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Thermal Performance Evaluation of Residential Buildings in Al-Jufrah, Libya

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***Abstract*—Studying the thermal performance of residential buildings based on climate data analogous to local weather conditions and prevailing architectural and structural designs—has become increasingly essential due to the significant deficit in energy production (electricity) in Libya. This study aims to provide thermal comfort for housing occupants in accordance with international standards while minimizing energy consumption through passive design strategies (without relying on mechanical equipment).**

This research investigates the thermal behavior of two different building models from the study area (Al-Jufrah region, Libya): the first with insulation and the second without insulation. Eight alternative cases of the two models were analyzed using Autodesk Ecotect 2011 software. The results demonstrate a significant reduction in energy consumption—up to 56% per m² unit—when using different types of wall slabs and insulation systems. This indicates the effectiveness of insulation and the selection of optimal structural elements for thermal efficiency. The study emphasizes the importance of construction techniques in achieving energy efficiency.

***Index Terms*—thermal performance, thermal insulations, passive design, Ecotect.**

A. INTRODUCTION

The problem of shortfalls in power generation in Libya has become chronic due to the increasing demand for electrical power supply, and the largest portion of electric power is used in the housing sector, which consumed 36% of the generated electric energy in the year 2012 [1] and the majority of household energy consumption is used for cooling, accounting for around 70% of peak demand [2]. Most of the existing housing in the study area (Al-Jufrah, Libya) was designed and built without considering passive design or providing thermal comfort to occupants, while minimizing energy consumption.

Because the study region is dominated by certain structural systems from the use of one-way hollow block slabs or solid slabs (roof and ceiling), further, walls concrete hollow block and finishing for tiles and plastering...etc. The study of the thermal performance of residential buildings plays a role in the operation and control of thermal comfort consumption, based on their construction characteristics (skeleton and finishing phases). Consequently, many buildings in the study region use large—and often unnecessary—amounts of energy. Additionally, despite all the energy they consume, they often fail to provide a reasonable level of thermal comfort. The low quality of thermal comfort of the residential housing is caused by construction techniques and poor skill knowledge labours. Therefore, most of the houses in the study region have poor thermal comfort conditions. To improve this condition, occupants always use cooling systems to provide a more comfortable, fresh and suitable living environment for their family. This action causes occupants have to pay for their high electricity bills every month.

The researchers conducted several studies for the purpose of understanding the thermal behavior of buildings and trying to control it. Omar S. Asfour [3] studied the effects of thermal insulation for residential roofs and walls using the Ecotect program under local weather conditions in the Gaza Strip, Palestine, comparing interior and exterior applications in a single-room model. Kherbek et al [4] analyzed two buildings using the Ecotect program, studying the potential of local cladding materials for external walls and comparing their impact on energy consumption. Mojtaba Valinejad Shoubi [5] Darwwa Vera and Pause Where BIM was used Revit and Ecotect programs where different materials were used for walls, roofs, window and tropical weather window for Johor Baru in Malaysia, Vahid Ebadati [6] studied a group of insulators with a number of seven and another in which deception is used after modeling them using the EnergyPlus program and comparing the cooling, heating and total energy that is provided with the use of types various of insulators for the weather of Tehran-Iran.

This study's research objective will provide an adequate detailed view of the energy saving potential and thermal performance improvement of different passive strategies, applied individually as well as in combination. attention to energy saving is a great guideline for having the best efficiency in the residential sector. These diverse roles

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have described guidelines for decreasing energy consumption such as general roles about designing and implementation, of residential building. collect relevant information on dominant construction methods/materials and on their environmental impacts.

Most of this work involved case studies or comparisons among a small number of areas. Only a few studies have focused on regions or states. The questions that the research will answer are:

1- What is the efficiency of the architectural and structural construction methods used in buildings in the region?
2- In case of adding any insulation, what is the impact on the thermal performance?

