Heat Transfer Analysis of Double and Triple Glazed Glass Windows

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Abstract. In this paper, a numerical study is carried out using MATLAB to investigate the heat transfer through the double and triple glass pane windows. The gabs between glass panels are filled with Argon gas. Calculations are performed for different outdoor temperatures which correspond to daily temperature in London, United Kingdom on April. The results of the temperature distribution profile in the cavities of multi-panel glass windows show that this type of window greatly affects the reduction of heat loss, as these glass panels act as radiation shields that suppress heat currents by slowing the flow in the cavity. It can be concluded that the amount of heat loss through windows is based greatly on the width of cavity between the glass layer, the thermal characteristics of the cavity filler and the temperature difference between the interior and the outside. As for the thickness of the glass panels, it was found to have an unnoticeable effect on the amount of heat transferred inside the multiple glass window system. In addition, the number of glass panes thought to have inconsiderable effect on the amount of the transferred heat within the multiple glass window systems.

Keywords: Double glass · Triple glass · Windows · Layer · MATLAB

1 Introduction

Reducing energy consumption in buildings has gained significant attention all over the world. One of the reasons which increase the energy consumption in a building is the heat loss through the building structure itself. One of the main heat loss sources is the building windows through their glasses due to their high thermal conductivity comparing with walls [1]. For example, the energy losses through windows are more than 6% of the total energy loss in the United Kingdome [2]. The heat loss in windows is changing according to many parameters such as the glass type, glass components, and environmental conditions [3].

Due to the continuous increase in the global population with the rise in the standard of living and the consequent increase in global energy needs, the problem of energy availability has become one of the most important global issues, especially in countries with limited energy sources [4]. According to [5] IEA statistics for the past few years, the

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building sector in general is responsible for about a third of global energy consumption and about 40% of total carbon dioxide emissions. Despite the importance of windows in buildings, in terms of ventilation and providing natural lighting, they cause high heat transfer rates (gain and loss) for buildings. Windows were considered to be responsible for increasing energy consumption in the building envelope by about 25%−30% of energy use in heating and cooling [6].

1.1 Heat Transfer Through Window

According to thermodynamics laws, heat transforms from the higher temperature region towards the lower temperature region via conduction, convection, or radiation. All these mechanisms of heat transfer are important for studying the thermal performance of windows [7]. Considering the thermal response of the structural members, including windows, it can be branched to two sections. The first is the boundary condition from the source of heat which combines convection and radiation. While the other is the heat conduction through the structural member which considered as a governing equation which can be expressed by the Fourier equation. Heat conduction can be defined as the process of transferring the thermal energy through a substance (solid or fluid). This thermal transfer process occurs at the molecular or atomic level without mass motion according to Fourier's law [8]. In order to study the heat transfer behavior through a window, the temperatures of the internal and external window facades must be determined, which requires solving the heat balance equations on each face at specific intervals. In regard to the multiple layer windows, it is required to solve as many heat balance equations equal twice the number of glass panes. For example, in the case of a double-glazed window, four heat balance equations should be solved, while, in the case of the triple glass window, six equations will be solved. As for the variables used in these equations, they are illustrated in Fig. 1 [9].

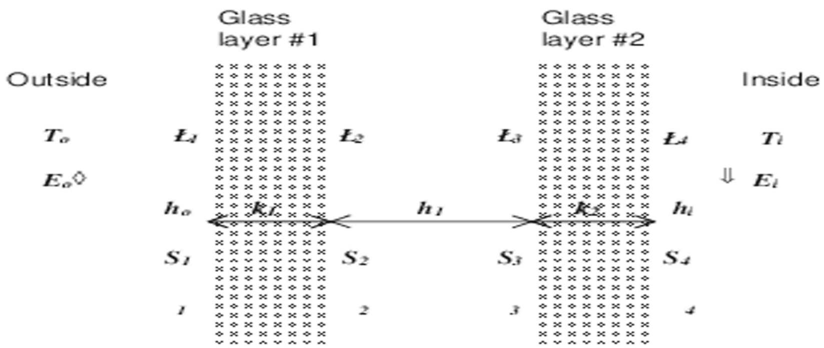

Fig. 1. Double glazed window system with variables of heat balance equations [9].

