Numerical Analysis of the Effect of Various Window Parameters on the Thermal Performance of a Double Glaze Window in the Climatic Region of Libya

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Abstract

This study presents a numerical analysis of the effect of window parameters on the thermal performance of double glazed windows in the climatic region of Libya. A 2D model of a double glaze window was developed, meshed and solved using a commercial CFD software ANSYS Fluent V15.0. The window was exposed to temperatures representing the highest and lowest temperature in the Libyan capital of Tripoli for the

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year 2016. Parameters that were investigated are the windows gas space thickness, gas filling where air and argon were studied and compared and frame material with U-pvc, wood and aluminum used for this study. Results show that increasing the gas space thickness increases the windows thermal performance, until however, the optimum space thickness is reached, after which the effect of increasing the gap thickness brings diminishing returns. Argon was proven to have a much better thermal performance than air and U-pvc had the best thermal performance followed by wood and aluminum.

Keywords: *Double glaze window,gas filling window, frame material window.*

Nomenclature

Gravityacceleration
Convective heat transfer coefficient ν
Thermal conductivity
Nusselt number
Pressure
Heat flux
Gas spacing thickness
Temperature
x-velocity component
y-velocity component

Greek Symbols

Thermal expansion coefficient
Viscosity Λ
Thermal diffusivity
Density ł

Introduction

Increasing a systems efficiency has always been a focal point for engineers wether it be simple machinery used in daily life or turbines used in power stations, this can be done by either increasing the systems performance or decrease its consumption and in some cases both. When it comes to buildings, decreasing the consumption of the building greatly effects its efficiency especially when it comes to heating and cooling since they are the greatest contributors to the buildings consumption. A buildings heating and cooling consumption is quite high in desert reigns such as Libya and Saudi Arabia were the energy consumption for heating and cooling can reach approximately 70%, one word in the US it reaches approximately 30-40%. This led to engineers developing numerous methods to decrease the need to heat and cool a building by decreasing the amount of heat gained or lost by it, i.e. increase its thermal performance. One of the methods used to increase a buildings thermal efficiency is by using more thermally efficient windows, such as double glaze windows, since windows are a large contributor to the thermal loss or gain by the building, this led to many numerical and experimental studies to study and improve the thermal performance of windows.

Korpela et al. [1] published a numerical study about heat transfer through a double-pane window using finite difference method and presented his results as detailed plots of the stream patterns and isotherms. Aydın [2,3] also presented numerical studies to determine the critical value of air layer thickness between two panes for different climate zones considering only the amount of energy. Soylemez [4] presented a thermo-economic optimization analysis yielding a simple algebraic formula for estimating the optimum number of panes for windows. The overall heat transfer coefficient values were correlated for single, double, triple and quadruple pane windows that are used in HVAC and refrigeration applications. The effect of the gas type between panes and frame materials on the energy loss was investigated by Weir and Muneer [5].

There are several methods to improve thermal performance of glazing units, such as optimizing the air layer thickness of double glazing [6], filling the cavity between panes with a participating gas [7], water [8] or aerogel [9], coating pane surface with low-emissivity materials [10-12], and using multiple pane windows [13-15]

There are a great number of studies to determine the optimum thickness of the insulation material depending on climate zones and energy sources. A systematic approach for optimization of insulation material thickness applied to Palestine was developed by Hasan [16]. This study was based on the life cycle cost analysis that presented generalized charts for selecting the optimum insulation thickness as a function of degree-days and wall thermal resistance. There also multiple studies with aim of obtaining the optimum gas spacing thickness for certain regions and climatic zones such as the following studies by Bolatturk [17,18], Dombayci et al. [19], Kaynakli [20], Sisman et al. [21] and Ucar and Balo [22] that focused on the climatic regions of Turkey.

To the best of knowledge of the authors, there has been very little interest in this field from engineers in Libya, possibly due to cheap energy prices. However, we the authors hope this publication will help garner interest in this field, especially with rising oil and gas prices coupled with a weak energy infrastructure and a large growing demand of energy.

Physical model

The physical model used for this study is based on a model developed and used by Ahmadi and Yousefi [23], which consists of an upper and bottom frame, inner and outer glass panes and a gas spacing. The model represents a cross-section of the window side since most of the heat transfer happens through this section of the window. Figure (1) shows the model used for the problem.

