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Numerical study of the effect of thermal insulation and window-to-wall ratio on reducing the thermal loads of the residential sector in iraq

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HIGHLIGHTS

- Energy saving in residential houses in Iraq was numerically investigated
- Effects of thermal insulation, window-to-wall ratio (WWR), and orientation were explored
- The lowest thermal load was at 5 cm thermal insulation
- The optimal WWR was 25% for south orientation
- Optimizing insulation, WWR, and orientation reduces electric power consumption

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ABSTRACT

The climate change that the world is witnessing has cast a greater shadow on the Middle East. Iraq, one of the region's countries, is experiencing harsh thermal conditions. With the increase in population growth in the country, there was a significant development in the housing sector, which exacerbated the thermal loads that the residential sector requires to overcome harsh weather conditions. This leads to increased energy consumption. To reduce this consumption and energy waste, a simulation study was conducted using the TRNSYS program to analyze the thermal behavior of a building whose walls consist of Gypsum, Juss, brick, and mortar, as well as the roof consisting of Gypsum, Juss, and high-density concrete covered with sand and shtyger under weather conditions of Baghdad city with coordinates 33° N latitude and 44° E longitude, and to study the essential parameters such as building envelope, window-to-wall ratio (WWR), and internal sources that have a direct impact on the residential buildings. These parameters were processed and optimized to minimize the thermal loads annually. The results show that the optimal WWR is 25% in the south orientation. The annual thermal load can be reduced by about 49 % when covering the building envelope with a thermal insulation type (stone wall) with a thickness of 5 cm.

1. Introduction

Due to global warming, Iraq has relatively high summer and low winter temperatures, with the maximum values occurring in June, July, and August between 43 and 50°C and January between 1 and 8°C [1]. The rest of the year is short when the weather is mild. People spend most of their time indoors, especially in the summer and winter, so the buildings must be scientifically designed to provide comfortable conditions for the residents. The housing sector in Iraq consumes more than half of the total energy consumed compared to other sectors [2]. Most materials used in construction are commonly used, such as fireclay bricks, concrete blocks, etc., and the roof is usually made of reinforced concrete. All these materials can absorb heat at a certain time and release it at another time. They do not have a good thermal insulation characteristic, which results in uncomfortable conditions.

TRNSYS was used by Bhaskoro and Gilani [3] to investigate the cooling load characteristics of an academic building. The analysis found that the primary source of cooling demand is heat absorption from the building envelope, about 50% from other sources, followed by heat gain from the machine, 23%, 5% from lighting, and 2% from infiltration and ventilation air. The parameters studied were the shading of the walls and windows, as well as the effect of double glazing, in addition to studying the operation of the air conditioning system by adjusting the room temperature. Qatta [4] used a numerical program to study the effect of using local natural thermal insulators for walls on the thermal response under the influence of solar radiation and the temperature difference in the summer. The natural thermal insulators were reed mat, palm fiber, and local plastic mat. The study

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was to reduce heat gain and obtain comfortable conditions. The solution to the program was using the finite element method. The results showed that using an insulator of local reeds can save 50% of energy through the walls compared with other insulators.

Evangelisti et al. [5] used TRNSYS and MC11300 to forecast monthly energy consumption for homes, apartments, and older buildings and then compared the results. In the event of a heating need, the scientists determined that MC11300 predicted higher values. TRNSYS displays higher numbers when it comes to cooling demand forecasts. Tian et al., [6] studied a model using the TRNSYS program to simulate a 12-story residential building designed according to the standard reference design in Beijing. The building envelope was treated according to the German standard (high-performance) house. Without a fresh air heat recovery system, there is a reduction in the annual heating load of about 63.6% compared to the reference building. In the case of a fresh air heat recovery system, the heating load decreases by 49.3% compared to the high-performance building and 81.5% compared to the reference building.

Gupta et al. [7] examined the performance of a solar cooling system in a multi-zone office complex using TRNSYS. The writers chose four cities to symbolize India's four climate zones. In the four climatic zones, the scientists found energy conservation ranging from 44% to 62%. To convert a house in the United States into a zero-energy building, Alajmi et al. [8] examined the energy of the dwelling. First, altering the natural ventilation and the occupants' behavior proved successful. This part's simulation revealed a 17% annual decrease in energy use and a 10% annual avoidance of CO_2. Murano et al. [9] studied the effect of windows on thermal loads to reach zero energy for the building target. Increasing the window-to-wall (WWR) ratio is not a desirable design technique. Furthermore, the window position greatly impacts the building's energy performance.

The use of big windows raises the peak power and the energy required for heating and cooling in all orientations. The WWR with the lowest Energy is always 10% in all localities and orientations. To choose the different system parameters and adjust them to boost solar system efficiency. A study was conducted by Mahmood et al. [10] using MATLAB software to investigate the thermal response of different types of walls under the influence of the prevailing climate in Iraq. Local thermal insulations, including straw mats, wood shavings, and cork granules, were used. The testing was carried out in June, July, and August. The study revealed that walls containing thermal insulations can reduce heat gain by approximately 50% when using straw mats as insulation, 44% when using wood shavings, and 40% when using cork granules, compared to conventional walls. Muhieldeen et al. [11] studied reducing the heat load of a room in order to save energy, and they found that the outer wall greatly affects energy transfer. They used three types of thermal insulators for the wall: polyethylene Aluminium Single Bubble (PASB) with 5 mm, Expanded polystyrene (EPS) foam with 23 mm, and Rockwool 52 mm, as well as without insulation. Among the experimental data obtained by the researchers were the air temperatures inside the room without a thermal insulator and after using them.

The air temperature inside the room decreased the most when using the Rockwall insulator with a thickness of 52 cm. The results showed that the best insulation material is Rockwool, which has the highest percentage of reducing the internal room temperature by 3.85%. A study achieved by Al-Tamimi [12] in the Kingdom of Saudi Arabia of a building using a simulation method to study the effect of the thickness of a type of thermal insulation XPS Extruded Polystyrene on energy saving and the cost. The study was in three different climates in the Kingdom: hot and dry, hot and humid, and temperate. Energy saving in the hot and dry climate was 32% and less expensive at a thickness of 6 cm, humid climate it was 38.35% and less expensive at 8 cm, and in the moderate climate it was 16.4%. The lowest cost is with 2 cm thick insulation.

Alwetaishi and Benjeddou [13] studied the effect of WWR on the energy load of a school classroom in the city of Abha in the Kingdom of Saudi Arabia. The WWR ratio was determined using TAS EDSL modeling software. The results showed that there is no heating load when WWR = 40% in the southern orientation. It was also shown that the northern façade is the worst, in contrast to the southern façade, which is the best, as the heating load is the lowest possible during some times of the day. Maximum solar heat gain in the northern direction when WWR = 40%, 35% in the eastern direction, and 35% in the southern direction. From the above, it was suggested that the WWR in hot places should not exceed 30% on the northern facade, and 25% on the southern facade. The maximum drop in energy load is 9% when it is in the southern orientation, and the minimum drop is 2% in the northern orientation.

