines can be developed for providing energy efficiency in residential Libyan buildings by passive means (Table 6).

Table (6). Passive design strategies for increasing energy efficiency.

1. The main design decisions such as building form, orientation and layout should be based on the climatic conditions of the locality.

2. Materials with high thermal insulation properties should be selected for the walls, ceilings, floors and windows to minimize heat transfer through the building fabric.
3. The size and placement of openings should be decided based on avoiding extra heat gains and losses, as well as releasing excessive heat through natural ventilation.
4. The design approach should include adjustable features such as exterior and interior shading devices to control solar heat gains and losses.
5. Vegetation and trees can be used to reduce the heat gains caused by solar radiation.

To sum up, in order to improve the thermal performance of buildings while lessening their impacts, architects should rely on passive design strategies instead of mechanical heating and cooling systems. Particularly countries such as Libya can benefit from effective use of passive design strategies in the construction industry, for overcoming environmental and economic problems, and creating sustainable built environments.

4. CONCLUSION

This study analyzed some of the passive design strategies, namely; orientation, use of materials and effects of thermal mass and window size as a case study for providing energy efficiency in residential buildings in Tripoli, Libya. These parameters were examined in Autodesk Ecotect environmental analysis software program, on a building model designed based on the typical residences constructed in Libya.

As to the findings of the study, the best orientation for the designed building model was found as 162.5° North and 17.5° South. Moreover, it was seen that, regarding material selections, assembly noted as *Alternative 2* (floors: carpet on 100 mm concrete slab, walls:70 mm limestone, 130 mm concrete cinder block, 30 mm polystyrene with 20 mm plaster, ceilings: 10 mm suspended ceiling with plaster and 50 mm insulation and 150 mm joists as air gap, windows: double glazed with timber frame) showed a better performance, since the heat gains and losses for the traditional material assembly, noted as *Alternative 1,* were found to be significantly high. In other words, it was seen that using materials with lower U-values and thus, having higher insulation properties, contributed to the energy efficiency of the building. The findings revealed that the correct orientation and use of materials lead to a 60% increase in the thermal performance of the building. On the other hand, when the window size was increased, it was observed that heating and cooling loads also increased. Therefore, together with the window size, factors such as insulation properties, correct placement and use of vegetation and shading devices at the exterior should also be assessed.

Regarding the results on PMV analyses, it was seen that, unfavorable conditions might occur during the evenings in the North-Eastern side of the building. Therefore, to reach thermal comfort, the quality or the thickness of insulation materials on the North-Eastern side could be increased. Furthermore, the spaces inside the building could be assessed by taking the time of usage and functions into account, and the building could be designed accordingly. Spaces to be used during the day or having lower usage frequencies can be allocated at the mentioned areas. Yet, as to an overall evaluation, it can be concluded that the residential building would be thermally comfortable for its users.

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