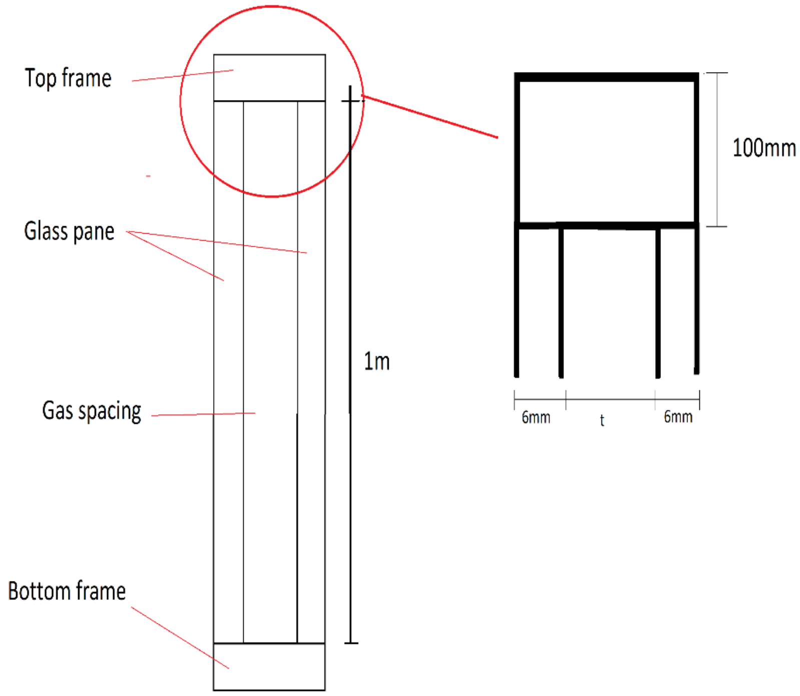

Figure (1) Physical model used for the problem

Where (t) is the gas spacing thickness. The glass pane thickness used are 6mm for the outer and inner windows and the glass height is 1m. the gas space thickness will be in the range from 6mm to 22mm. the frame thickness will be 100mm. The materials used for the frame will be aluminum, wood and U-pvc while the fluids used for the gas spacing will be air and argon.

Assumption

The assumptions made in this problem are:

1. All walls are stationary, impermeable, and have no slip conditions.
2. No air cavities in the frame.
3. The effects of gravity are valid.
4. Heat transfer by radiation was neglected.
5. Top and bottom frame walls are adiabatic.
6. No condensation occurs on the surface of the glass and frame.
7. The confined fluid is assumed incompressible and Newtonian.
8. Viscous dissipation is neglected.
9. Constant and homogenous material properties except gas density which follows the Boussinesq approximation.
10. The flow is laminar and in steady sate.

Mathematical model

Governing equations

The governing equations are written based on the previous mentioned assumptions as: -

Mass equation:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \tag{1}$$

Momentum equations with Boussinesq approximation and gravity for x and y-direction respectively:

$$\rho \left(u \frac{\partial (u)}{\partial x} + v \frac{\partial (u)}{\partial y} \right) = -\frac{\partial P}{\partial x} + \mu \left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} \right) \tag{2}$$

$$\rho (u \frac{\partial (v)}{\partial x} + v \frac{\partial (v)}{\partial y}) = -\frac{\partial P}{\partial y} + \mu (\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2}) + g\rho\beta(T - T_\infty) \tag{3}$$

Energy equation without heat generation and viscous dissipation:

$$u\frac{\partial(T)}{\partial x} + v\frac{\partial(T)}{\partial y} = \alpha\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2}\right) \quad (4)$$

Boundary Conditions

The boundary conditions used in the problem are shown in figure (2):

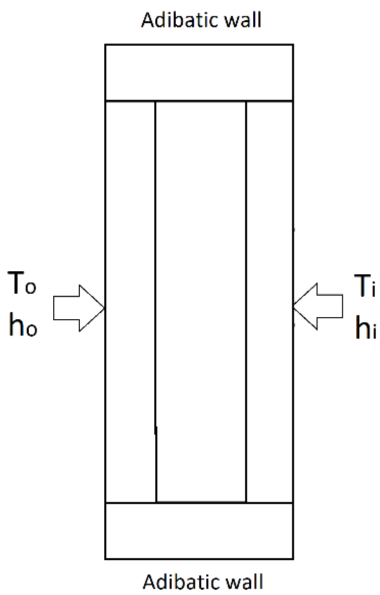

Figure (2) Boundary conditions

The ambient temperatures (T_o, T_i) and convective heat transfer coefficients (h_o, h_i) used for the outside surfaces in this problem are displayed in table (1): -

Table (1) Ambient temperatures and heat transfer coefficients (h) used for the outside surfaces

	Temperature (K)	h (w/m^{2}K)
Hot	320	29
Cold	279	22
Room	295	20.67

These temperatures represent the maximum and minimum temperature for the Libyan climate in year 2016.

