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The Influence of Thermal Insulation on Cooling a Residential Building in Khartoum

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Abstract: This paper aims to investigate and present energy saving techniques in buildings. In this study, the effect of thermal insulation on cooling a residential building in Khartoum was evaluated using Elite's Commercial Load Calculation Software (Chvac). A model design of a common one storey household was considered. Ten scenarios of different insulations or configurations were applied in the simulation. The cooling load of the building without insulation was found to be 47.48kW (13.5ToR). Using double glass pane windows, insulated walls and insulated roof reduced the cooling load to 29.54kW (8.4ToR) which translates into 38% reduction in electricity consumption.

Keywords: *Air conditioning; thermal insulation, heat transfer; AC efficiency, energy savings.*

1. INTRODUCTION

Energy consumption rate is gradually increasing due to urbanization, industrial growth and population growth. Population growth leads to contracting more buildings, which increases energy expenditure. In Sudan and as of 2017, there were 2.2 million residential consumers, constituting about 60 present of the total electricity sales, The World Bank [1]. More than 70% of that energy needs originate from thermal power plants using non-renewable sources such as crude oil, diesel and gas, The World Bank [1]. Therefore, a nationwide attempt to improve the thermal efficiency of buildings would help to decrease cooling energy use. A direct approach to achieve that is the use of thermal insulation in buildings. Cooling load demand of buildings can be reduced significantly in thermally insulated buildings located in hot dry and hot humid regions Mehmet et al [2]. Thus, reducing energy usage for space cooling in buildings. It is a key measure to energy conservation and environmental protection.

The main question is whether thermal insulation is a viable solution to reduce energy consumption due to air conditioning systems in Khartoum. Another question is focused on what is the best available method to attain that. The effects of many variables, including material properties, climate, and the adopted insulation strategy, on the thermal efficiency of the building thermal envelope make it harder to give a direct answer.

In hot and dry climates, the greatest thermal gain occurs through the roof and external walls Asadi [3]. Hence, the use of thermal insulations may minimize the overall heat flux. In recent years, considerable attention was given to the use of thermal insulations to cut the escalating electricity's bills. Yet in Sudan the use of thermal insulations is uncommon. This is due to the high, initial and the installation, costs of the insulation materials. Also, the heavy subsidy of the electricity doesn't urge the customers to have energy efficient buildings. Therefore, the state of the economic benefits and energy savings don't ever justify the high initial expenses of the buildings' thermal insulations.

1. Literature Review

Thermal insulation hinders conductive, convective and/or radioactive heat transfer ASHRAE fundamental handbook 2001 [4]. Providing insulation for walls and roof in a building increases their thermal resistance and limits conductive heat flow through the building envelope. The building envelope insulation is a main component because it plays a major function in the energy consumption. The building's roof, windows, walls and floors lead the flow of energy between the indoor and the outdoor of the building. The envelope insulation is very important, and it is the best solution in order to have an efficient and less consuming energy building. New building technologies are trying to reduce their energy consumption by improving the air tightness and increasing the thickness of insulation Taylor and Imbabi [5].

Many studies have quantified the energy savings from thermal insulation; Ternes et al. [6] showed that by retrofitting exterior masonry wall insulation from R-3 to R-13, energy consumption reduces by 9 -15% in Arizona. A study of a typical insulated masonry house in the hot and humid climate of Bangkok, Thailand by Chulsukon [7] indicated 3-4% annual energy savings from light weight walls with R-11 bat insulation and from cement tile roof with R-11 bat insulation. Another study of a similar house in Bangkok, Thailand showed 8% of total energy reduction from light-weight concrete block walls with R-10 exterior insulation, and 9% reduction from similar wall construction with R-10 interior insulation Rasisuttha and Haber [8]. Mehmet et al. [2] studied the influence of different thicknesses of insulation on cooling load and energy consumption of air conditioning system. Energy performance of the building for cooling period was investigated with life-cycle cost analysis.

