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A Numerical Study to Determine the Effect of an Insulator Location on the Transient Heat Transfer

Ridha Hameed Mageed[1], Hayder J. Kurji[1*], Ali A. Abdulrasool[1]

[1] Department of Mechanical Technology/Technical Institute of Karbala, Al-Furat Al-Awsat Technical University, Kerbela University, College of Engineering, Mechanical Department, Kerbela, Iraq

* Corresponding author's e-mail: inkr.red@atu.edu.iq

ABSTRACT

Given the importance of thermal insulation in the walls of buildings to provide both electrical energy and thermal comfort in different weathers. In this research, the ANSYS-14 simulation program was used, considered one of the programs used to evaluate the thermal behavior of buildings, considering the effect of weather changes and building components during the steady and unsteady heat transfer of a composite wall from several layers. The simulation program was used for four types of insulation inside the wall with different thermal properties (Glass-Fiber Slab, Polyurethane Board, Hardboard (Medium) and Softwoods). A model was built for a traditional wall without an insulator and a model for a traditional wall that contains an insulator in different locations (from the outside, in the middle, and from the inside). Also, the model was isolated from the top and bottom surfaces, and each insulation material was applied in three locations in the wall. The conventional composite wall was exposed to a constant thermal load of 60 °C from the outside, and the inside wall was exposed to a thermal load of 25 °C This study focused on three steps. The first step is to know the best type of the four thermal insulators used in this study. The second step was to evaluate the best location of the insulator in the wall. The third step included the results of the previous two steps through which the best insulator was chosen and the best location in the wall. Three values of insulator thickness 2, 5 and 8 cm were used. Through the results of the study, it was found that placing the insulator on the outside of the wall plays a large role in reducing the rate of unsteady heat transfer and that its effect decreases by approaching the steady state, as it does not affect it in the case of the total steady state. The results also showed that the rate of unsteady heat transfer decreases by decreasing the thermal diffusivity of materials. It is also noticeable that the effect of the density and specific heat capacity appears clearly at the beginning of the thermal loading on the material. That effect decreases by approaching the steady state as the effect of the heat transfer coefficient of conduction appears. It was also found that both hardboard and polyurethane are the best in thermal insulation. It was also observed that the relationship between heat transfer rate and thickness is inverse-linear.

Keywords: unsteady heat transfer, thermal properties, numerical methods of heat transfer, thermal conduction problems.

INTRODUCTION

Heat insulation is one of the most important factors used in building walls. Because about 40% of total power consumption is related to the building area. The unsteady heat transfer in the wall of buildings depends on several variables such as thermal conductivity, density and heat capacity of composite wall layers. These variables will add to the rise in the heat transfer rate due to temperature differences.

Unsteady 1-dimensional heat conduction equation solved numerically by implicit method for walls with insulation models with different orientations (internal, external and sandwich) materials in winter and summer conditions. The results explained that the wall of sandwich insulation is more suitable for heat gain and heat loss in all weather. Also, the results were compared with Turkish buildings' thermal insulation and the calculated insulation thickness established on the TS825 [1]. Unsteady heat conduction was studied analytically for composite sheets, including layers. Function shifting is primarily applied to get the analytic solution under classical outer boundary environments. The orthogonal expansion method was used to solve the differential equations' derivation. A numerical solution is complete for two composite sheets with a trigonometric or exponential function of the heat transfer coefficient with time on the warm surface. Numerical results explained the transitory difference effects in the coefficient of heat transfer on the unsteady temperature range of composite sheets [2]. The unsteady one-dimensional heat transfer pattern was advanced and numerically solved by employing a finite difference method to study the effect of PCMs on the walls of exterior buildings. Various exterior wall arrangements were resolved for a typical wall by changing the position of the PCM layer, the wall orientation and the surrounding conditions. Results of the study explained that there is no significant decrease in the overall heat lost through the winter in any case of the wall direction or the PCM transport temperature. Higher variations in heat obtained through the summer interval were noticed because of higher flows in solar radiation [3].