Mesh

Table (2) shows the mesh dimensions used is this study: -

Table (2) Mesh dimensions

	No. divisions (x)	No. divisions (y)	Bias Factor
Top frame	50	50	12
Bottom frame	50	50	12
Inner glass	50	500	12
Outer glass	50	500	12
Spacing	50	500	12

The mesh was made to be smaller near the glass wall to ensure greater accuracy in the gained results and to ensure that the no-slip condition is realized. Figure (3) shows a sample of the mesh used:

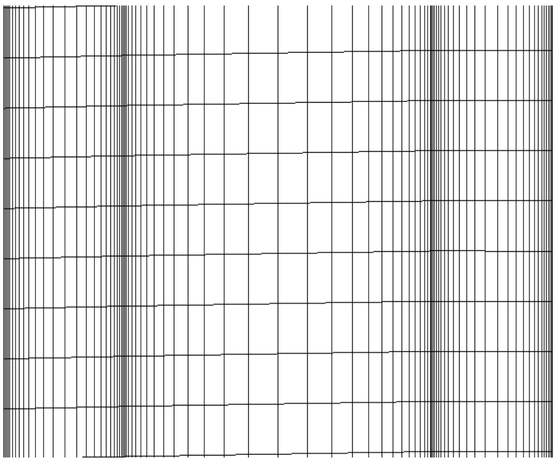

Figure (3) sample from the mesh used (mid-section)

Nusselt number

To calculate the average Nusselt number in the gas spacing the following equation was used: -

$$Nu = \frac{\mathrm{h}t}{k} \qquad (5)$$

Results

Mesh dependency study

To ensure that the chosen mesh provided accurate results with minimum computational time, a mesh dependency study was conducted. For this study mesh dimensions of 20*200, 30*300, 40*400, 50*500 and 60*600 were used for the glass pane and the gas spacing and 20*20, 40*40, 50*50 and60*60, and were used for the frame while average velocity of the gas spacing was chosen for the comparison. Table (3) shows the results of the mesh dependency study.

Table (3) Mesh dependency study

Mesh dimensions	No. Nodes	Average velocity (m/s)	Error%
20*200	8250	0.04449835	NA
30*300	18179	0.04914216	10.44
40*400	31296	0.044404376	9.64
50*500	48560	0.044507127	0.23
60*600	69600	0.044427969	0.18

As it can be seen from the previous table, mesh dimensions of 50*500 provided an adequate percentage of error, therefore it was chosen for this study.

Gas spacing

Results have shown, as expected, that the increase in gas spacing leads to a decrease in the amount of heat transferred through the glass, this is obviously due to gas layer since gasses are poor thermal conductors. Results have also shown that the impact of increasing the gas spacing continues to decrease until the optimum thickness is reached after which increasing the gas spacing's thickness yields insignificant results. Figure (4) shows the effect of gas spacing's thickness on the heat transfer through the window at different outside temperatures and gas fillings while table (4) shows the optimum thickness of each case. It should be mentioned that the decrease in the effect of increasing the spacing's thickness is due to the gas gaining enough space to develop convective currents which undermines the purpose of the gas layer.