1.2 Double Glazed Windows

Windows and double-glazed facades are one of the best ways to save energy used in lighting inside the building, which helps achieve sustainable development in the building sector. Therefore, a study explored and evaluated the advantages of double-glazed window systems, and the study demonstrated the effectiveness of double-glazed windows in improving current buildings, but their cost is higher than traditional glass facades. On the other hand, many experts believe that double-glazed window solutions are better in the long term in terms of durability, maintenance cost and energy consumption compared to single-pane windows. In addition, double-glazed windows help reduce noise inside the buildings and bring comfort to the occupants [10].

A study performed a numerical analysis, using the finite difference method, for heat transfer through a double-glazed window. The main objective of this study was to optimize the geometry of window cavity (distance between the two panels) to suit different climates, assuming that the panels represent isothermal surfaces. Weather conditions were simulated in four different regions. Figure 2 illustrates the geometry of double-glazed window cavity [11].

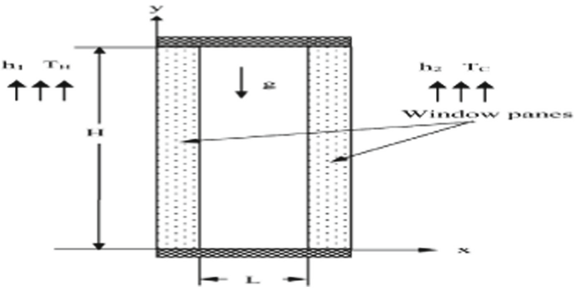

Fig. 2. Double glazed window with cavity [13]

Two main conditions for thermal boundary have been applied on the outer surfaces of the panels (interior and exterior surfaces of the window), the first is the stability of temperature, while the second is the convection heat flux. According to the simulation results of the constant temperature condition, the optimum distance between the two panels differed due to the surrounding weather conditions. The possibility of improving window insulation was also mentioned by using fluids with low thermal conductivity between the two glass panels. Whereas in the case of convection, the effect of surface heat flux on heat transfer has been shown to be insignificant [12]. [13] investigated three different types windows, they are; single frame and single glass window, double frames and double glass window and single frame and double glass window. The thermal characteristics of the investigated windows are presented in Fig. 3. It can be seen that the thermal property of both the double framed windows and the double glazing as well as the single-frame window and the double-glazed window is superior to the thermal characteristic of the single frame window and the single glass window. This can be explained by the presence of air cavity between the two panes of glass, which increases the thermal resistance and thus reduces the transfer of heat through the window.

This study concluded that in cold regions, single frame windows and double glazing are the best choice in terms of thermal performance as they are characterized by a lower heat transfer coefficient and thus make the interior temperature higher. The next option

Types	frame	Heat transfer coefficient (W/m2·K)
Single frame and window	Steel and aluminum	6.4
	Plastic and wood	4.7
Double frames and double glass	Steel and aluminum	3.7
	Plastic and wood	2.5
Single frame and double glass	Steel and aluminum	2.70—3.09
(air space is 12mm)	Plastic and wood	2.34—2.47

Fig. 3. Thermal properties of investigated windows [4]**.**

is double framed and double-glazed windows. While it was advised not to use single frame windows and single glazing windows [12].

1.3 Triple Glazed Windows

A triple glass window, as illustrated in Fig. 4, containing dry air in the cavities between the glass panes was examined experimentally and mathematically using Visual Basic software. Several scenarios are determined according to environmental, temperature and climate conditions. The temperatures of the inner and outer window surfaces were determined and the heat flow behavior of the triple glazed window was evaluated. U-factor values were noted to be varied according to the temperatures of both sides of the window. Moreover, the efficiency of the numerical model has been verified, as its results agree with the experimental results. Experiments have also demonstrated the efficiency of the triple glazed system in increasing the thermal resistance and reducing the overall heat transfer coefficient of the window [13].