After reviewing the literature, it was found that insulators and WWR make a significant contribution to improving the thermal behavior of the building. There are very poor studies on the insulation thickness and WWR according to the Iraqi climate on thermal loads and the internal conditions represented by internal thermal conditions such as temperature and relative humidity. Comfortable indoor design conditions are around 24°C and 60% relative humidity of the building in Baghdad City [14]. This research studied the gap in this field and, therefore, improved the thermal behavior of the building, which leads to energy saving and consumption reduction, as well as maintaining comfortable conditions within the space.

2. Methodology

2.1 Assumption and limitation

The building's boundary conditions were assumed, such as the materials of the walls, roof, and windows, as well as the internal thermal loads inherent in the building's design, such as the number of people occupying the space, the number of lamps, and the necessary electrical appliances. The case was built and processed in the TRNSYS program. One of the things that may hinder the simulation from working properly is importing some of the necessary components appropriate to deal with the case.

Internal heat sources are varied, such as the people occupying the space. The number of people occupying the space is determined at a rate of one person for every 10 m^2 in residential buildings. The total load resulting from one person at a med activity is estimated at 120 W. The power emitted by radiation from the artificial lighting turns into a cooling load after some time, as the cooling load factor = 1. Most lighting designs require a lighting intensity of about 25 W/m^2. Six incandescent lamps with a capacity of 150W were selected. The third heat source is the electrical appliances. Their use depends on the type of application and need for them. There are multiple types, which were calculated appropriately for the case of the study [14]. Some useful ways to reduce heat load and improve energy efficiency include installing smart thermostats that can automatically adjust temperature settings based on occupancy and time of day. Zoning Systems: Implement zoning systems that divide the building into different areas with separate temperature controls. Energy Monitoring and Management: Implement energy monitoring systems to track energy usage and identify areas for improvement. The outer wall and roof without treatment consist of the following materials, as shown in Table 1.

Table 1: The details of normal envelopes

Item	Area (m^2)	U-value W/ m^2K	Details (cm)
Roof	20	0.381	1.5 gypsum + 2 juss + 20 high-density concrete +5 of sand +4 of cement shtyger
External wall	14, 17.5	0.5847	1.5 gypsum + 2 juss + 25 brick +2 plaster
Glass of window	6.13	1.1	Double-glazing with a gap of 8 mm

2.2 Trnsys

Modeling the behavior of transient systems is done using Transient Systems Simulation software (TRNSYS), a highly customizable software environment with a visual user interface. The great majority of simulations have the performance of thermal and electrical energy systems as their primary objective. TRNSYS is commonly used by engineers, architects, and energy consultants to design and optimize energy systems (with a focus on renewables and recently discovered efficient technology) and to construct low-energy buildings. The TRNSYS software is a versatile tool for thermal systems and energy management [15].

The application comes with a library of components that represent the building project used to construct the system under test. Each component is referred to as a "Type". These distinct parts constitute a piece of machinery, such as pumps, pipelines, cooling coils, chillers, solar collectors, etc. Around 150 components "Type", including pumps to multi-zone buildings, wind turbines to electrolyzes, weather data processors, and basic HVAC equipment to cutting-edge emerging technologies, are available through TRNSYS' Standard Libraries [17].

2.3 Trn build

In the core of the program, there is a window called TRN Build. Through this window, it is possible to control most of the variables related to the structure of the building in all its details, such as adding layers of specific materials specified by the user, creating a new wall, and creating a roof with certain layers. Layers or walls can be selected from the standard internal library of the program. Figure 1 shows the interface of this window, where it is possible to add and delete any element related to the thermal zone and the basic systems that are related to it. The operation period of the system can be controlled by a tab schedule [17].

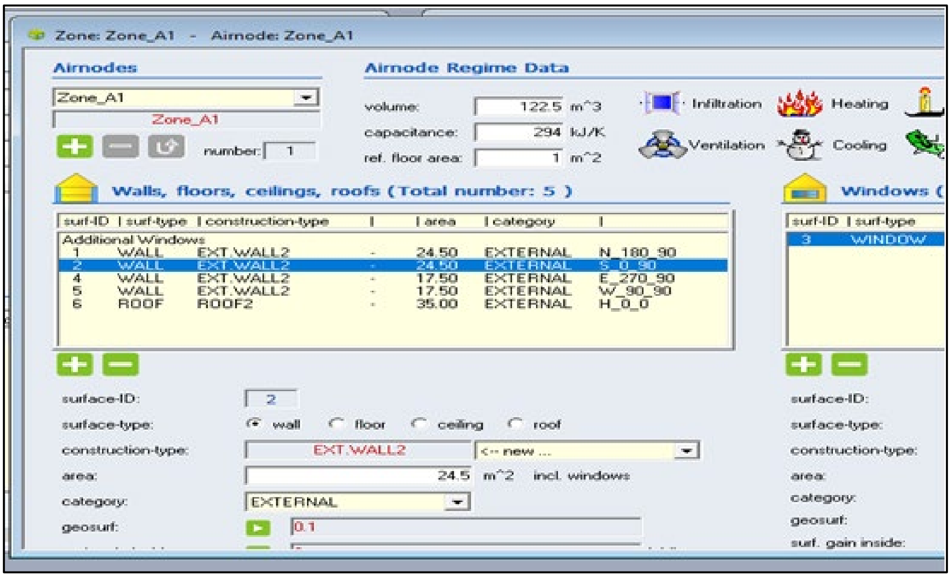
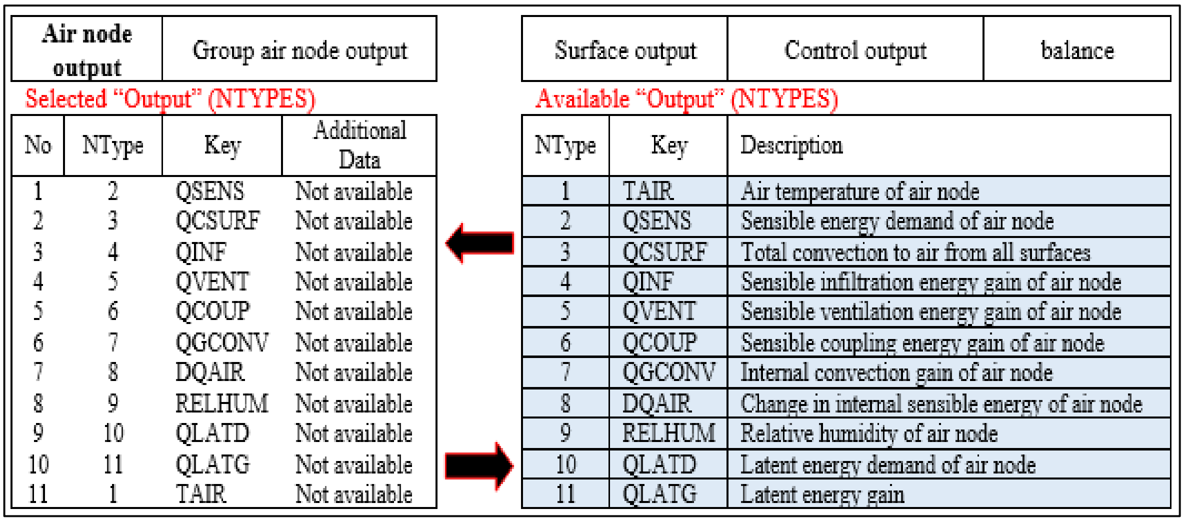