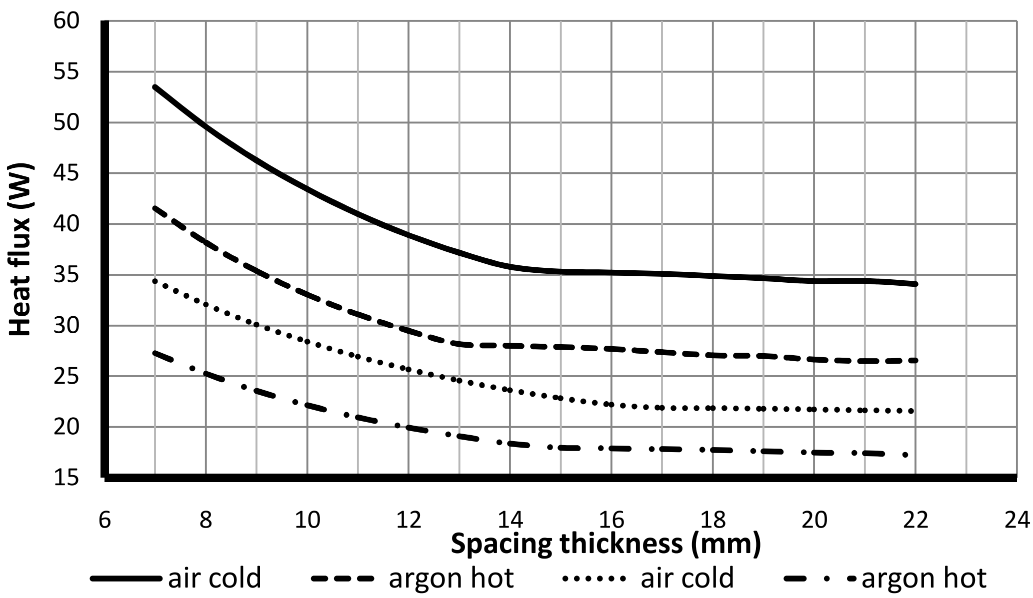

Figure (4) Effect of gas spacing's thickness on the heat transfer through the window at different outside temperatures and gas fillings

Table (4) Optimum thickness of each the cases studied

Argon cold	Air cold	Argon hot	Air hot
15mm	17mm	13mm	15mm

Figure (4) also shows that increasing the temperature difference between the outside air and the room not only affects the heat flux through the window but it also has an effect on the optimum gas spacing's thickness, this is due to the fact that the gas gains enough energy to develop convective currents in smaller gas spacing thicknesses. Figure (4) also shows that using "heavier" gasses such as argon yields better results than conventional air with a maximum heat flux decrease of 24.26%, this due to argon having a higher density and a lower thermal conductivity than air therefore it's more resistant to developing convective currents and conducts less heat.

To study the effect of the gas spacing thickness on the development of convective current the average Nusselt number of each spacing's thickness was used. Figure (5) shows the effect of gas spacing's thickness on the average Nusselt number at different outside temperatures and gas filling.

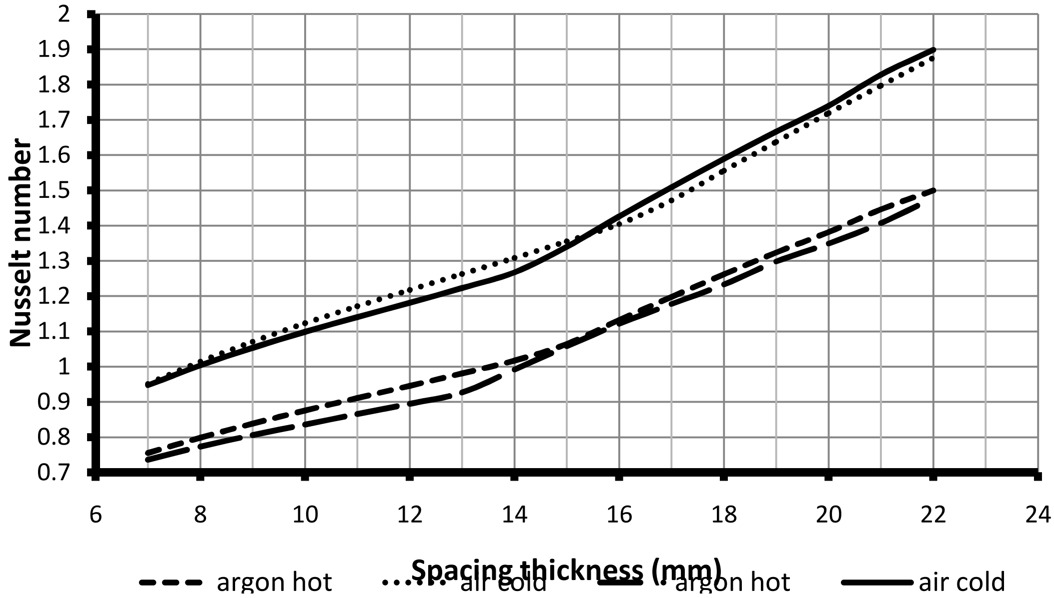

Figure (5) Effect of gas spacing's thickness on the average Nusselt number at different outside temperatures and gas filling