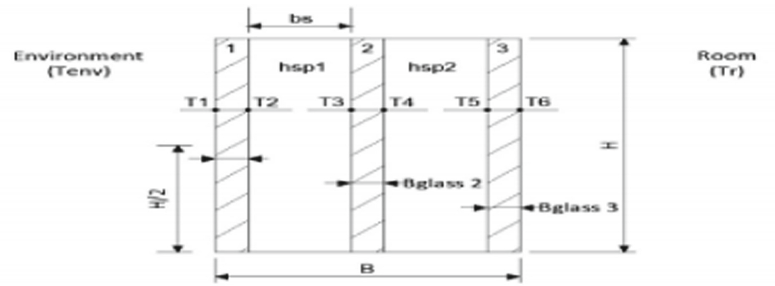

Fig. 4. Triple glazed window with two cavities [13].

A study proposes a mathematical model to examine the efficiency of fluid flow in transferring heat through multiple glazed windows. Several scenarios were studied in terms of different thickness of gaps between glass layers and different outside temperatures according to different locations, considering the radiative heat transfer being ignored in the mathematical model. As shown in Fig. 5, the glass panels of the window unit are separated by equal distances L filled with air, assuming constant interior temperature [4].

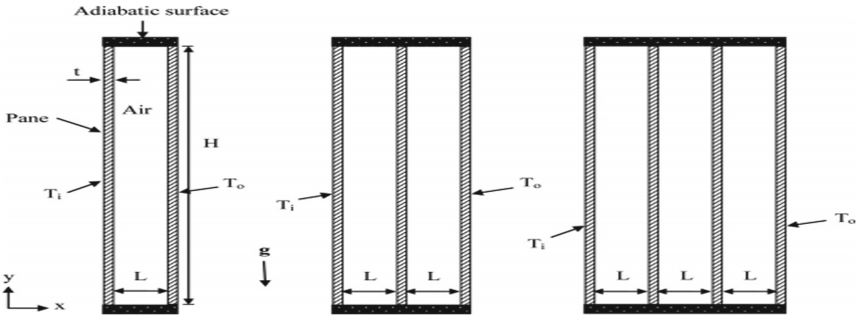

Fig. 5. Schematic of the modeled window system with simulation variables [4].

The resulted temperature and velocity profiles of this study showed linear temperature variation in the regions of solid glass. The approach of increasing the number of glass panes in windows has been proven to reduce the heat flux and reduce the total energy lost, as it can save approximately 50% or 67% of energy when using triple or quadruple glazed window systems, respectively, instead of double windows, while maintaining a high level of interior lighting [4]. Daylight and heat gain are affected by building façade parameters and in particular the transmittance properties of window panels. Therefore, a study investigated the behavior of single, double, and triple-panel windows in terms of gaining or losing solar energy through thermal conductivity and radiation. Where this study searched for formulas to link between daylight levels and the amount of heat gained per unit area according to the difference in the number of glass layers in the window, which in turn prevent heat transfer without reducing light and solar radiation through windows. Some architectural designers believed that glass panels could be added to a window unlimitedly. However, this study proved that the addition of the triple glass window had a negative effect on the penetration of solar radiation, which reduces heating loads in winter in areas with cold climates. Therefore, the study recommended the importance of improving the number of layers of window glass during the architectural design phase according to the expected climatic conditions and the temperature difference between the outside and the inside [14].

2 Technical Approach

2.1 Methodology

According to the main aim of this research which is studying the heat transfer behavior through double and triple glazed window systems, the study was planned to be performed both theoretically and using a mathematical model. Schematic illustration of the investigated double-glazed window system is shown in Fig. 6. In this paper, it was assumed to use multiple glazed window system filled with Argon in the cavity between glass panes. The layers specification of the investigated window system (double glazed and triple glazed) are presented in Table 1 and Table 2 respectively. The thickness of glass panes is 4 mm. The glass panes are separated from each other equally by a space of width (*L*). Calculations are planned to be conducted for different cavity width of 8 mm, 12 mm, 16 mm and 20 mm. While, the window height (H) is assumed to be 1 m. The interior temperature is constant at 25 °C, according to the human comfort zone. The window system is planned to be investigated in two different conditions of external temperature, the first is at 35 °C, while the second is at 0 °C, Heat flux between glass panes is supposed to be laminar and unsteady.