Figure 1: Building zone in TRNBuild

2.4 Thermal load

Thermal loads are a set of heat gain or loss of the building from external sources such as solar radiation and the difference in external and internal temperatures, as well as internal sources such as space occupants, artificial lighting, and electrical appliances. These loads are a function of many elements determined by the program and displayed from an option "Output" as shown in Figure 2. These elements are accurately calculated by the program after entering all the required variables related to the building specifications, the file of weather data of the specified location, the specifications of the internal loads, the specifications of the specific air conditioning system, the thermostat to adjust the desired conditions, and the work schedule. To simulate the annual thermal load of the building under these conditions, a building consisting of at least two thermal zones is chosen, which is represented in the program after giving it all the required characteristics.



Air node output	Group air node output

Selected "Output" (NTYPES)

No	NType	Key	Additional Data
1	2	QSENS	Not available
2	3	QCSURF	Not available
3	4	QINF	Not available
4	5	QVENT	Not available
5	6	QCOUP	Not available
6	7	QGCONV	Not available
7	8	DQAIR	Not available
8	9	RELHUM	Not available
9	10	QLATD	Not available
10	11	QLATG	Not available
11	1	TAIR	Not available

Surface output	Control output	balance

Available "Output" (NTYPES)

NType	Key	Description
1	TAIR	Air temperature of air node
2	QSENS	Sensible energy demand of air node
3	QCSURF	Total convection to air from all surfaces
4	QINF	Sensible infiltration energy gain of air node
5	QVENT	Sensible ventilation energy gain of air node
6	QCOUP	Sensible coupling energy gain of air node
7	QGCONV	Internal convection gain of air node
8	DQAIR	Change in internal sensible energy of air node
9	RELHUM	Relative humidity of air node
10	QLATD	Latent energy demand of air node
11	QLATG	Latent energy gain

Figure 2: The interface of the "Output" option

2.5 Weather data

The only sort of standard hourly data set that is available for Iraq is the Typical Meteorological Year (TMY) and three major cities in Iraq (Baghdad, Mosul, and Basra) are provided to the (TRNSYS) [17]. In this study, the weather data of the geographical location of the city of Baghdad was determined. The file contains all weather conditions for each hour, such as temperature, relative humidity, wind speed, and solar radiation. The TRNSYS program presented these data collected from the Metronome software. Figure 3 represents the temperature and Total horizontal solar irradiance for a typical day in Baghdad.

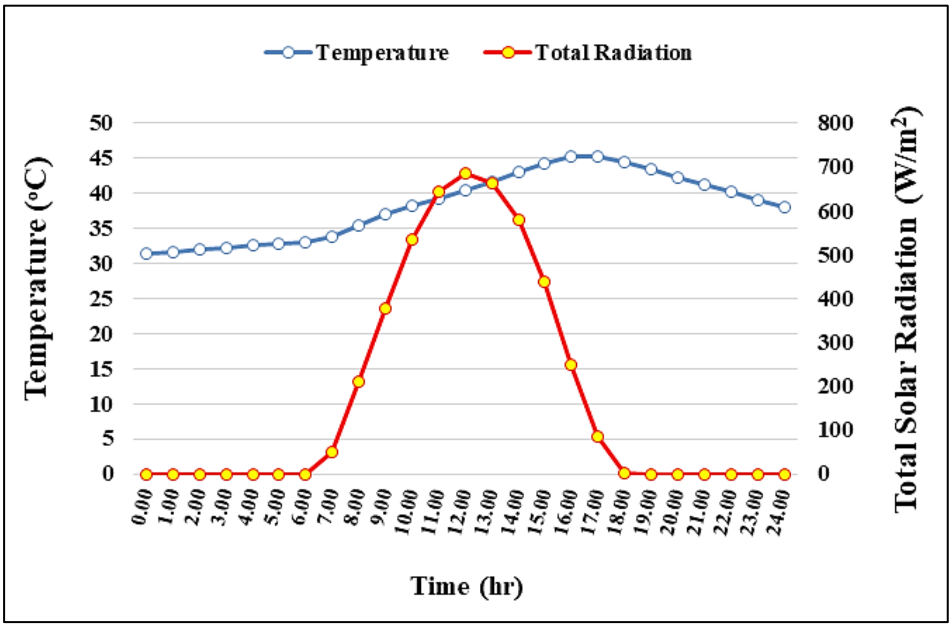


Figure 3: Weather data for a typical day on 21 July

3. Numerical simulation

3.1 The assumption for numerical solution and simulation

There are some assumptions for the theoretical solution and simulation based on which the case in the program is built.

3.1.1 Building geometry

TRNSYS assumes a simplified representation of the building geometry, typically using a series of interconnected zones.

3.1.2 Material Properties

The program assumes that the building materials have homogeneous properties and neglects the effects of thermal bridges or variations in material properties.

3.1.3 Weather data

TRNSYS relies on weather data inputs to simulate the outdoor conditions. The accuracy of the simulation depends on the quality and representativeness of the weather data used.

3.1.4 Simplified heat transfer

TRNSYS uses simplified heat transfer models, such as conduction, convection, and radiation, to simulate the thermal behavior of the building. These models may not capture all the intricacies of heat transfer in real-world scenarios.

3.1.5 Control strategies

The program assumes predefined control strategies for HVAC systems, such as setpoint temperatures or occupancy-based controls, and there is a possibility that the user can specify them.

It is important to carefully consider these assumptions and their potential impact on the accuracy and reliability of the results obtained from TRNSYS simulations.

3.2 Description of case study building

The building consists of two rooms (two thermal zones), one of which is a living room and the other a Bedroom. Each room has a double-glazed window, six external walls and one internal wall separating the two rooms as shown in Figure 4, and the floor is insulated with thermal insulation to eliminate its influence on the results. The building faces south, and the characteristics of the walls and roof are shown in Table 2 [18]. The layers are presented in Table 2, and their respective properties are entered into the program via the TRNbuild window. For the wall, the arrangement of these layers follows an inside-to-outside sequence, as illustrated in Figure 5. The thickness of each layer is established based on the project requirements. To ascertain the total number of layers comprising the intended wall or roof, a careful determination is made.