As it can be seen in figure (5) the average Nusselt number increases steadily with the increase in the gas spacing's thickness until it reaches optimum thickness after which it starts to rapidly increase. This proves the previous statement that increasing the gas spacing's thickness increases the development of convective currents, it should also be mentioned that at lower thicknesses the average Nusselt number was less than one therefore proving that the majority of the heat is transferred by conduction. Figure (5) also shows that increasing the temperature difference increases the formation of convective currents while using argon instead of air decreases it. An argon filled double glaze window with 13mm gas spacing thickness will be used for the rest of this study since they are the optimum thickness and gas filling while an outside temperature of 320K will be used since it represents the highest thermal load

Temperature distribution

To show the temperature distribution across the window's glass pane and gas spacing, the temperature contour for the glass pane and gas spacing is shown in figure (6) for (a) the top section of the window, (b) the middle section of the window and (c) the bottom section of the window.

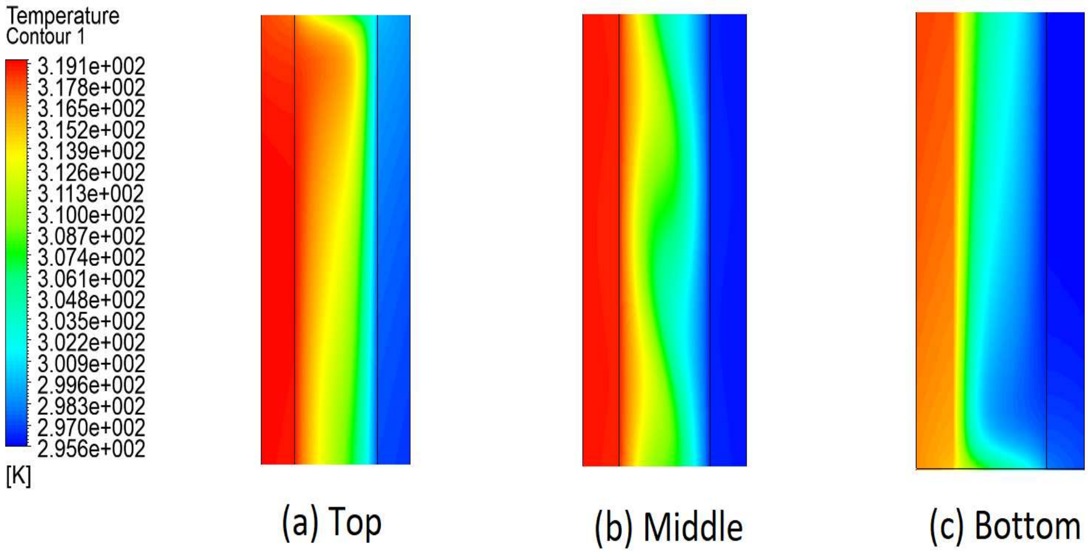

Figure (6) Temperature contour for the glass pane and gas spacing for (a) the top section of the window, (b) the middle section of the window and (c) the bottom section of the window

As the previous figure illustrates, the glass panes had a uniform temperature equating the temperatures they are exposed to (room and outer temperatures), this is to be expected since glass isn't a thermal insulating material. As for the gas spacing, the gas's temperature decreased in a systematic matter from the outer glass pane to the inner glass pane, this is probably due to the gasses low thermal conductivity coupled with the rotation of the gasses in the gas spacing due to the changes in the gas's density. This would also explain why the gas's temperature was higher at the top section as compared to the bottom section, since parts of the gas with higher temperatures will have lower density causing it to rise and parts of the gas with lower temperature will have higher density causing parts of the gas to fall towards the lower sections of the gas spacing.