2.2 Modelling

The governing equation for heat transfer in walls, can be expressed as Eq. 1

$$\rho C_p \frac{\partial T}{\partial t} = k \frac{\partial^2 T}{\partial x^2} \tag{1}$$

where,

ρ: The density.
k: The thermal conductivity.
C_p: The specific heat.
$\frac{\partial T}{\partial t}$: The partial derivative of temperature per time.
$\frac{\partial^2 T}{\partial x^2}$: The second partial derivative of temperature per distance (direction of heat transfer).

The heat transfer from the wall surface to surrounding via radiation and convection as shown in the following figure.

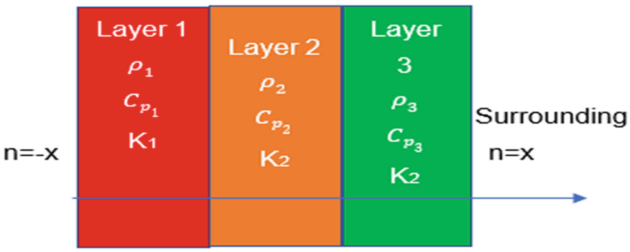

Fig. 6. Heat transfer through three layers wall exposed to radiation and convection

The boundary conditions for solving this equation as an ambient exposed condition can be written as shown below

$$-k \frac{\partial T}{\partial x} = \alpha (T - T_g) + \sigma \varepsilon \left((T + 273)^4 - (T_g + 273)^4 \right) \tag{2}$$

where,

T_g: The gas temperature.
σ: Stefan- Boltzmann constant.
ε: The emissivity of the surface.
α: The convection heat transfer coefficient.

2.3 Numerical Solution Using MATLAB

Figure 7 presents the methodology of solving the proposed numerical model using MATLAB software.

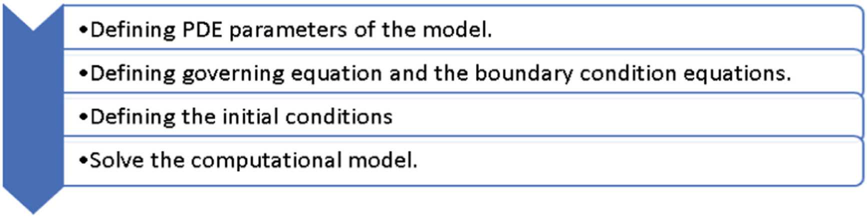

Fig. 7. The procedure of modelling PDE equations in MATLAB

Double glazed window. To solve the above-mentioned equations, a MATLAB code was created according to the following procedure.

Defining the coefficients of the partial differential equations
The double glassed window has three layers of interior gab layer. The density, specific heat and thermal conductivity of these layers are summarized in the following table;

Table 1. Layers specifications for double glassed window [15, 16]

Layer number	Material	Density (kg/m^3)	Thickness (mm)	Specific heat (kJ/kg. K)	Thermal conductivity (w/m. K)
Layer 1	Glass	2190	4	0.74	1.38
Layer 2	Argon gas	1.728	10	0.521	0.0166
Layer 3	Glass	2190	4	0.74	1.38

Triple glassed window. In accordance to the triple glazed window system, it has five different layers. The specification of these layers is presented in Table 2;

3 Comparing Between Double and Triple Glass Window

After coding the double glass and triple glass window systems using MATLAB and solving this code with boundary and initial conditions, the below obtained results will be analysed and discussed in this chapter. It should be mentioning that in this code the double glassed window system has considered to have three interior gab layers there

Table 2. Layers specifications for triple glassed window [15, 16]

Layer number	Material	Density (kg/m^3)	Thickness (mm)	Specific heat (kJ/kg. K)	Thermal conductivity (w/m. K)
Layer 1	Glass	2190	4	0.74	1.38
Layer 2	Argon gas	1.728	10	0.521	0.0166
Layer 3	Glass	2190	4	0.74	1.38
Layer 4	Argon gas	1.728	10	0.521	0.0166
Layer 5	Glass	2190	4	0.74	1.38

are the interior glass layer, the argon gas layer and the exterior glass layer accordingly. However, the triple glass window system consists of three layers of glass separated by layers of argon gas producing five different interior gab layers. In MATLAB code it was assumed that, the thickness of each glass layer is 4 mm and the thickness of the gas gob is 20 mm.