They found that the initial cost of the ACS for CAV and VAV systems are about 22% less, operating cost of the ACS is 25% less for VAV and 33% less for CAV with respect to the no insulation building. Another study conducted by Ozel [9] calculated the optimum insulation thickness for building external walls using an economic model over a lifetime of 10 years in Turkey. The results revealed that optimum insulation thickness in a south oriented wall is 5.5 cm and 7 cm for extrude polystyrene and polyurethane respectively. As for the best arrangement for insulation Kossecka and Kosny [10] researched the Influence of insulation configuration on heating and cooling loads in a continuously used building. They concluded that walls with massive internal layers and with high values of the structure factor show the best thermal performance for different climatic zones: minimum annual heating and cooling energy demand. Differences in total energy demand between the configuration ‘‘all insulation inside’’ and the most effective configuration from the point of view of energy savings ‘‘all insulation outside’’ may exceed 11% for a continuously used residential building.

2. Thermal Insulations in Sudan

There are not many available thermal insulation materials and applications in Sudan since it is not commonly used in construction especially in residential buildings. None the less there are a few types even some being locally fabricated. Generally, there are glass wool, rock wool, mineral wool, expanded polystyrene and polyurethane spray foam. There is also a lack of local researches validating the effectiveness and benefits of using such insulations and comparison between different materials. Consequently, contractors and construction companies prefer not using any insulation unless it has been specially requested by the client.

3. Building Description and Design Conditions

For this study, one-storey residential household model was designed. The build-up area is 217m^2. The architectural plan of the ground floor is provided in Fig 1. Ground floor consists of 3 bed rooms, 1 saloon, 1 hall, 1 dining area, kitchen and 3 bathrooms. The height the floor is 3.2m. Table 1 shows the area details of the building components.

Table 1. Areas of the Building

The Whole Building	
Total Area	217 m^2
Conditioned Area	173 m^2
Walls Area	176 m^2
Glass Area	20 m^2
Roof Area	217 m^2

Khartoum city location follows a latitude of 15 °N and a longitude of 32 °E with an altitude of 380m above sea level. Khartoum features a hot desert climate. Based on the annual mean temperatures, Khartoum is one of the hottest major cities in the world. Temperatures may exceed 53 °C in mid-summer BBC Weather [11]. The months of April, May, June and July were used in the simulation to calculate the peak cooling load. Information about outside/inside design conditions are provided in Table 2.

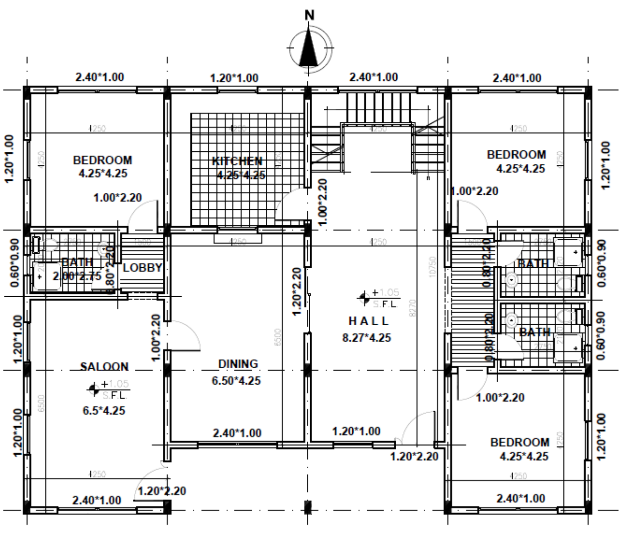

Fig .1. Ground Floor Architecture Plan

Table 2. Outside/Inside Design Conditions

Month	April	May	June	July
Outdoor DB Temperature °C	43	44	44	43
Outdoor WB Temperature °C	23	24	28	31
Indoor DB Temperature °C	24	24	24	24
Indoor Relative Humidity %	50	50	50	50

The following assumptions were considered in calculating the cooling load:

- The Building is a residential household located in Khartoum city.
- Indoor/Outdoor design conditions are in Table 2.
- The residents are family members of 7 people.
- CLTD method was used in cooling load calculations.
- Bathrooms and staircase were excluded from the cooling load calculations.