B. METHODOLOGY

Current and alternative cases were identified for walls and roofs to evaluate the impact of each case on thermal performance, based on their thermal conductivity. The study examines the outcomes of:

1- Using different types of slabs, namely:
    - One-way hollow block and solid slabs,
    - Insulated or non-insulated slabs,
    - With or without finishing,
    - With or without additional insulation.
2- The thickness and material of walls (concrete or clay), by analyzing typical types of hollow concrete blocks.
3- The effect of varying air gap widths (5 cm, 7.5 cm, and 10 cm) in wall insulation.

The thermal performance assessment and energy efficiency.in this paper involves analyzing factors like insulation quality, and thermal bridging to determine how well the building maintains comfortable indoor temperatures while minimizing energy consumption.

A. *Case Studies (Current)*

Case 1: A residential structural concrete building, its roof constructed as solid slabs (thickness 12cm) with drop beams, while all walls constructed as single wythe-walls, without heat insulating for roof and walls was chosen in which located at Al-jufra-Libya region with an estimated area 152,820 m^2 as shown in the Figure 1.

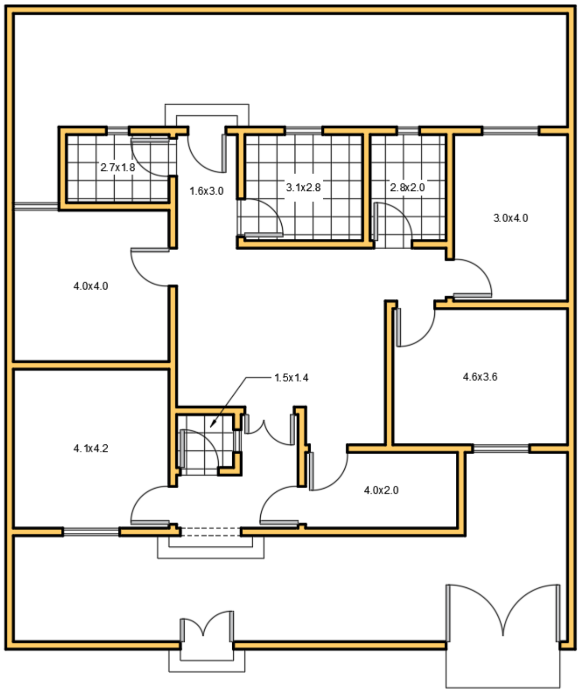


Figure 1. Horizontal section for plan 1

Case 2: also, residential structural concrete building. With flat slabs roof concrete system, it is a model with a covered area of 148.180 m^2 provided with thermal insulators for roofs and walls as shown in Figure 2 and Table 3 (current case) This building was chosen because it was implemented using thermal insulators and as for the structural system for the roof, it is a flat slab with a thickness of 16 cm.