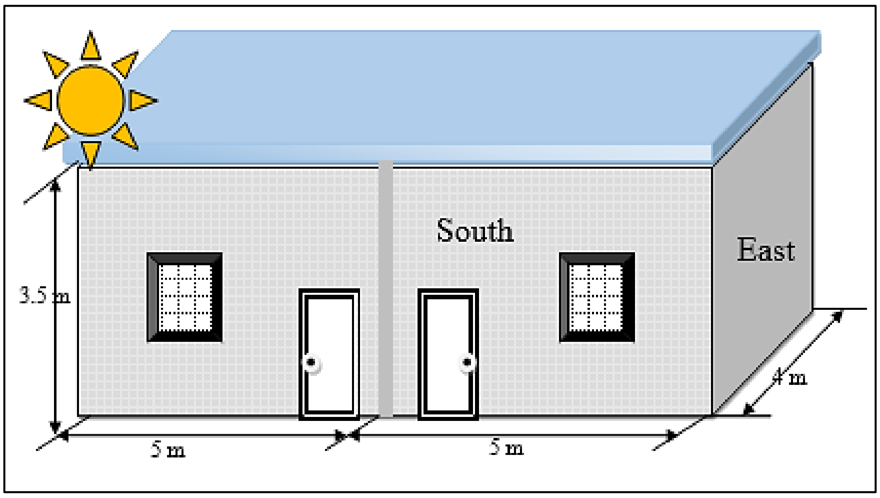


Figure 4: A simple schematic drawing of the building

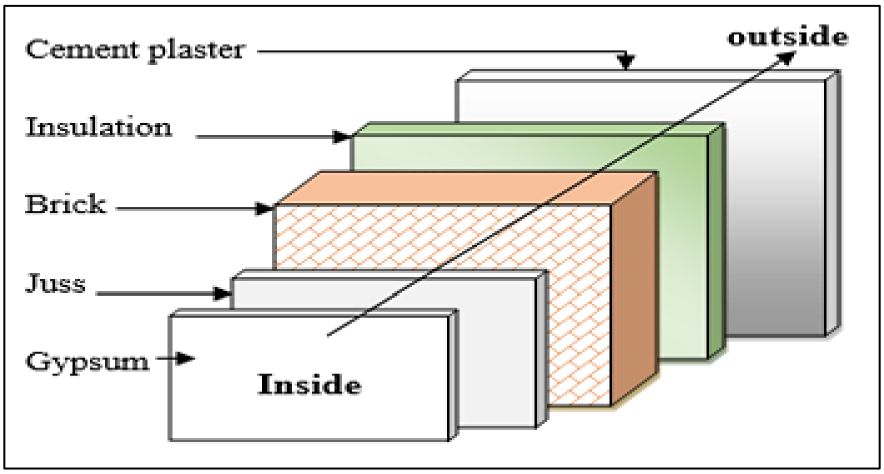


Figure 5: The layers of insulated wall

Table 2: The characteristics of the walls and roof

Layers		Thermal conductivity W/mK	Specific heat kJ/kg K	Density kg/m^3	Thickness (m)
Wall	Gypsum	0.57	0.84	1200	0.015
	Juss	0.72	0.84	1858	0.02
	Brick	0.812	0.83	1416	0.25
	Mortar	0.77	0.84	2050	0.02
Roof	Gypsum	0.57	0.84	1200	0.015
	Juss	0.72	0.84	1858	0.02
	Concrete	1.49	0.84	2300	0.15
	Sand	0.25	0.84	1450	0.04
	Shtyger	0.85	0.837	2220	0.04
	Stonewood	0.039	0.8	150	0.04

3.3 Overall heat transfer coefficient

Anybody shows thermal resistance when exposed to a certain heat flux. If a composite body, for example, a multi-layer wall or a heat exchanger, the total thermal resistance is the sum of the resistances shown by these bodies (layers). As shown in Figure 6, a multi-layer wall is exposed to heat flux (W/m^2) from one side. As a result of a temperature difference on both sides of the wall, heat transfer occurs per unit area. Each layer has a certain thermal conductivity (k) and thickness. Likewise, for the fluid layers adjacent to the wall on both sides, each layer has its convective heat transfer coefficient (h).

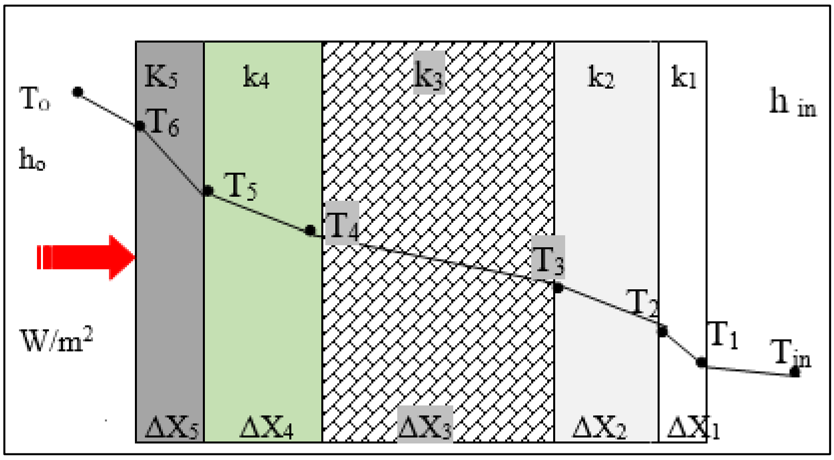


Figure 6: Multi-layer wall

The total thermal resistance (R) is as shown in Equation 1.

$$R = \frac{1}{h_{in}} + \frac{\Delta x_1}{k_1} + \frac{\Delta x_2}{k_2} + \frac{\Delta x_3}{k_3} + \frac{\Delta x_4}{k_4} + \frac{\Delta x_5}{k_5} + \frac{1}{h_o} \tag{1}$$

The overall heat transfer coefficient (U) is related to the total thermal resistance and depends on the geometry of the problem. Where for unit area as shown in Equation 2.

$$Q = \frac{\Delta T_{overall}}{R} = U \times \Delta T_{overall} \Rightarrow \quad U = \frac{1}{R} = \frac{1}{\frac{1}{h_{in}} + \frac{\Delta x_1}{k_1} + \frac{\Delta x_2}{k_2} + \frac{\Delta x_3}{k_3} + \frac{\Delta x_4}{k_4} + \frac{\Delta x_5}{k_5} + \frac{1}{h_o}} \tag{2}$$

where $\Delta T_{Overall} = (T_o - T_{in})$ [19].