Before starting the simulation scenarios, a reference baseline must be set to have a clear picture about the cooling load and its constituents. Also, to understand each component’s participation in the total cooling load of the building. Fig 3 shows the contribution percentage of each building component in the total cooling load. The baseline theme falls into the common practice of construction in Khartoum city which means:

- Walls: Brick walls, 200mm thick, common, plaster finish.
- Roof: Flat roof, 150mm heavy weight concrete deck with no insulation, no ceiling below.
- Glasses: Single glass pane, clear with no internal shade.
- Partitions: Brick walls, 200mm thick, common, plaster finish.

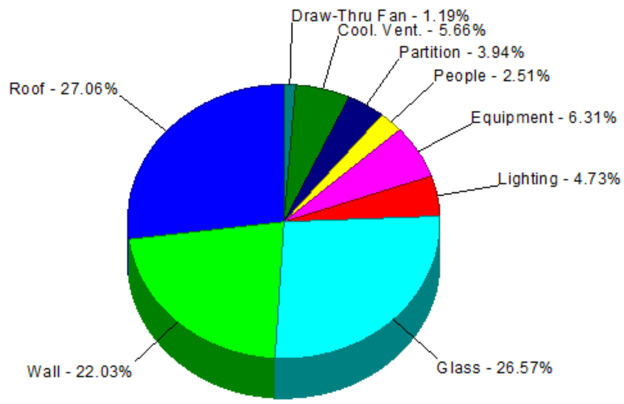

Fig .2. Components contribution in the Cooling Load

4. Results and Discussion

A total number of 10 different simulations were conducted. In each one a selected variable (walls, roof or glass) was changed to be the main factor in the cooling load except for the last two simulations where two or more of the variables were changed in a certain manner to give the least expected cooling load. Table 3 shows the scenarios information.

The building peak load was found to be in June at 5:00 PM where most of the heat gain has converted into cooling load after the time lag effect took place. The roof load was the most demanding sector of the cooling load with a 27.06%. The contribution of the glass and walls in the total cooling load were 26.57% and 22.03% respectively. The resulting cooling load of each scenario has been presented in Table 4 in terms of kW of refrigeration with the savings included.

To interpret these results into money and savings, the electricity consumption must be first set. Looking into a few companies catalogue of split air conditioning systems the rate of electricity consumption per ton of refrigeration was about 1.2 kWh. Assuming 7 hours of working per day in each zone then multiplying the results by 30 days provides the monthly electricity consumption for cooling. In Sudan, the tariff of electricity follows a block meter rate tariff rates based on the monthly consumption. It varies from 0.15, 0.26, 0.32, 0.52, and 0.85 SDG per kWh for 0-200, 201-400, 401-600. 601-800, and more than 800 kWh, respectively. Table 5 shows the cost of monthly electricity consumption in each scenario and the estimated savings.

The reduction of electricity consumption cost per month was clear. It costs 2,462.55 SDG per month in the original (no insulation) case. Where when thermal insulation of walls, roof and double glass in windows were applied the cost dropped down to 1369.62 SDG with is 38% of savings. The percentage savings of all scenarios are shown in Fig 4.

Table 3. Simulation Scenarios.