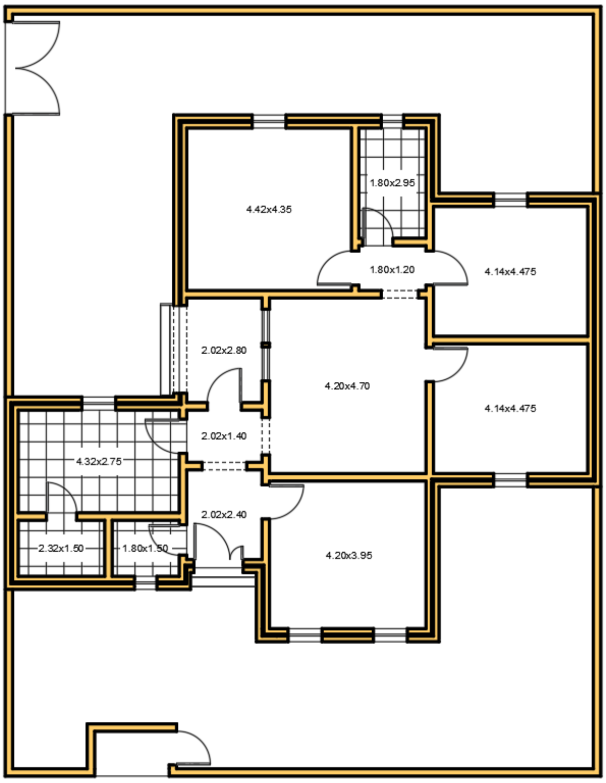
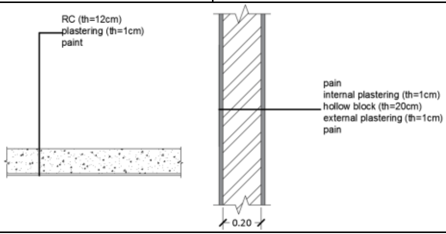
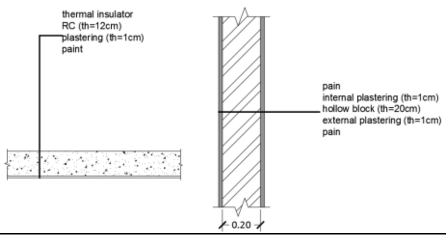
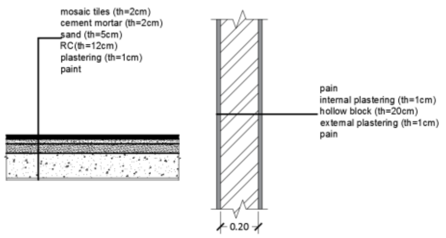
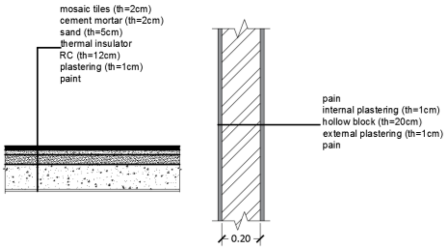
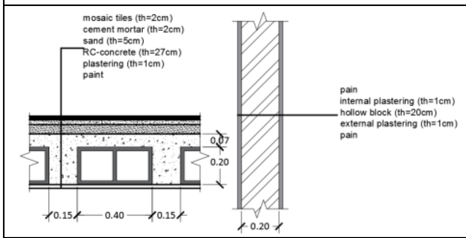
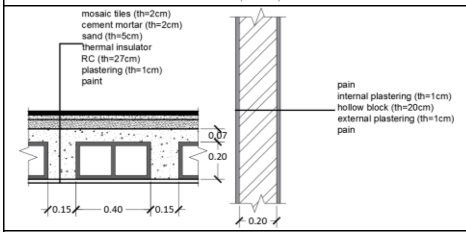
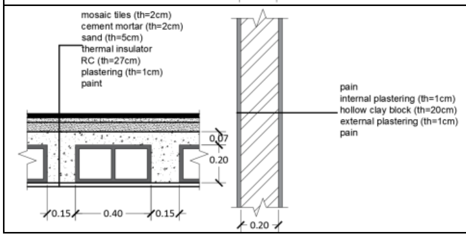
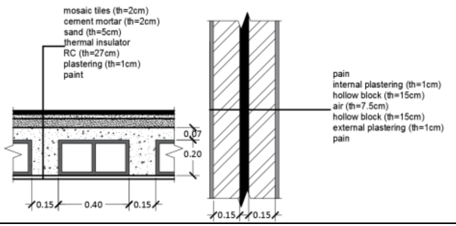
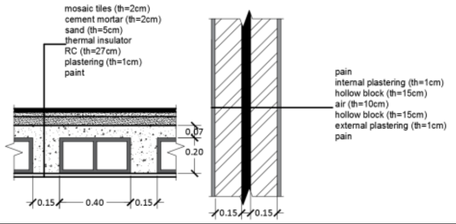