3.4 Building model

Creating the study case in the program, loading all the characteristics and parameters that pertain to the system completely, and using the necessary components from the program library. All weather data and details, such as solar radiation, temperature, relative humidity, wind speed, and other data related to the weather at each hourly time for an entire year, are represented in a txt. File. It is listed under the “Type 56” component through the External File tab, where a file related to the test area can be included. Figure 3 represents the outdoor temperature and solar radiation for a typical day, 21 July. Internal sources are selected from the program's internal library depending on the source type. This library contains standard values that are chosen according to the appropriate situation. Enter the names and characteristics of the layers required to create the walls that are used in the building, creating the required walls. Determine all the elements and components necessary for the program to function properly and determine the period required for testing. After all these operations, the status will be created in the program, as shown in Figure 7. The main components that were used in the program for this study are shown in Table 3

Table 3: Main components of the project

No.	Type	TRNSYS Name	Real Component
1	Type 56	Zone Building and TRNBuild	Building
2	Type txt. file	Weather Data Processor	Weather Data
3	Type 697	Performance Cooling Coil	Cooling Coil
4	Type 112b	Single Speed Fan/ with Relative Humidity Inputs	Fan
5	Type 3d	Single Speed Pump	Pumps
6	Type 108	Five-Stage Room Thermostat	Thermostat
7	Type 65d	Online Plotter with Out-File	Online Plotter
8	Type 25c	Printer, Unformatted, No Units	Printer

The components are linked physically to each other, represented by arrow lines. A "Type" component's output is input to another component. There are four main loops in the project: The first loop connects the air fan "Type" 112 to the cooling coil "Type" 697 to the humidifier "Type" 641 to the building "Type" 56. The second loop connects the air fan to the heating coil "type" 140 to the building. The remaining two loops are related to the water movement from the well "Type" 557 to the cooling coil and the humidifier and then back to the well. The last water loop circulates between the well and the solar collector "Type" 1, the auxiliary heater "Type" 6, and the heating coil, then returns to the well. The rest of the components are printers and plotter lines that represent the outputs of the results.

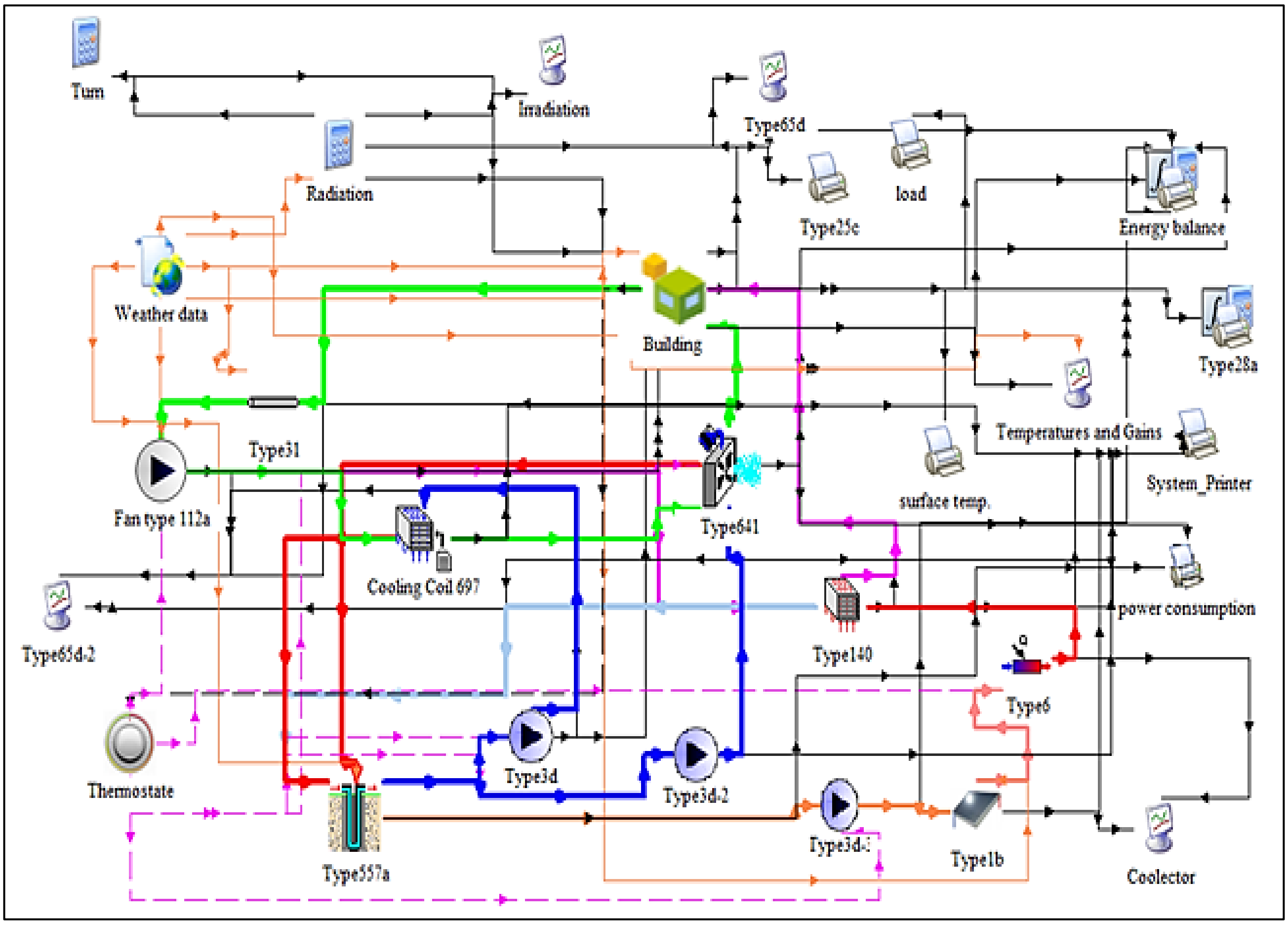


Figure 7: Representing the building model in the TRNSYS program

3.5 Validation

The current computer model has been verified with experimental data of a wooden room with (1.2 × 0.8 × 0.8) m^3 in Malaysia with a location (3° N latitude; 101° E longitude) obtained by Muhieldeen et al., [11]. They studied the effect of the type and thickness of the thermal insulator on the drop in the indoor air temperature of the room. The researchers used three types of insulators, as mentioned and reviewed in the introduction. This case was built programmatically and simulated through the TRNSYS program. All the characteristics of the important factors related to the case were carefully entered, such as the weather data represented by the test site's weather file, the room's characteristics, and the properties of the insulators used, in addition to other parameters. Figure 8 shows the correspondence between the experimental data and the results obtained from the program for indoor air temperatures at using Rockwall insulation because it was the best condition, and the results were largely identical, and there was a good agreement between the experimental data and the theoretical results by 4.2%, also according to the Figure 9. This gives the impression that the program is valid and can analyze the results for an optimal case.