Another study aims to develop and enhance the composite wall with a width of 68 mm, which contains two layers of innovative techniques such as phase change material (PCM) and vacuum insulation plate (VIP). The modification involved a parametric study on PCM plates and VIP's location in the thin, lightweight structure wall. This study compared with heavyweight structure envelope buildings (time delay of a heat wave up to 12 hours) can be reached; also, the thermal transferal is significantly reduced [4]. The 3-dimensional transient heat conduction was solved analytically in a cylinder with many layers in the radial- direction. The variables separation technique was used to get the unsteady temperature distribution. The solution acquired is applied for any collection of homogeneous boundary conditions in the (axial & angular) orientation and the non-homogeneous. The solution suggested is also suitable for multiple-layer cylinders with zero interior radiuses [5]. The steady state of one-dimension heat conduction was studied for cylindrical shapes and composite rectangular slabs. A numerical simulation was used for theoretical heat conduction equations by Ansys software. This program demonstrates interactions of all physics disciplines, vibration, structural, heat transfer, electromagnetic and fluid dynamics for engineers. The results of this study explained the change in heat flux and temperature that occur during cylindrical and rectangular slabs [6]. A modern analytical pattern is advanced to know the unsteady heat diffusion into multilayered compound packages for spherical and cylindrical shapes. It is supposed that the combined exchanges heat via radiation and convection mechanisms with the environmental fluid, whose temperature changes randomly with time. New relationships are advanced to compute the temperature distribution in n-layered media, and numerical emulation is also accomplished using COMSOL software. The data obtained from numerical simulation had the farthest relative variation when compared with the analytical pattern [7].

Three techniques were studied and compared to improve the performance of the phase change compound's thermal metal foam/ material. The compound contains foam of aluminium with a porosity of 90% and wax of paraffin-like PCM. The numerical study was applied for the melting procedure of the paraffin established as aluminium. The results showed that moderating the cold wall form could develop the thermal response of the composite and moderate the efficiency better than pure paraffin [8]. A numerical study was examined by applying the finite difference implicit procedure for the location of insulation and its effect on the heat transfer property of building walls and the suitable insulation thickness. Insulation was put inside, middle and outside of the wall. It is noticed that the greatest temperature oscillation and maximum loading in winter and summer happen when the insulation is put in the middle of the wall. In contrast, the insulation location on the outside wall gave little fluctuation [9]. The insulation in the structure envelope was used to develop thermal building performance. This study finds the optimal thickness of insulation for outside walls of various structures and orientations, considering cooling and heating intervals with the speed of the wind and its direction. Three kinds of composite walls were chosen and isolated thermally. Unsteady heat flow during the exterior walls was applied by employing climatologic data for every hour in Athens. An economic study was applied according to the arrangement, different insulation material thicknesses and various orientations. The result of the study explained that the optimal thickness of insulation for any wall among 7.1–10.1 cm [10]. Therm isolation was used to use the energy to supply the demand for thermal refreshing. The truth of thermal isolation is how to use suitable isolation in the installation by choosing suitable material which decreases the heat gain or loss that leads to decreased energy cost. Finally, the study focused on collecting the modern thermal isolation technique in the building by choosing the best material [11]. Another study focused on a modifying model for a comparative choice of dense wall buildings in humid and hot weather like in Kish Island, which depends on four main factors: efficiency of energy, the efficiency of cost, humidity control and thermal comfort. Much research was studied in this field, and computer simulation was done. Results showed that employing the modified form can save energy and advance the thermal condition of indoor climate as well as knowing the risk of the possible structure produced through condensation in humid and hot weather [12]. One of the research suggested a system of the exterior isolated concrete wall. This system was simulated to achieve analytic productivity. The results explained that the improvement of exterior isolated concrete wall performance was more than 40% than the conventional wall, and its performance agreed with materials testing of American Standards [13].

Another study used a wall containing hollow for ventilation, representing an innovative structure used as a ventilation channel. This channel is used to reduce the stored heat in the construction in summer and warm the construction in winter, reducing the heating and cooling loads. The thermal performance of a wall is examined experimentally under various temperatures and airflow rates. Results explained that the air speed in the channel greatly affects thermal performance. The increasing thermal resistance leads to increased air speed and reduced heat transfer during the inside surface compared to walls with no ventilation [14]. An unsteady one-dimension heat conduction equation was used to compare two plaster configurations to study the effect of plaster as a thermal insulator under transient climate conditions. For this aim, the material's thermal properties for all layers, plaster insulator and autoclaved concrete were measured separately in their specific heat, thermal conductivity and density properties. The study results showed identical thermal performance by applying 0.5 cm isolating plaster and 2cm available plaster [15]. Thermal performance and suitable isolation thickness of construction walls with various frame materials were studied through the dynamical thermic condition. Expanded and extruded polystyrene was chosen as a material for insulation. The finite difference is implicit through stable conditions and was used to calculate heating and cooling transport loads. The examination was executed for a wall of south-facing. Results explained that the suitable insulation thicknesses change between 2 to 8.2 cm [16]. In this study, lateness and reducing factors for various construction materials used in Iran have been examined. The function of green depends on time convection limits conditions used for solving an unsteady heat conduction equation. Several parameters were studied, like the thickness of the wall and the influence of the layer of thermal insulation in the wall of the sandwich as well as coefficients of heat transfer for outer and inner on the time lateness and factor of reducing. Constructing material type and thickness greatly influence the time lateness and reducing factor of the wall, which concluded from the results. It's possible to use the current results in designing more efficient buildings with passive solar [17].