Figure 2. Horizontal section for plan 2

B. *Cases Description (Alternative)*

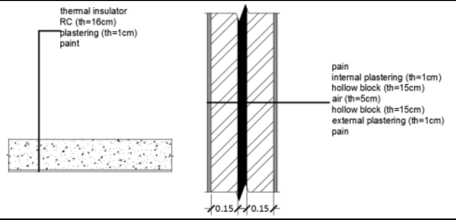
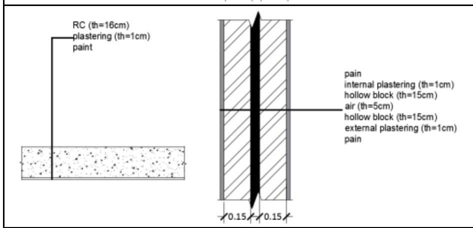
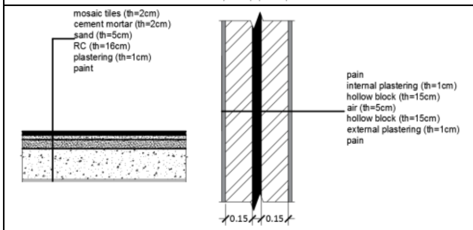
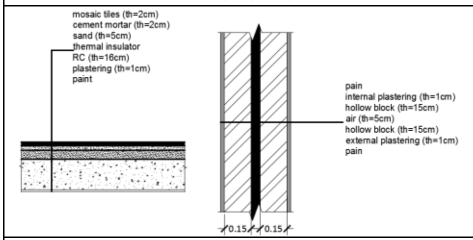
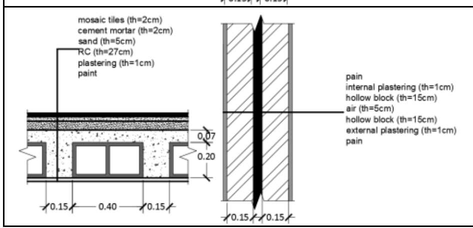
Eight alternative cases in which clearly identifiable in Table 1 and Table 2 are associated with their arrangement and material properties as what constructed

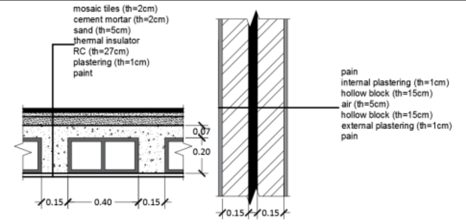
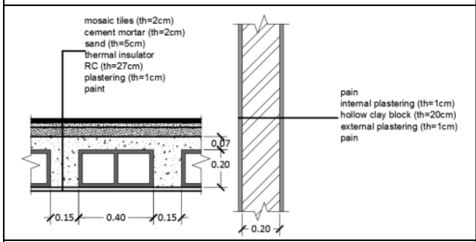
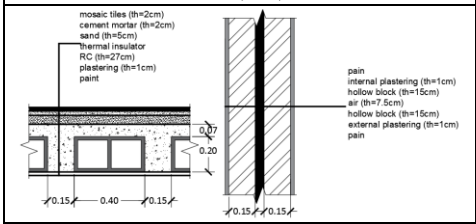
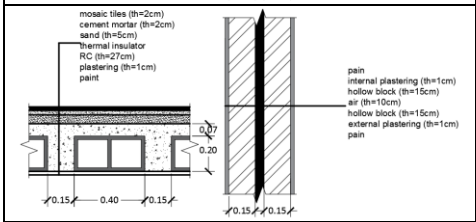
TABLE I. Current and alternative cases for plan 1