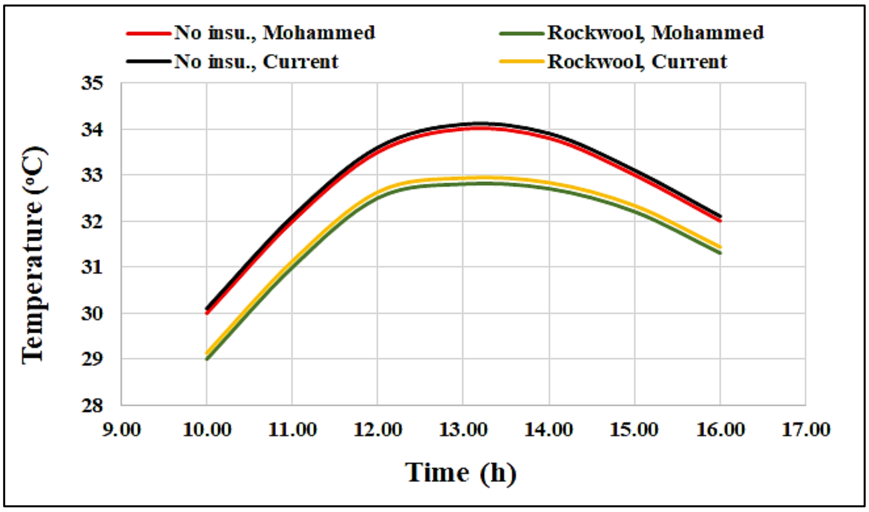


Figure 8: Validation of current numerical results with experimental data by [11]

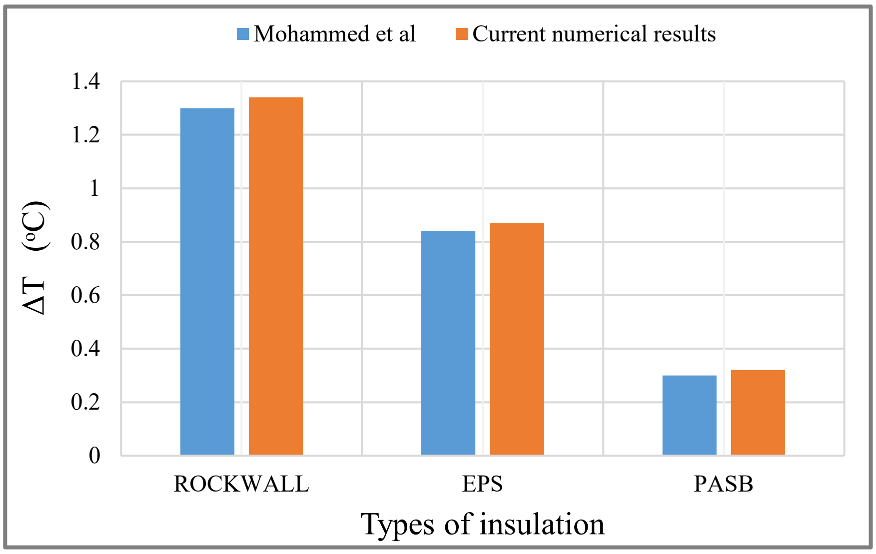


Figure 9: Validation of the current numerical model with [11]

4. Results and discussion

4.1 Internal heat sources

Sensible and latent heat is emitted from these sources, depending on the source type. These sources are usually heat gain, which reduces the annual heating load and increases the cooling load. The effect of lighting and equipment loads is small compared to the load of people. The occupants increase the total load by about 7%, and lighting and equipment increase the annual load by about 3%.

4.2 Building envelops

The wall and roof of the building constitute an essential and pivotal element in determining the thermal behavior of the building, as it suppresses the wave of severe weather fluctuations, and the wall assists in maintaining the internal conditions at comfortable conditions. The walls are exposed to large effects of heat transfer rates due to their direct exposure to fluctuations in weather conditions, temperature differences, and direct solar radiation.

4.2.1 Effect of window-to-wall ratio

The building was tested in normal condition without thermal insulation. Changing the window size in several orientations, where the window was installed in the north or south direction. When the window has a north orientation, in winter, there is a large loss of heat through the window due to the temperature difference between the inside and the outside. This increases the heating load significantly as the window area increases because the window is considered a weak area to resist heat flow. In the summer, the window also works to increase the thermal load (cooling load) due to the increase in heat transfer through it, and the greater the window area, the greater the amount of heat transferred to the inside of the space due to heat gain. Therefore, the load increases as the window area increases in both cases (summer and winter).

When the window is in the southern orientation, as shown in Figure 10, a slight decrease in the thermal load occurs when the (WWR) increases from 20% to 25%, and the reason for this drop in thermal load is due to the increase in heat gain (decrease in heating load in winter) as a result of the increase in (WWR). This is due to the solar radiation shining on the window, which increases the transfer of heat through the window to the space and the penetration of solar radiation into the window and its passage into the space, greatly reducing the heating load. The cooling load in this case does not increase because the increase in (WWR) is small, but when the increase is more than 25%, the cooling load increases and thus increases the total load. It was found that the lowest annual thermal load is when the window is in the south orientation, and the window-to-wall ratio is 25%, as shown in Figure 10. These factors can be adopted for the window in subsequent tests.

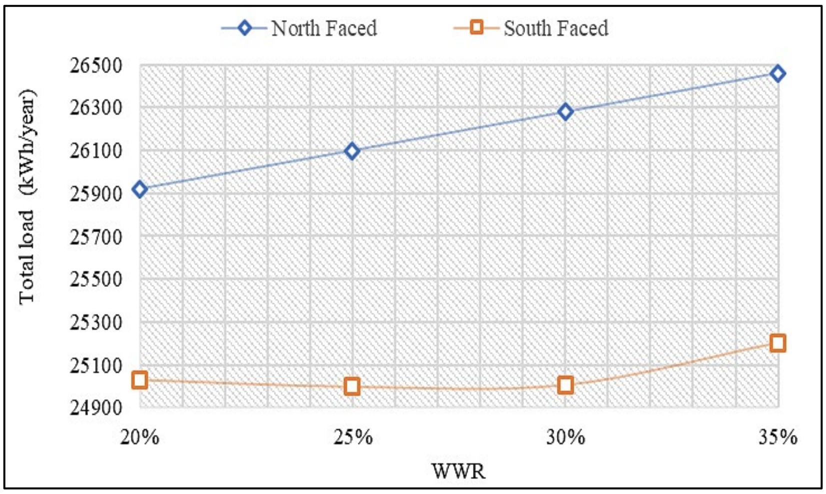


Figure 10: Total thermal load with WWR

4.2.2 The insulated wall

When installing an insulating type of Rock stone (It is a thermal insulator composed of natural inorganic material in the form of fibers. It is characterized by its low thermal conductivity and resistance to natural and chemical influences), which has a thermal conductivity of 0.039 W/mk with a thickness of 2 cm for the outer surfaces of the walls, it is noticed that the temperatures of the inner surfaces of the walls drop and with better stability, as well as a slowdown of the rise compared to a wall without insulation. In the case of thermal insulation, there is a delay in temperature arrival to the inner surface compared with the wall without insulation for many hours. The greater the thickness of the insulator, the greater the temperature stability in the space. In contrast, the percentage of temperature reduction decreases when the insulator's thickness increases. The best thickness of the insulator is 5 cm, as shown for the south wall in Figure 11.