The MATLAB function code was created to solve the different standard partial and differential equation coefficients considering the thermal conductivity coefficient of each layer. The interior temperature was defined initially to be (25 °C). The boundary conditions were formulated based on the Stefan- Boltzmann constant is $5.67 * 10^{-8}$, the emissivity was assumed unity, while the heat convection coefficient was considered to be 10 w/m^2. K. The boundary conditions are applied for the both sides of each layer. When solving the MATLAB model, the profiles of temperature distribution in the x-direction in accordance to time are resulted as presented below.

3.1 Double Glass Window

Upon solving the governing equation and the boundary condition equations for the double glass window system, according to variable temperature all the day, using the MATLAB code, according to the defined layer's specifications in terms of the density, specific heat and thermal conductivity of these layers, the following results have been obtained. As mentioned above, the internal temperature is assumed to be room temperature ($T_1 = 25$ °C), Fig. 8 shows the temperature profile along the day in London according to April conditions.

As shown in Fig. 8 the lowest temperature ($T_2 = 5.5$ °C) and the maximum is 14.3 °C. the resulted temperature distribution of the double-glazed window system is as presented in this section. Where the temperature was fitted vs. the time to second order polynomial equation, find the temperature distribution due the change in weather conditions, the fitted equation was created using excel by inserting a trendline for temperature vs. time plot.

Figure 8 shows the temperature contour along the day when the double glass was suggested to be used, it can be noted the highest temperature at the middle of the contour and the minimum at the edges of the contour. In other words, the maximum temperatures for the glass layers were noted at midmorning and the minimum temperature at

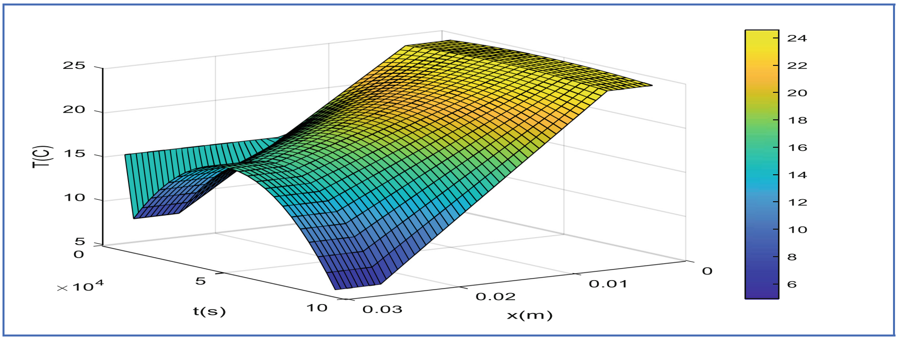

Fig. 8. Case study

the midnight, where these temperatures were compared to find the effect of the outlet temperature on the temperature distribution through the layers of the window.

3.2 Triple Glass Window

After that the MATLAB code was modified to solve the governing equation and the boundary condition equations for the triple glass window system. In this case the code considers five different layers, three layers of glass 4 mm thickness separated with two gas gabs of 10 mm thickness. When solving the created MATLAB code for the triple glass window, Fig. 9 shows the temperature contour along the day when the triple glass was suggested to be used, it can be noted the highest temperature at the middle of the contour and the minimum at the edges of the contour. where these temperatures were compared to find the effect of the outlet temperature on the temperature distribution through the layers of the window.

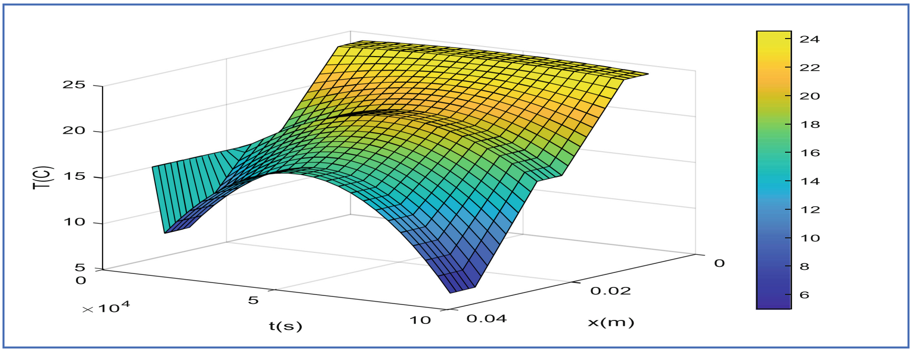

Fig. 9. Contour temperature distribution- along the day based on april weather conditions for triple glass.