Velocity distribution

the velocity distribution of the gas spacing, the velocity contour of the gas spacing at each of the previous sections is shown in the following figure:

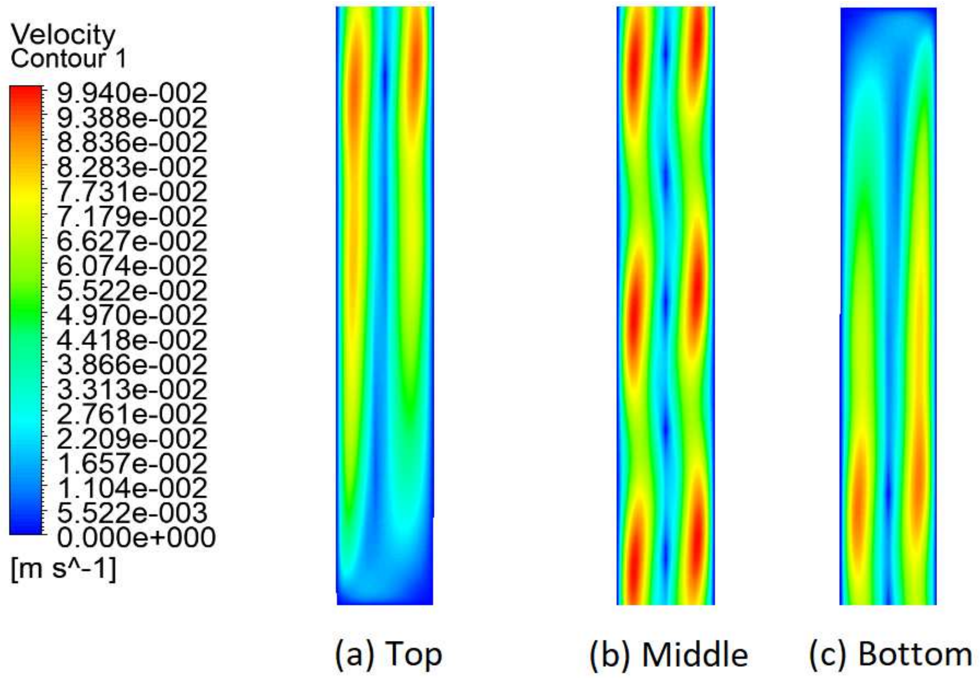

Figure (7) Velocity contour of the gas spacing for (a) the top section of the window, (b) the middle section of the window and (c) the bottom section of the window

The rotation of the gas in the gas spacing can be seen clearly from the previous figure. However, the gas does not rotate at a uniform velocity, it instead rotates in bursts of velocities. The reason for this is unclear, but it could be due to the difficulty of sustaining enough kinetic energy for a relatively heavy gas such as argon to rotate in a uniform velocity. It should be mentioned that a similar model with air (which is lighter than argon) as the gas was also tested with results showing uniform rotation velocity.

Frame material

To ensure that the most thermally efficient frame material is used, the thermal performance of three of the most used frame materials will be evaluated, which includes aluminum. Figure (8) shows the heat flux comparison between each of the frame materials.

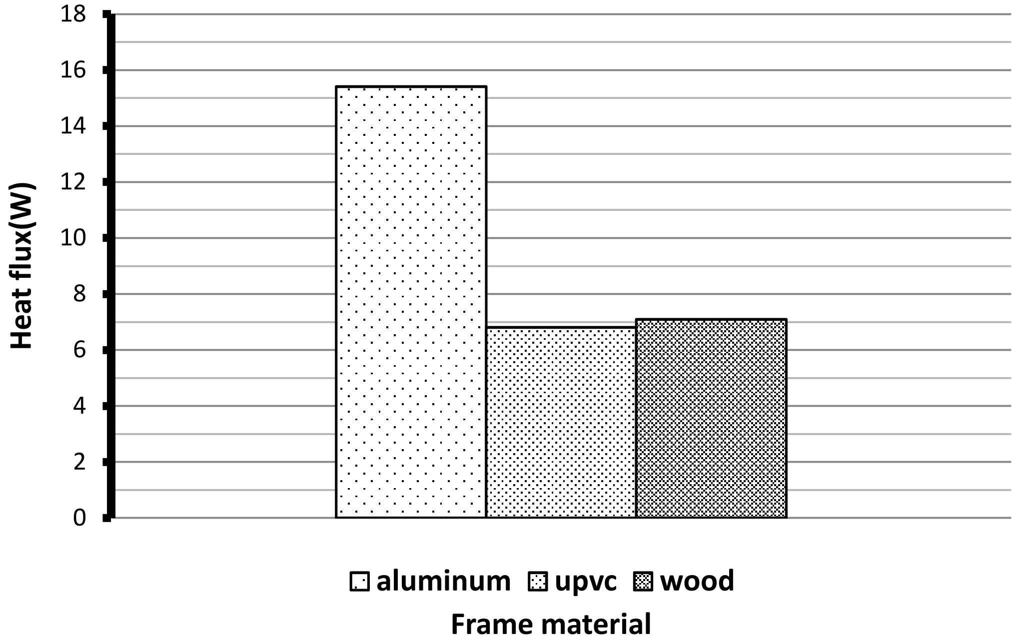

Figure (8) Heat flux comparison between each of the frame materials

As it can be seen U-pvc provided the highest thermal insulation and provided 55.78% more insulation than aluminum, this is due to aluminum having a much higher thermal conductivity than U-pvc. Figure