The effect of thermal insulation was demonstrated in the above studies, where some studies have a numerical solution by using finite difference implicit method for unsteady one or three dimensional heat conduction equation by using ANSYS and COMOSOL software and analytical solution for composite sheet by using a trigonometric or exponential function of coefficient. Some studies were developed and enhanced the composite wall or thermal building performance by finding the optimal insulation thickness for outside walls of various structures and orientations and choosing the best insulator materials. Another study suggested a system of exterior isolated concrete walls and choosing of dense wall building or using a wall containing hollow for ventilation as well as used two types of plaster configurations to study the effect of plaster as a thermal insulator. This study focused. This study focused on using the ANSYS program to build a model for a traditional wall without insulators and with an insulator in different locations for four types of insulators during the steady state and transient heat transfer of a composite wall and to know the best type in the thermal insulator as well as assess the best location and thickness of the insulation in the wall.

Nomenclature

Tocp	Outside cement plastering temperature (°C)
Ticp	Inside cement plastering temperature (°C)
Tgp	Gypsum plastering temperature (° C)
Ti	Inside room temperature (°C)
Tins	Insulator temperature (°C)
Tb	Brick temperature (°C)
Mid ins.	Medium insulator
$h_{conv.}$	Heat transfer coefficient (W/m^2·°C)
K	Thermal conductivity (W/m·°C)
ρ	Density (kg/m^3)
Cp	Specific heat (J/kg·°C)
Q	Conduction heat transfer rate (W/m^2)

NUMERICAL HEAT TRANSFER SAMPLE OF A COMPOSITE WALL

ANSYS-14(APDL) was used to study the steady and unsteady heat transfer through a composite wall, as shown in Figure 1, which was subjected to thermal load in the steady and unsteady heat transfer case. Four insulator types were used (Glass-Fiber Slab, Polyurethane Board, Hardboard (Medium) and Softwoods) in different locations throughout the wall, as shown in Figure 2 and three thickness value for the insulator was used. The materials' thermal properties and the insulators are explained in Table 1. The models were insulated from the lower and upper surfaces, and heat generation was assumed to be zero. One dimension heat transfer (x-direction) was used. The outside surface of the wall was subjected to 60 °C while the inside surface was subjected to convection at 25 °C. Additional boundary and thermal conditions used in this study were explained in Table 2.

RESULTS

The effect of the type of insulator materials, the insulator's location, and the insulator's thickness through the steady state and transient heat transfer were studied using the ANSYS program.