At the lowest outlet air temperature, temperature distribution of the triple glazed window is as presented in Fig. 10 It is obvious that the temperature distribution profile consists of five stages. The first stage represents the internal glass panel which has a constant temperature of 24 °C.

The following stage of the first gas gab represents a gradually decrease in the temperature from 24 °C to 15.25 °C. After that, the temperature stabilized at 15.25 °C for the thickness of the medium glass panel. In the fourth stage the temperature decreased steadily to reach 6.5 °C. The final zone has a steady temperature of 6.5 °C through the external glass panel.

3.3 Comparing the Results of Double and Triple Glazed Window

When comparing the resulted temperature distribution for the double glass and triple glass window system, Fig. 10 is obtained. It is obvious that the temperature of the internal glass panel is the same for both window systems. Moreover, the reduction in the temperature within the gas gab, due to convective heat transfer, do not change for the same thickness. The existence of the intermediate glass layer in the case of triple glass window system make the temperature steady within its thickness, after that the temperature decreases due to the natural convection inside the gas gab with the same rate. According to the temperature distribution profiles, it can be concluded that the temperature of the triple glass layer at the same distance is higher comparing to the double glass window system. In other words, increasing the number of glass panels has been approved to slow down the flow of heat inside the gas gabs.

Figure 10 compares the obtained results of the temperature distribution profiles when running the MATLAB code for the double glass and triple glass window systems at maximum air temperature. The same as lowest air temperature, it can be notice that the temperature of the internal and external glass panel are similar for both double and triple glass window systems. However, it can be concluded that the increase in the number of glass panels has an effect on slowing down the heat flow within the gas cavities.

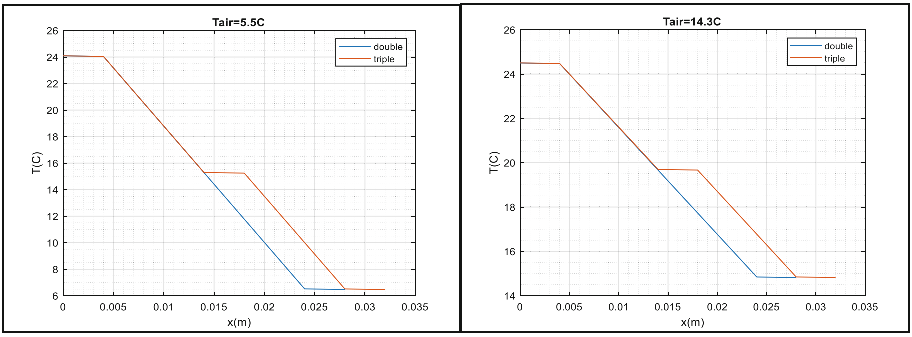

Fig. 10. Comparison of the temperature distribution profiles of double and triple glass window at lowest & maximum temperature

4 Conclusion

In this paper, the performance of two different systems of multiple glazed window are investigated. The glass panels of the two systems are considered to have a thickness of 4 mm. These glass panels are separated by Argon gas cavities. Concerning the double glass window, it consists of two layers of 4 mm glass separated by a gab of 20 mm width filled with Argon. However, the triple glass window system consists of three glass panel 4 mm thickness separated by two argon gas cavities of 10 mm thickness. A mathematical model consists of governing equation and the boundary condition equations was solved using MATLAB codes considering the heat transfer along the day. After analyzing and. discussing the results of running MATLAB code in terms of the temperature distribution profile and the contour of temperature distribution, the following points can be concluded;

1. Through the multiple glass window systems, the heat is transferred by radiation depending mainly on the width of gaps between glass layer and temperature difference.
2. The glass thickness has an insignificant effect on the amount of transferred heat within the glass window.
3. The amount of heat transfer is directly proportional to the width of the gap and inversely proportional to the temperature difference.
4. The amount of heat transfer through the multiple glass window systems is almost independent of the number of glass panes.

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