Scenario No.	Walls	Roof	Glasses
0	200mm Brick walls, plaster finish.	150mm Flat roof, h. w. concrete, no insulation, no ceiling	Single glass pane, clear with no internal shade.
1	300mm Brick walls, plaster finish.	As in (0)	As in (0)
2	As in (0)	As in (0)	Double glass pane, 6mm air space gab, clear with no internal shade.
3	200mm Brick walls, 25mm extruded poly insulation on N & E walls.	As in (0)	As in (0)
4	200mm Brick walls, 25mm extruded poly insulation on S & E walls.	As in (0)	As in (0)
5	200mm Brick walls, 25mm extruded poly insulation on N & W walls.	As in (0)	As in (0)
6	200mm Brick walls, 25mm extruded poly insulation on S & W walls.	As in (0)	As in (0)
7	200mm Brick walls, 25mm extruded poly insulation on all walls.	As in (0)	As in (0)
8-	As in (0)	150mm Flat roof, h. w. concrete deck with 50mm insulation, no ceiling.	As in (0)
9	As in (7)	As in (8)	As in (0)
10	As in (7)	As in (8)	As in (2)

Table 4. Cooling Load in each scenario.

Scenario No.	Total Cooling Load kW	Savings in kW
0	47.48	0.0
1	45.37	2.1
2	45.02	2.5
3	44.67	2.8
4	44.31	3.2
5	44.31	3.2
6	44.31	3.2
7	41.50	6.0
8	37.63	9.8
9	31.65	15.8
10	29.54	17.9

Table 5. Savings in Electricity Consumption Cost per Month in each Scenario.

Scenario No.	Total SDG per Month	Saving SDG per Month
0	2,462.55	0
1	2,334.01	128.54
2	2,312.69	149.87
3	2,291.36	171.19
4	2,269.43	193.12
5	2,269.43	193.12
6	2,269.43	193.12
7	2,098.24	364.31
8	1,862.48	600.08
9	1,498.17	964.39
10	1,369.62	1,092.93

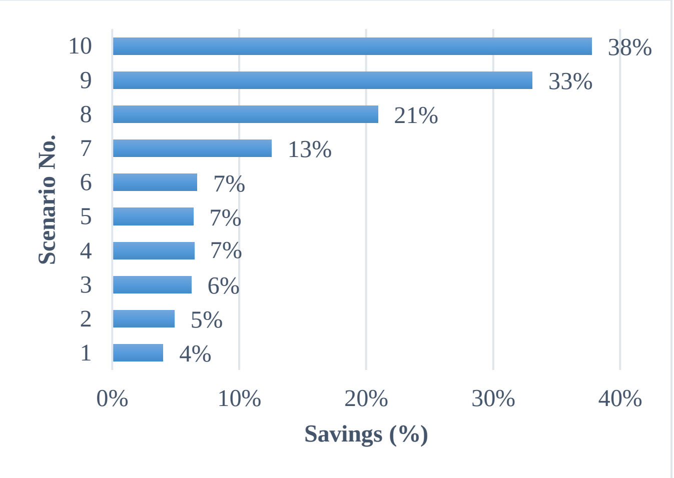

Fig .3. Percentage Savings in Electricity Consumption

When an insulation of extruded polystyrene is applied to the north and east walls, south and east walls, north and west walls and south and west walls separately the resulted savings were 6%, 6%, 6% and 7% respectively. But applying the same insulation on all of the walls of the building resulted in a savings of 13%. Using clear double glass panes instead of one pane made a difference of 5% in savings. The least savings occurred when using a 300mm brick thickness rather than the usual 200mm brick thickness which returned a 4% saving. In scenario 8 the roof was insulated which resulted in 21% savings. While in scenario 9 where the walls and roof was insulated savings were found to be 33%. For the last scenario an additional glass pane was added to the last configuration and that elevated the savings to 38%.

5. Conclusion

In this study, a sample of one storey residential building located in Khartoum city was considered for assessing the influence of insulation applied to the opaque building external envelope components on cooling loads. Energy performance of the building for cooling was investigated with energy simulation using Chvac software. Design cooling load of the sample building decreased to a maximum 38% due to thermal insulation. The capacities of the equipment used in the air-conditioning system for the insulated buildings were lower than that of the no insulation building resulting in an electricity monthly savings up to 1,092 SDG.

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