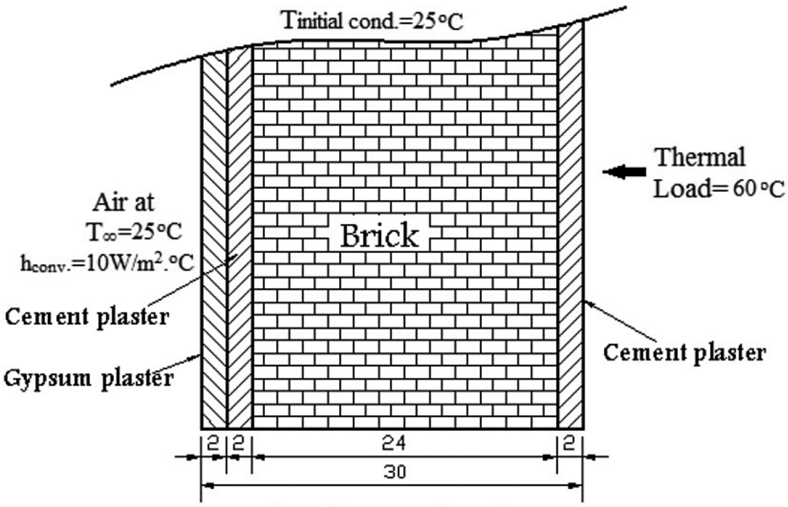


Figure 1. Composite wall

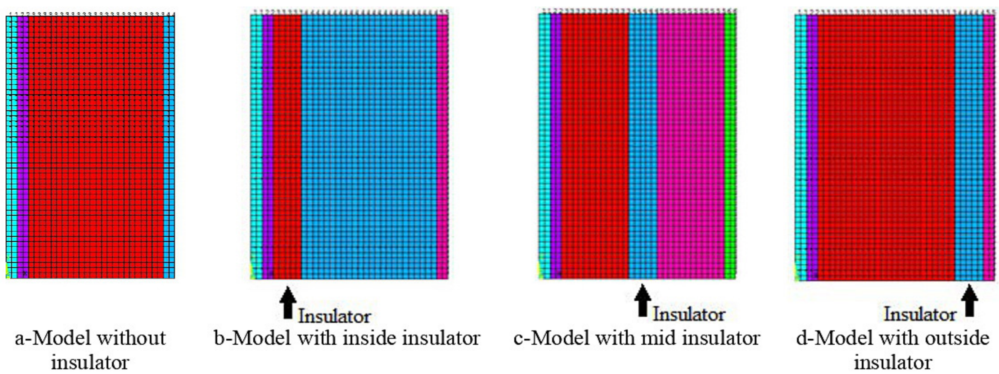


Figure 2. ANSYS modeling of composite wall

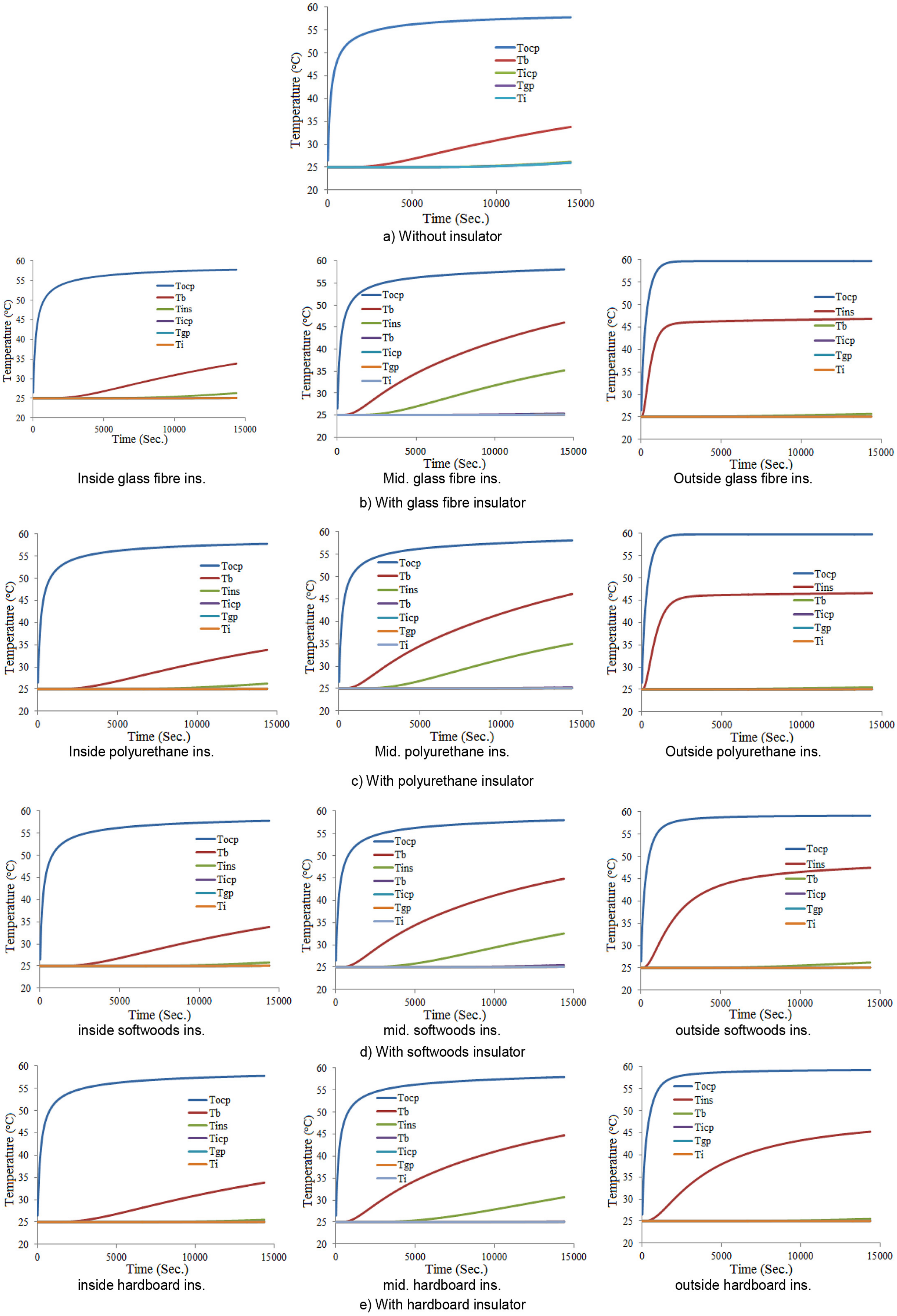


Figure 3. Thermal behavior of specific points for different insulation materials at different locations throughout the wall