Figure 11 shows that the inner surface temperature of the uninsulated wall reaches 29.84 ^{o}C at 8:00 am, while the same wall under the same weather conditions. Still, it is insulated with a 2 cm thick insulator reaching this degree at 12:30 pm, meaning that the wall insulated is delayed in reaching this degree by three and a half hours. When the wall is insulated 4 cm thick, the time difference is estimated to be about six and a half hours, as the inner surface temperature reaches 29.9 ^{o}C from 8:00 am for the case of wall without insulation to 2:30 pm for the 4 cm insulation thickness. When using insulation with a thickness of 5 cm, the isolated wall is seven and a half hours later than the non-insulated wall to reach the same temperature. Slowing the temperature rise indicates a decrease in the amount of heat transmitted by conduction through the wall, and this is due to two reasons, one of which is the low thermal conductivity of the materials used in the wall, as well as the high thermal capacity that the wall possesses, which works to store the largest amount of heat inside it as a result of the large thermal mass of the wall.

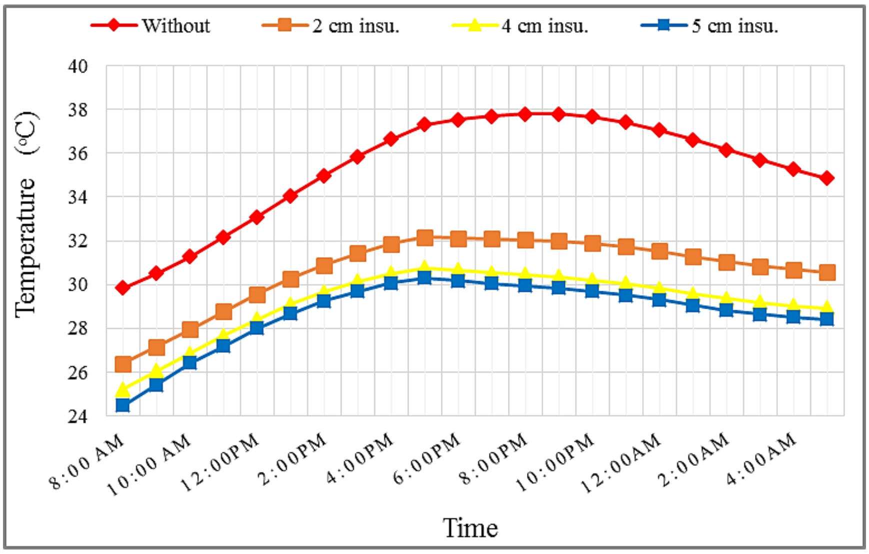


Figure 11: The inner surface temperatures with different insulation thicknesses at 21 July

The decrease in temperature at low levels and for longer periods leads to the thermal stability of the space and a reduction in the rates of thermal loads—the transfer of heat from the inner surface of the wall to the space by convection and radiation. Convection heat transfer is related to the convection heat transfer coefficient (h). (h) is largely related to air velocity, and usually, inside the space, the air is at rest. Therefore, the value of the convection heat transfer coefficient is low, which leads to a decrease in the convection heat transfer within the space. As for heat transfer by radiation, it is electromagnetic waves that do not need a medium but depend greatly on the temperature difference between objects. If the temperatures are relatively low, this leads to a decrease in the heat transfer rate in this manner. Thermal load is the total heat gain or loss of a building due to changing ambient weather conditions. Figure 12 (a-d) shows the monthly thermal loads and the effect of the insulation thickness used for the walls on reducing them. When using an insulator with a thickness of 2 cm, a drop in the thermal load is estimated at 26.4%. This reduction increases to 31.7% when the insulator has a thickness of 4 cm, but when using the insulator with a thickness of 5 cm, the reduction in the annual thermal load reaches 33.3%.

Figure 13 shows the decrease in the thermal load with the thickness of the insulation type (Rock stone), which has a thermal conductivity of 0.039 W/m K, used in building envelopes.

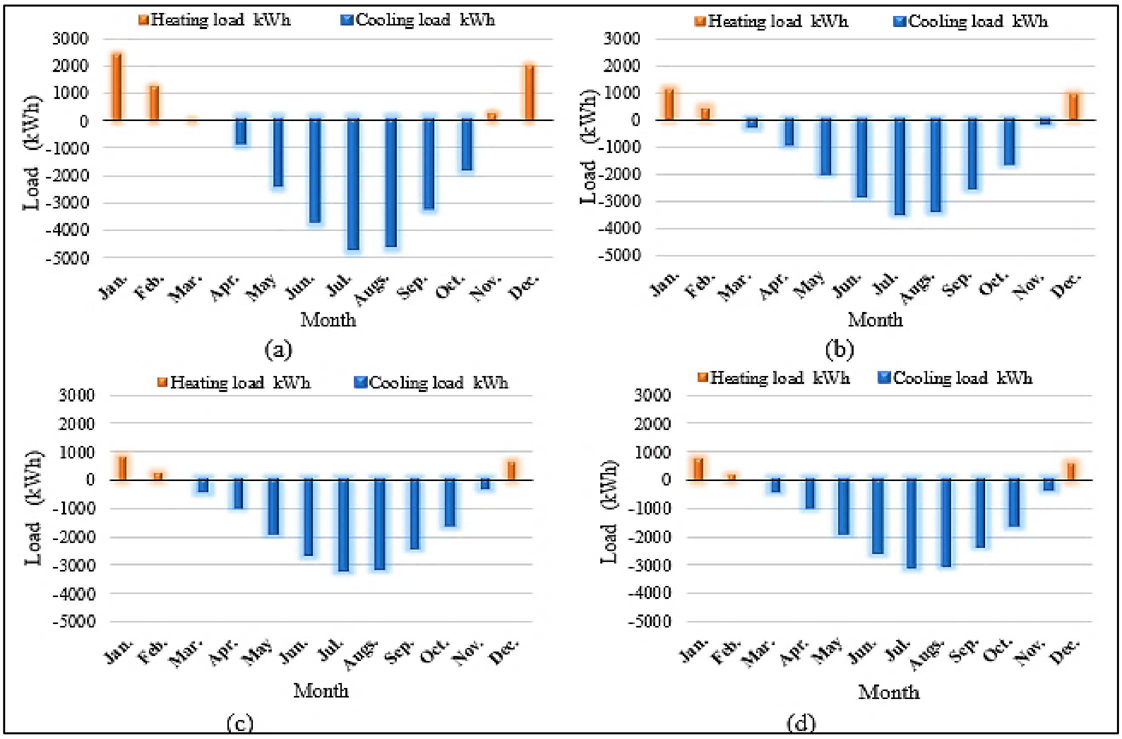


Figure 12: The thermal loads are (a) no insulation, (b) 2 cm, (c) 4 cm, and (d) 5 cm