Roof	Wall	Case
 RC (th=12cm) plastering (th=1cm) paint	pain internal plastering (th=1cm) hollow block (th=20cm) external plastering (th=1cm) pain 0.20	Current
 thermal insulator RC (th=12cm) plastering (th=1cm) paint	pain internal plastering (th=1cm) hollow block (th=20cm) external plastering (th=1cm) pain 0.20	1
 mosaic tiles (th=2cm) cement mortar (th=2cm) sand (th=5cm) RC(th=12cm) plastering (th=1cm) paint	pain internal plastering (th=1cm) hollow block (th=20cm) external plastering (th=1cm) pain 0.20	2
 mosaic tiles (th=2cm) cement mortar (th=2cm) sand (th=5cm) thermal insulator RC (th=12cm) plastering (th=1cm) paint	pain internal plastering (th=1cm) hollow block (th=20cm) external plastering (th=1cm) pain 0.20	3
 mosaic tiles (th=2cm) cement mortar (th=2cm) sand (th=5cm) RC-concrete (th=27cm) plastering (th=1cm) paint 0.07 0.20 0.15 0.40 0.15	pain internal plastering (th=1cm) hollow block (th=20cm) external plastering (th=1cm) pain 0.20	4
 mosaic tiles (th=2cm) cement mortar (th=2cm) sand (th=5cm) thermal insulator RC (th=27cm) plastering (th=1cm) paint 0.07 0.20 0.15 0.40 0.15	pain internal plastering (th=1cm) hollow block (th=20cm) external plastering (th=1cm) pain 0.20	5
 mosaic tiles (th=2cm) cement mortar (th=2cm) sand (th=5cm) thermal insulator RC (th=27cm) plastering (th=1cm) paint 0.07 0.20 0.15 0.40 0.15	pain internal plastering (th=1cm) hollow clay block (th=20cm) external plastering (th=1cm) pain 0.20	6
 mosaic tiles (th=2cm) cement mortar (th=2cm) sand (th=5cm) thermal insulator RC (th=27cm) plastering (th=1cm) paint 0.07 0.20 0.15 0.40 0.15	pain internal plastering (th=1cm) hollow block (th=15cm) air (th=7.5cm) hollow block (th=15cm) external plastering (th=1cm) pain 0.15 0.15	7
 mosaic tiles (th=2cm) cement mortar (th=2cm) sand (th=5cm) thermal insulator RC (th=27cm) plastering (th=1cm) paint 0.07 0.20 0.15 0.40 0.15	pain internal plastering (th=1cm) hollow block (th=15cm) air (th=10cm) hollow block (th=15cm) external plastering (th=1cm) pain 0.15 0.15	8

It should be noted that alternative cases were selected based on the context of the study area, including the dimensions of structural elements such as the thickness of slabs and walls, the types of materials used, and the type of insulating material employed. Other cases were chosen due to their high likelihood of occurrence.

TABLE II. CURRENT AND ALTERNATIVE CASES FOR PLAN 2

Roof	Wall	Case
 thermal insulator RC (th=16cm) plastering (th=1cm) paint	pain internal plastering (th=1cm) hollow block (th=15cm) air (th=5cm) hollow block (th=15cm) external plastering (th=1cm) pain 0.15 0.15	Current
 RC (th=16cm) plastering (th=1cm) paint	pain internal plastering (th=1cm) hollow block (th=15cm) air (th=5cm) hollow block (th=15cm) external plastering (th=1cm) pain 0.15 0.15	1
 mosaic tiles (th=2cm) cement mortar (th=2cm) sand (th=5cm) RC (th=16cm) plastering (th=1cm) paint	pain internal plastering (th=1cm) hollow block (th=15cm) air (th=5cm) hollow block (th=15cm) external plastering (th=1cm) pain 0.15 0.15	2
 mosaic tiles (th=2cm) cement mortar (th=2cm) sand (th=5cm) thermal insulator RC (th=16cm) plastering (th=1cm) paint	pain internal plastering (th=1cm) hollow block (th=15cm) air (th=5cm) hollow block (th=15cm) external plastering (th=1cm) pain 0.15 0.15	3
 mosaic tiles (th=2cm) cement mortar (th=2cm) sand (th=5cm) RC (th=27cm) plastering (th=1cm) paint 0.07 0.20 0.15 0.40 0.15	pain internal plastering (th=1cm) hollow block (th=15cm) air (th=5cm) hollow block (th=15cm) external plastering (th=1cm) pain 0.15 0.15	4

	5
	6
	7
	8

C. Building numerical Models:

Basically, four major steps are required to set up a model.

1- CAD model

Create a 2D model with the required drawing scale, in this study is created through AutoCAD software, the diagram was exported as DXF file format into Ecotect software. Then create zones which need to be fully enclosed, individually of other zones around them as shown in Figure 3.