Table 1. Thermal properties of materials used [18, 19, 20]

Thermal properties of materials	K (W/m·°C)	p (kg/m^3)	Cp (J/kg·°C)	α (m^2/sec)
Glass-fiber slab	0.035	25	1000	1.4E-06
Polyurethane board	0.025	30	1400	5.95238E-07
Softwoods	0.115	513	1380	1.62443E-07
Hardboard (medium)	0.08	600	2000	6.67E-08
Cement plaster	0.72	1860	840	4.60829E-07
Gypsum plastering	0.42	1200	837	4.1816E-07
Building brick	0.69	1600	840	5.2E-07

Table 2. Boundary conditions and constants of Ansys

Length of model	0.3 m without an insulator	
	0.35 m with insulator	
Sample height	0.5 m	
Thermal load on the left side	Convection at T_{∞} = 25 °C	$h_{conv.}$ = 10 W/m^2·°C
Thermal load on the right side (°C)	60	
Temp. difference between two sides (ΔT) (°C)	35	
Model Initial condition	$T_{initial\ cond.}$ = 25 °C	
Length of element edge	0.01 m (mesh = fine)	
Preferences for filtering	Thermal	
Type of analysis	Steady state and transient	
Length of the model (m)	0.3	0.35
Number of nodes	30	35

Figure 3 shows the wall's thermal behaviour at specific points by using different insulation materials and at different locations throughout the wall. This study was carried out at a specific thickness of the insulation. During a specific time of four hours, where the effect of different variables on the rate of temperature rises over time did not appear for the approved points inside the wall layers, so we need other shapes to show the effect of these variables.

Figure 4 shows the difference in the location of the insulator through the wall and for different insulation materials. It was found that the location of the outside insulator is the best in reducing the rate of temperature rise for the inside surface of the room with time, thus reducing the heat transfer

Figure 5 shows that the insulator's presence significantly reduces the room temperature and the inside surface temperature of the insulator for all the insulating materials used compared to the heat transfer in the absence of an insulator.

Through Figure 6a, which expresses the rate of rise in the inside surface temperature of the insulating material over time, we observe the following.

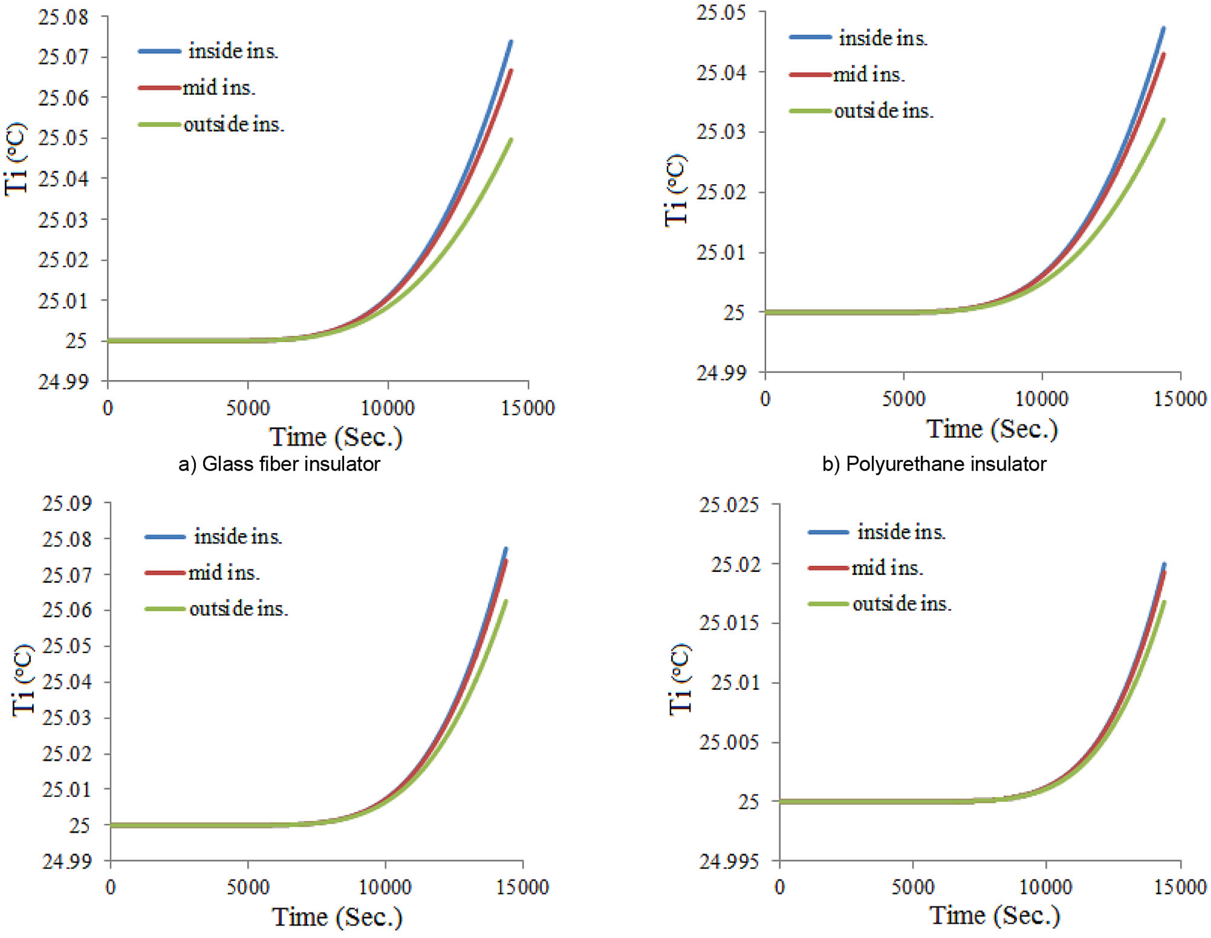
The high temperature of the glass fibre at a rate much higher than the another's during the first 2000 seconds, and the reason for this is the decrease in the thermal storage of this material compared to other materials, which is expressed by the product of multiplying each of (Cp·ρ) as it reached 25000 J/m^3·°C, after that, we note that its temperature rises at a rate lower than the first case, due to the low impact both of specific heat (Cp) and density (ρ) and the effect of high thermal conductivity appeared.