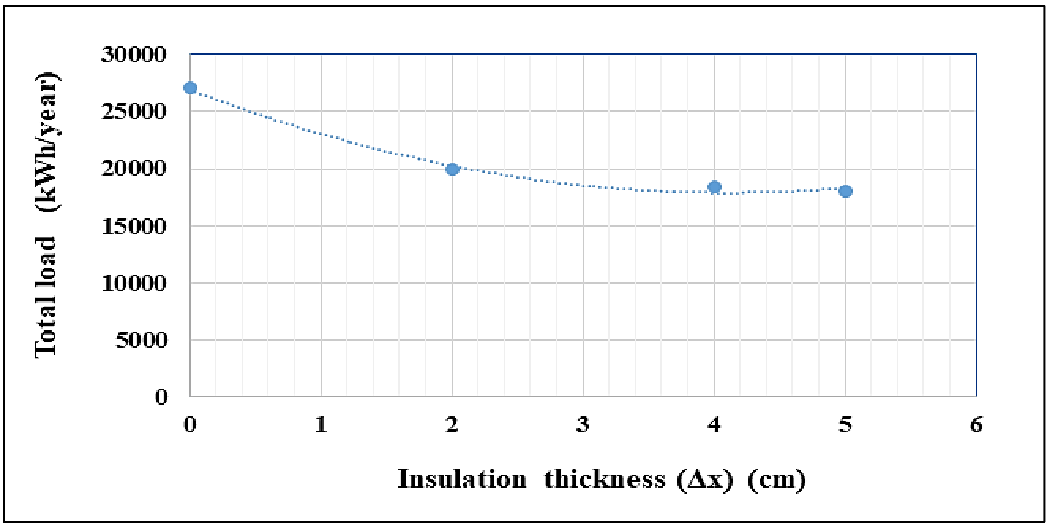


Figure 13: The relation between thermal load and insulation thickness

4.2.3 The roof

Figure 14 shows the two specific days, namely 20 and 21 of July. There is a clear difference between the temperatures of the inner surface of the roof in the two cases with the presence of insulation 5 cm and without insulation. The average temperature difference between the two cases was about 2.9 °C.

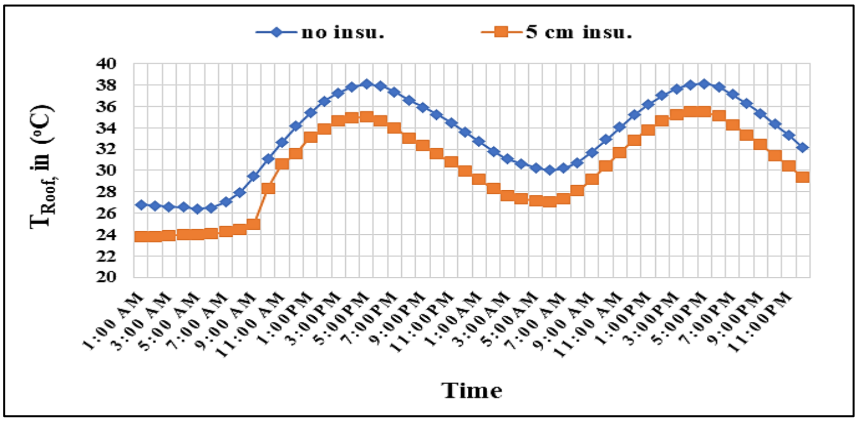


Figure 14: Inner surface temperatures of the roof on 21 July

Figure 15 (a,b) compares the thermal loads for two cases: the first is without any effect or treatment of the building, and the second is when the walls and roof are insulated with an insulator of 5 cm thickness. It is noted that there is a clear difference between the two cases, and this is due to the high thermal resistance that the isolated walls possessed, as well as the roof. When insulating the walls and roof, the load drops up to 49%.

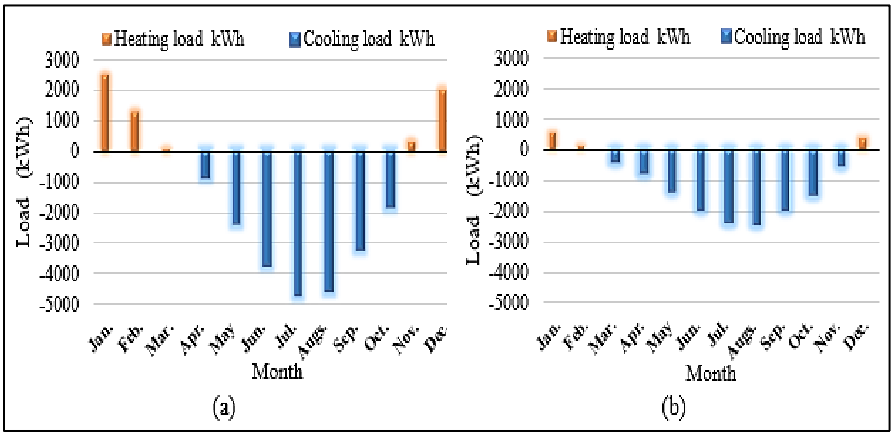


Figure 15: Thermal loads are (a) no insulation and (b) with wall and roof insulation

5. Conclusion and recommendation

The residential sector is one of the most energy-consuming sectors. It was found from the study that one of the most influential elements in thermal loads is the building envelope, as it is directly exposed to weather conditions and fluctuations. There are several important parameters, including WWR, the use of insulation for the building envelope, and internal heat sources. The best case was for the window in the southern orientation with 25% of the wall area and double glazing. The use of insulation-type Stonewall with a thickness of 5 cm for the building envelope can improve or increase the stability of the inside conditions for the space and works to reduce the annual thermal load by 49%. The total annual thermal load decreased from 27054 kWh to 13770 kWh, which resulted in an annual energy savings in this facility of approximately 13284 kWh. Internal heat sources also have a clear effect, especially on the space's occupants. There are several recommendations that the study concluded, including attention to the thermal insulation of the building envelope to reduce the thermal loads resulting from harsh weather conditions. As well as attention to the architectural designs of walls, facades, windows, and the quality of materials used in constructing the building. All of this leads to energy conservation and, consequently, a reduction in the amount of fossil fuel used for energy generation, as it is the primary energy source. It also reduces the amount of greenhouse gases emitted into the atmosphere, which have significant environmental impacts.

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Author contributions

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Data availability statement

The data supporting this study's findings are available on request from the corresponding author.

Conflicts of interest

The authors declare that there is no conflict of interest.

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