2- Zone settings:

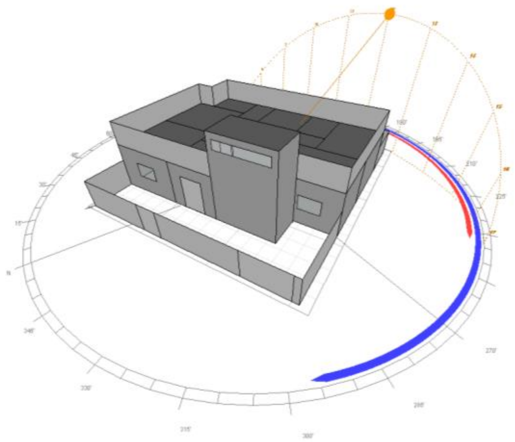
Ecotect needs to be provided to set what each zone or space is used for, through zone management such as adjusting the clothing factor, lighting level, number of people, activity level, etc. From the thermal properties tab to further adjust settings from select HVAC system, thermostat range, and hours of operation.

3- Materials:

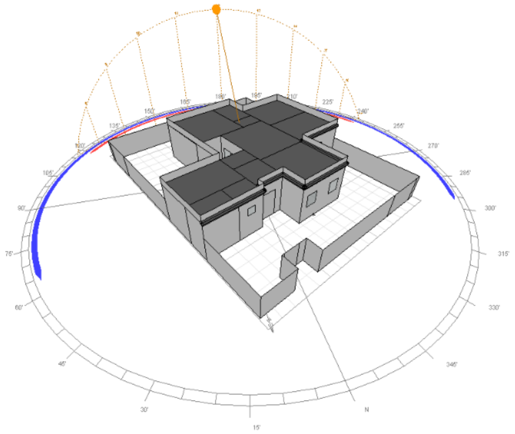
The program's library contains a large number of thermal properties of many materials, including reinforced concrete, types of wood and metals ... etc. Therefore, the calculation of the U-value heat transfer coefficient is done by the software automatically depending on the type of material, its thickness, its absorption ... etc. with the possibility of adjusting it in the form required if it is different from what is in the program library, the parameters of material properties used in this study presented in Table III. To obtain more accurate estimated values for thermal conductivity of hollow block slabs as shown in Figure 4 (after redesigning the slabs from solid slabs) Equation (1) can be used to obtain U-value of entire slabs.

$$U_R=(A_A\times U_A+A_B\times U_B)/A_T \qquad (1)$$

A_A: Area of blocks, A_B: Area of concrete, U_A: Thermal conductivity of blocks, U_B: Thermal conductivity of concrete and A_T: Total area of slabs



Model-1



Model-2

Figure 3. Numerical Models in Ecotect

4- Climatic data:

After creating the model, a correct and relevant weather data is chosen for the purpose of the analysis with the use current time and location. Due to there is no climatic data file for AL-jufra in Ecotect software, it is possible to count on Asyut-

Egypt climatic data file based on the similarity between these two cities [7]

TABLE III. Material properties usage

Notes	Thermal conductivity w/m^{2}k	Density Kg/m^3	Material
	1.2	2000	Plastering
	1.1	2100	Tile
	1.75	2300	Concrete
	1.0	1600	Hollow block
	0.7	1600	Hollow clay block
	1.2	2000	Cement mortar
	1.74	2240	Sand
	0.088	900	Asphalt
	5.56	1.3	Air
Fixed	1.046	2300	Window
Fixed	0.343	550	Door

For proper thermal analysis. all the default settings should be okay to use. more than likely,