The rate of rise in temperature over time for polyurethane is less than the average temperature rise of the glass fibre, and this is due to the rising value of the product multiplying each of (Cp·ρ), which reached 4200 J/m^3·°C. The very low polyurethane thermal conductivity also reduced the high-temperature rate over time.

The high value of the product of multiplying both (Cp·ρ) for each of the softwoods and hardboard led to a decrease in the rate of temperature increase during the first 2000 seconds, and then their average temperature rise after that, as a result of the rise of thermal conductivity, especially for the softwoods, as we note the high thermal conductivity for it significantly compared to others, which amounted to 0.115 W/m·°C.

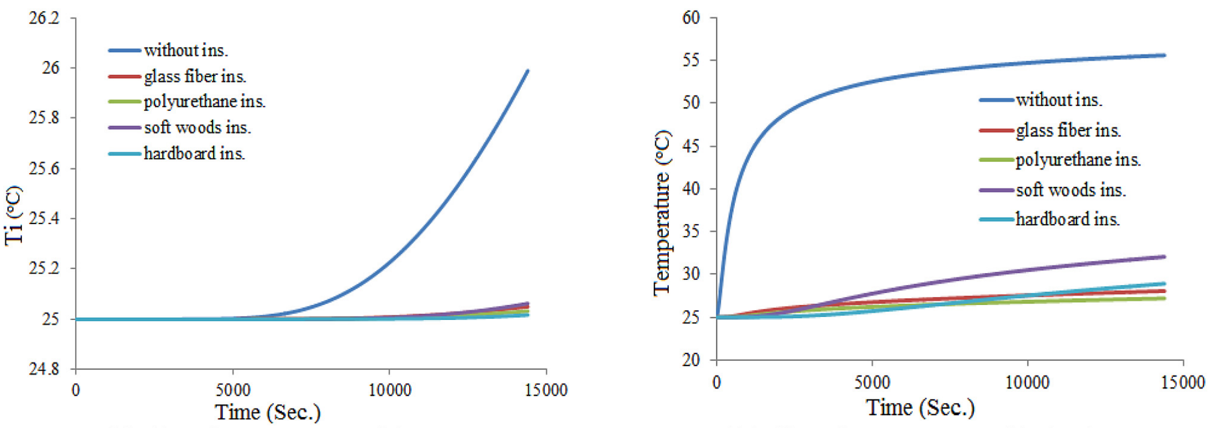
Figure 6b shows the temperature rise rates of the inside surface of the room over time using different insulation materials. Where we observe behavior similar to Figure 6a, especially in the first 2000 seconds, but due to the thickness of the wall between the temperature of the inside surface of the insulation and the inside surface of the room gave this shape, i.e. the need for more time to give the same behavior Figure 6a.