(8) also shows that there was a very small difference between the performance of U-pvc and wood (4.07% difference). However, due to the high maintenance cost of wooden frames among other disadvantages, u-pvc can be said to be the better choice. Another method to portray the thermal performance of the frame material is via the temperature distribution in the frame, figure (9) shows the temperature contours of the upper frame for (a) U-pvc, (b) wood and (c) aluminum.

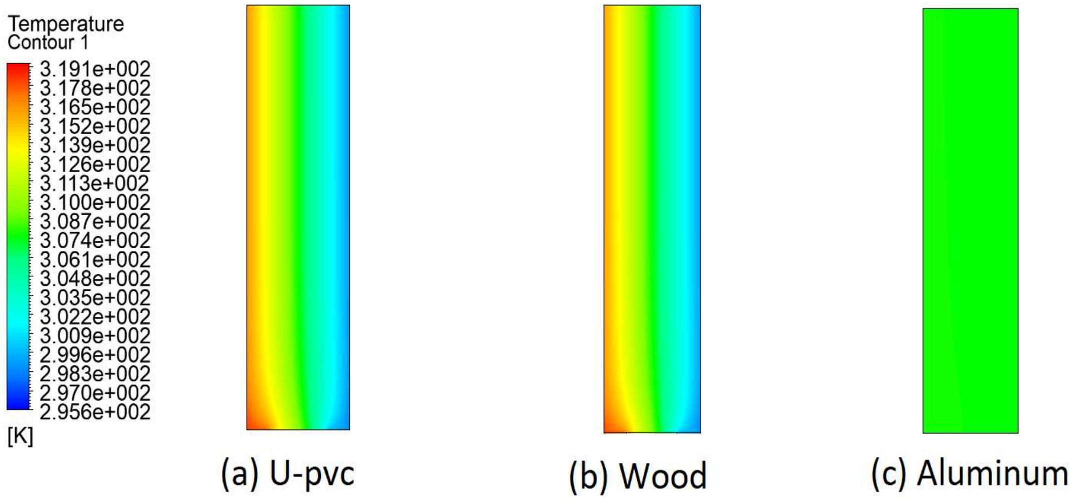

Figure (9) Temperature contours of the upper frame for (a) U-pvc, (b) wood and (c) aluminum

These results clearly show the similarity between the U-pvc and wooden frame as well as their disparity with the aluminum frame, which would explain why U-pvc and wood had similar a similar heat flux while aluminum had a much higher heat flux. Results also show that the U-pvc and wooden frame's temperature gradually decreases as it goes from the edges exposed to the outside towards the edges exposed to the inside in the form of layers. As for the aluminum frame, it had a uniform temperature across the frame. This is obviously due to the thermal conductivity of each material, where U-pvc and wooden frames have a much lower thermal conductivity, and consequently higher thermal resistance, than aluminum.

Conclusion:

In this study, a numerical analysis of the effect of various parameters on the thermal performance of a double glaze window in the climatic region of Libya was provided. Based on the gained results the following conclusions can be made:

1. The thickness of the gas spacing has had a significant effect on the thermal performance of a double glaze window, where an increase in the gas spacing thickness has led to an increase in the thermal performance.
2. Increasing the gas spacing thickness beyond its optimum value produces no significant enhancement in thermal performance.
3. Increasing the temperature difference between both sides of the window has a great effect on the heat transfer through the window as well as the optimum thickness of the gas spacing, where increasing the temperature difference has led to an increase in the optimum spacing thickness.
4. Using argon instead of air enhanced the thermal performance of the double glaze window greatly. Using heavier gasses should provide better performance, however, their cost would greatly out weight their benefit.
5. The material chosen for the frame has had a significant impact on its performance, where U-pvc has provided the highest thermal performance followed by wood and ultimately aluminum, which had a very poor thermal performance due to its high thermal conductivity.

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