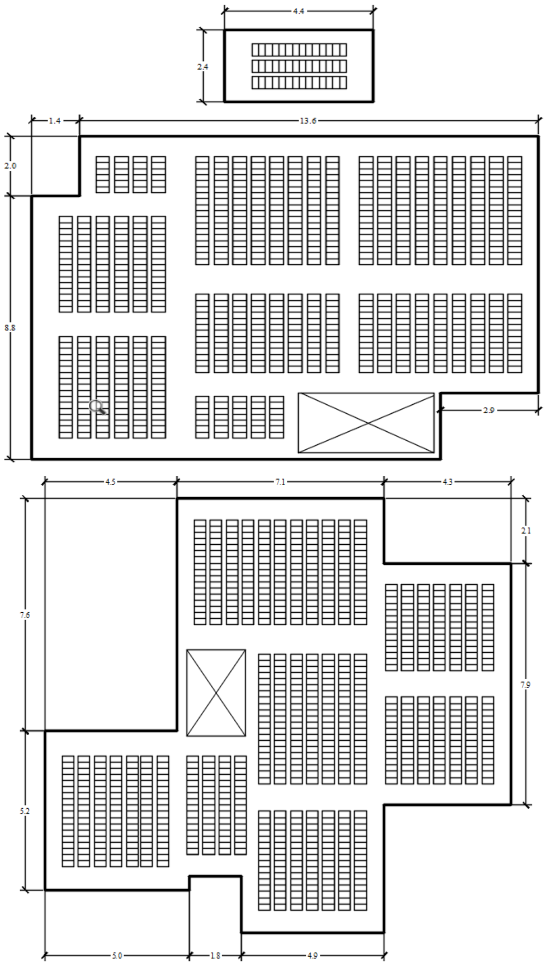


Figure 4. Ribbed slabs after redesign the floor

C. RESULTS AND DISCUSSIONS

A. Total consumption loads

Figure 5 shows the summation of heating and cooling consumption per unit area (m^2) along 1 year in case of the Model-1, for current case in which the structure is not totally insulated, the total consumption /m^2 is 357.10 Kwh. After installation of insulation to the roof only (case-1), the decrease in the energy consumed /m^2 is 21.55%. While in the absence of roof insulation and the roof is tiled with the layers mentioned in Table I (Case-2), the decrease percentage was higher than in the case of installing the insulation, so that it was 29.54%. If the tile and insulation are installed together (Case-4), the decrease percentage was 37.63%. However, if the type of tile is changed from solid to hollow tiles in one direction with the presence of tiles (Case -5), the total consumption of each meter decreases to 51.75%. If the insulation is added to the previous case (Case -6), the effect is not large or clear, so that it was 54.93%. However, the case of using clay blocks (Case-7) reduced consumption by a very small percentage compared to the case Using cement blocks, the decrease was 55.59%. However, when using double walls with an air void of 7.5 cm thickness (Case-8), the decrease was clear, reaching 67.07%. If the void thickness is increased to 10 cm from the previous case, there is almost no effect.

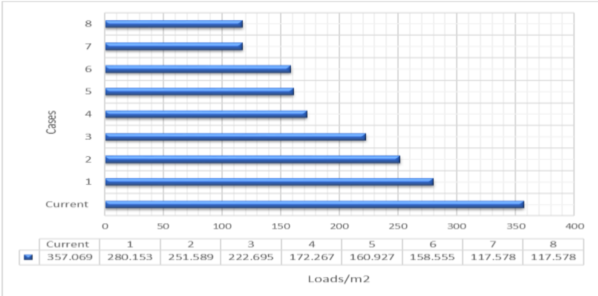


Figure 5. Total loads consumption (Heating and Cooling) per unit of area for Model-1

In Case of Model-2, as presented in Figure 6, for the current case the energy consumption /m^2 is 174.31 Kwh, which is significantly lower than the case of Model-1 for the uninsulated case. After removing the roof insulation only and keeping the wall insulation (Case-1), the total energy consumption value increased significantly by 32.17%. After tiling the roof (Case-2), consumption increased slightly from the current case, which is 3.36%, indicating that the effect of tiling is close to the effect of insulation. Adding insulation to the previous case, which is (Case-3), decreased consumption by 9.92%, which is a relatively small amount compared to the cost. In the case of changing the type of slabs from solid to one-way hollow block slabs with the presence of tiles and without roof insulation (Case-4), consumption decreased by 21.08%. With the addition of insulation to the previous case (case-5), the decrease increased, but not significantly by 26.85% from the current case. With only changing the type of wall from a double wall and the presence of an air insulator with a clay block wall (Case-6), where consumption decreased by 19.05% compared to the current case. However, in the case of using a double wall and increasing the thickness of the air insulator to 7.5 cm (Case-7), consumption decreased by 35.59% compared to Case-5, and with increasing the thickness of the insulator to 10 cm (Case-8), consumption values were not affected. significantly