From Figure 6, we conclude that the amount of thermal diffusivity of a material does not clarify the actual thermal behavior of the material without reference to each of the variables included in the description of thermal diffusivity, which is each of Thermal conductivity,



a) Glass fiber insulator
b) Polyurethane insulator
c) Soft woods insulator
d) Hardboard insulator

Figure 4. Effect of insulator location on the inside temperature of room surface



a) Inside surface temperature of the room
b) Inside surface temperature of the insulator

Figure 5. Effect of the insulation on the wall temperature with time

density and specific heat. We also note that the final judgment on thermal conductivity depends largely on thermal conductivity. As for specific heat and density, they express a delay in the heat transfer rates during the period of transient heat transfer, as they express the amount of heat storage of the material only. Therefore, the insulating materials used in the research can be listed according to their efficiency in thermal insulation as follows hardboard, polyurethane, glass fibre and softwood.

The results of Figure 4 concluded that the best insulation site is outside the wall. Through the results of Figure 6, both the hardboard and

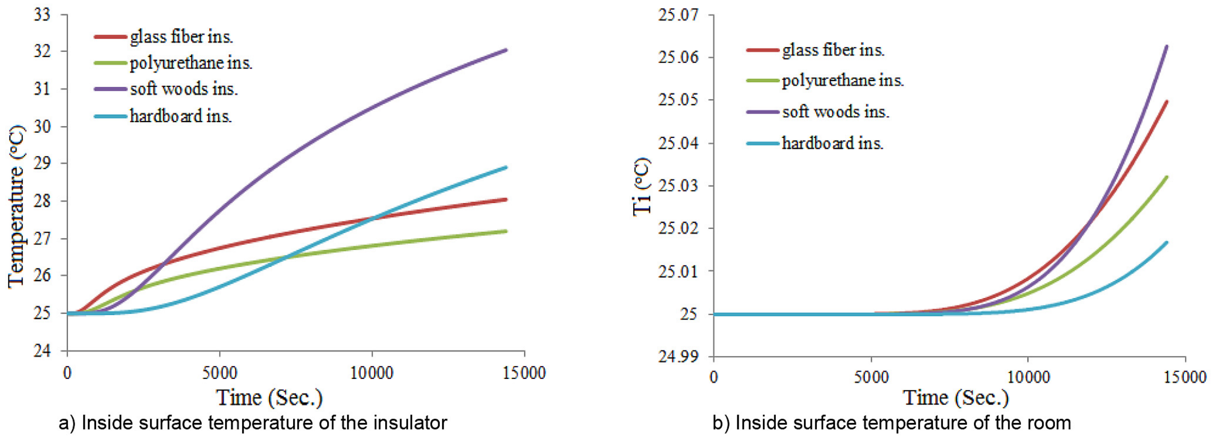


Figure 6. Effect of the insulator type on the wall temperature with time

polyurethane were selected as suitable insulation materials in the buildings, so a second study was included that included changing the thickness of the insulation when the insulation site was located outside of the wall, appropriate insulation materials (hardboard and polyurethane) were chosen only to discuss the effect of the thickness of the insulation as explain in Figure 7. The effect of the insulation thickness is very clear from the figure. However, the thickness change did not significantly affect the rates of rise in the inside surface temperature of the room. So it can be considered that the thickness of 5 cm is suitable for practical applications.

It was noted through the general practice data that the materials generally correspond to the surroundings after a short period. Therefore, they are always close to the steady state of the surroundings; therefore, the real effect is thermal conduction. The effect of each specific heat and density is often limited and can be neglected within very few periods. Therefore, the steady state was studied and clarified through Table 3 and Figures 8, 9.

Figure 8 shows the effect of the thickness and type of the insulator on the rate of heat transfer by conduction, where we notice that the heat transfer rate increases with a decrease in the dielectric's thickness value. Through the figure, it was found that the relationship between the heat transfer and the thickness of the dielectric is a linear inverse relationship. The figure also shows a large heat transfer without the presence of the insulator compared to the amount of heat transferred in the presence of the insulator.

Figure 9 shows the direct (semi-linear) relationship between the heat transfer rate in the steady state with the value of the thermal conduction (K) and at constant values of the insulator thickness.