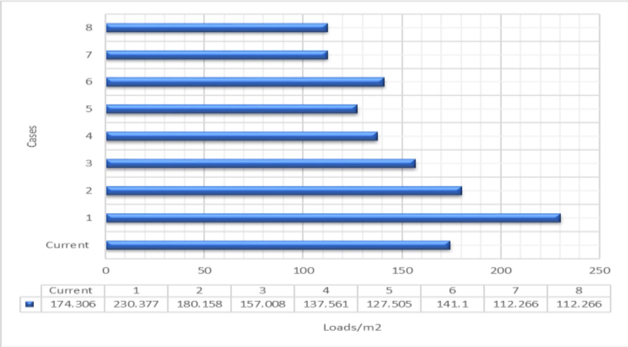
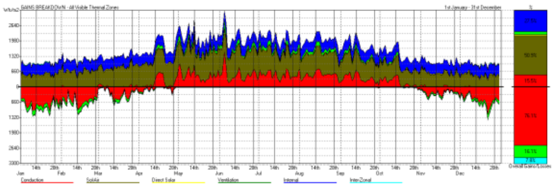


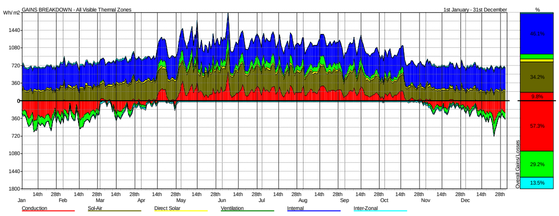
Figure 6. Total loads consumption (Heating and Cooling) per unit of area for Model-2

B. Passive gain and loss breakdown analysis

In Figure 7, the horizontal axis represents time (in months) over one year, where values above the axis indicate gains and values below indicate losses. The blue area in Figure 7 represents internal heat, and this area is larger throughout the year in Model 2 compared to Model 1 because Model 2 is highly insulated and retains more heat. Meanwhile, the red area represents the conduction component. In Model 1, this occurs because the material has low thermal conductivity, maximizing passive heat gains, particularly during cold seasons (76.1%). In contrast, Model 2 has higher material resistance, as shown in Figure 6 (57.3%). The losses in both models are primarily due to sol-air heat exchange. However, in Model 2, the losses are reduced because of the high-albedo coating, which reflects light. Both models show relatively small gains from direct solar radiation and small inter-zonal losses.



Model-1



Model-2

Figure 7. Analyzing energy losses and gains for current cases

5- Conclusion and Recommendations

Passive climatic and environmental design has become indispensable in architectural and structural planning. This study examined thermal performance based on various cases, analyzing materials in relation to their thermal properties under climate data similar to local conditions. The findings demonstrate significant economic benefits in reducing energy loads through insulation or the use of specific structural elements (walls or roofs), as summarized below:

1- Roof insulation alone can improve a building's energy efficiency by approximately 25% in total energy consumption per m².

2- Tiling a roof without insulation provides an insulation effect comparable to using insulation alone.

3- Combining insulation with tiles does not significantly enhance energy savings compared to using either method independently.

4- Hollow tiles contribute more effectively to thermal insulation than solid slabs.

5- Clay block walls offer slightly better insulation than cement blocks, but the difference is marginal, and cost remains a deciding factor.

6- Increasing the air gap between block rows may be ineffective if the distance is too large relative to the cost.

7- Based on the results and findings, authors recommend raising awareness among engineers and the authorities responsible for overseeing the implementation of construction projects both residential and government-owned buildings about the importance of insulation and its role in reducing energy consumption.

8- The authors also recommend future studies focusing on economic importance, particularly comparing government energy subsidies with the possibility of replacing them with support for insulating materials used in construction.

Acknowledgement

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