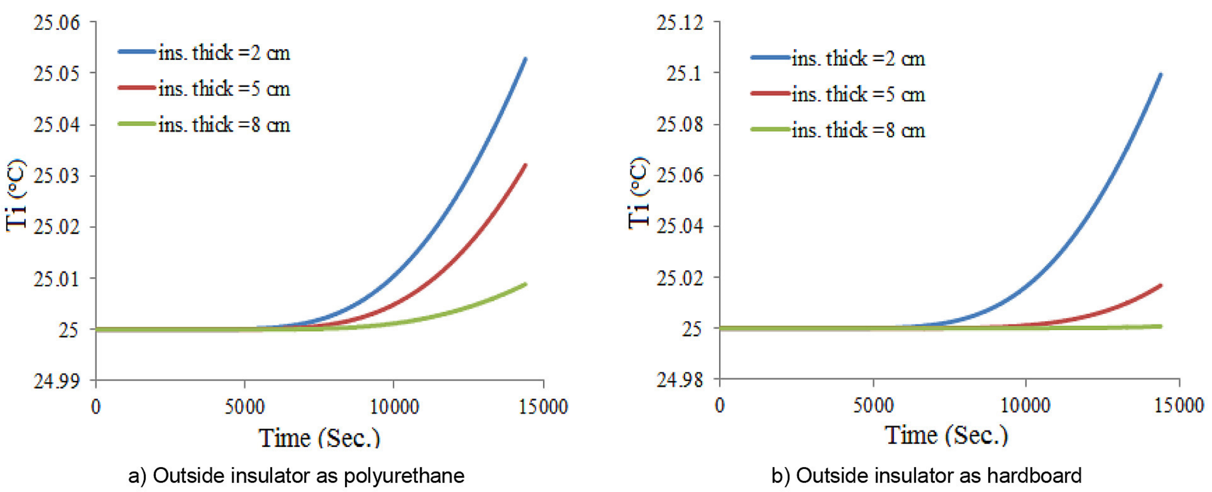


Figure 7. Effect of insulator thickness on the wall temperature with time

Table 3. Result of steady state heat transfer for different insulators and thickness

Ins. thickness X (cm)	Q (W/m²)				
	Without ins.	Glass-fiber slab ins.	Polyurethane board ins.	Softwoods ins.	Hardboard (medium) ins.
2	64	31	26	48	44
5	64	18	14	36	30
8	64	12	9	28	23

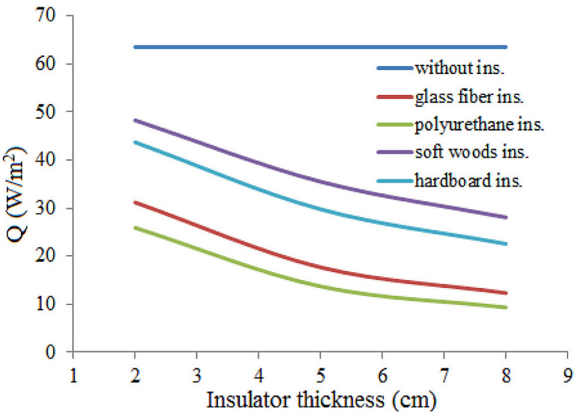


Figure 8. Relation between conduction heat transfer rate and insulator thickness with different insulator materials

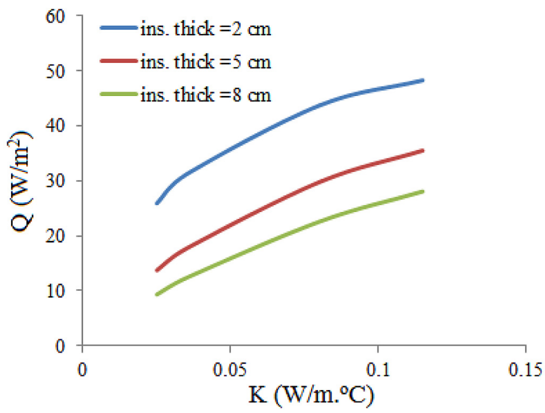


Figure 9. Relation between conduction heat transfer rate and thermal conductivity with different insulator thickness

CONCLUSIONS

Through the overall results, we note that the real effect is only for thermal conductivity in reducing the rate of heat transfer because the materials in the case of practical application are very close to the state of thermal stability and that the effect of both specific heat and density, in this case, decreases so that we can evaluate the material not based on thermal diffusivity but rather on the decrease in the values of thermal conductivity, density and specific heat. Thermal conductivity, density and specific heat played a fundamental role in reducing the heat transfer rate in the transient state at the beginning of the thermal load and each according to its value. Still, the effect of the thermal conductivity value seemed to be evident with the approach to the steady state. Polyurethane and hardboard were chosen as suitable insulator materials due to their thermal conductivity value and low thermal diffusivity.

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