Numerical Analysis for the Comparison of Thermal Performance of Single and Double-Glazed Windows in the Climatic Reign of Libya

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الملخص:-

تقدم هذه الورقة دراسة عددية للأداء الحراري للنوافذ الزجاجية الفردية والمزدوجة تحت ظروف المناخ في ليبيا (مطار معيتيقة). تم تطوير نموذج ذو بعدين في حالة الاستقرار، وذلك بناءً على المعادلات الأساسية للكتلة، والحركة، والطاقة. تم حل هذه المعادلات باستخدام برنامج ANSYS Fluent. وقد تم اختيار نموذج لنافذة بارتفاع 1.2 متر و بسمك زجاج من 6 ملم إلي 12 ملم للزجاج الفردي. و اختيار نموذج مشابه للزجاج المزدوج حيث كان سمك الفراغ من 7 ملم إلي 22 ملم. والاطار مصنوع من مادة U-PVC وتم اختيار الهواء و الأرجون ليكونا المادة المالئة للفراغ. حيث وجد أن السمك الأمثل للفراغ هو 14 ملم و 13 ملم للهواء و الأرجون، على التوالي. وكذلك وجد أن أقصي إنقاص في انتقال الحرارة عند استخدام النوافذ المزدوجة 90.5%، للأرجون و 86.9% للهواء مقارنة بالنوافذ الفردية. تعد هذه الدراسة الجزء الثاني من مشروع بحثي سابق و يهدف إلى إبراز فوائد استخدام النوافذ ذات الزجاج المزدوج وتأثيرها على تحسين الأداء الحراري للمباني في ليبيا.

Abstract

This paper presents a numerical approach to studying the thermal performance of single and double-glazed windows under the climate conditions of the Libyan (Mitiga Airport). A two-dimensional steady-state model, based on fundamental equations of mass, momentum, and energy conservation, was developed and solved by ANSYS Fluent. The window height was assumed to be 1.2m with glass thickness ranging from 6mm to 12mm for the single-glazed window. Similar thicknesses were used for the double-glazed window with internal gap thickness ranging from 7mm to 22mm. The frame is assumed to be made of U-PVC and the gap of the double-glazed window was filled with Air and Argon. The optimum gap spacing was found to be 14mm and 13mm for the Air and the Argon, respectively. The maximum heat transfer reduction for the Argon-filled double-glazed window was about 90.5%, while it was about 86.9% for the Air-filled double-glazed window in comparison with a single-glazed window. This study is part two of a research project aiming to justify the implementation of double-glazed windows and its impact on improving the thermal performance of the building envelope in Libya.

Keywords: Single-glazed and Double-glazed window, Argon and Air fillings, Heat saved

Nomenclature:

g	Gravity acceleration	m/s^2
h	Convective heat transfer coefficient	w/m^2k
k	Thermal conductivity	w/mk
N_u	Nusselt number	
P	Pressure	Pa
Q	Heat flux	w
t	Gas spacing thickness	m
T	Temperature	k
u	x-velocity component	m/s
v	y-velocity component	m/s
Greek Symbols		
β	Thermal expansion coefficient	k^{-1}
μ	Viscosity	$N.s/m^2$
α	Thermal diffusivity	m^2/s

1. **Introduction**

People spend most of their time in their homes and workplaces that have to be environmentally controlled for comfort, health, and productivity. The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) specified that the comfortable temperature for people should be in the range of 23°C to 25.5°C during summer and 20°C to 22.5°C during winter [2]. Keeping the temperature of these buildings at a comfortable level requires the usage of capable Air conditioning and heating systems. However, the utilization of such systems elevates the buildings running costs as well as increases their carbon footprint [2]. Most of the energy required by Air conditioning and heating systems comes from the limited reserve of fossil fuels, leading to global warming and environmental pollution. According to the International Energy Agency, buildings and buildings construction sector are responsible for consuming 36% of the total energy used worldwide [3]. On the other hand, it has been shown that 66% of the household's annual energy consumption can be saved by maximizing the thermal insulation of the building materials [4]. As a result of the fact that windows are the main building element that wastes thermal energy, one way to optimize energy consumption and reduce global warming is to design well-insulated windows that waste less energy. Studies have shown that the morale and productivity of workers within the building are significantly improved by implementing structures that allow for the penetration of natural daylight [5]. As a result, windows should provide a view of the exterior environment with natural daylight and a high thermal insulation performance. Large glass windows and in some cases, glass walls are also used to maximize the amount of sunlight entering the building which leads to maximizing the heat loss or gain to the surrounding. Reducing the overall energy consumption in buildings by improving the thermal properties of the windows has become critical [6]. Engineers developed various window designs to minimize the amount of heat lost or gained by the windows. One of the most popular methods for improving the thermal performance of windows is double-glazed windows. Double-glazed windows utilize the high insulation provided by the gap between the two glass panes to further increase the insulation of the windows without decreasing the amount of sunlight passing through the window or its visibility. The increase in the usage of double-glazed windows encouraged engineers to develop many designs and models to suit the different requirements of buildings in various environments and climates. Gratia and Herde [7] compared the thermal performances of the double-glazed facade of a building and the single-glazed facade. They used TAS software and advised using the double-glazed facade for better thermal control of the building. Moreover, Gratia and Herde [8] investigated the double-glazed facade performance under different facade orientations, wind degrees, and wind directions. Balcoo [9] introduced a non-dimensional model for a naturally ventilated double-glazed facade. The results have been validated against experimental and CFD simulation results. Grabe [10] presented a simplified simulation algorithm for the temperature and thermal performance of the double-glazed facade for a quicker assessment without using CFD tools. Kong et al. [11] state that double-glazed windows can create a "greenhouse effect" that without doubt enhances the thermal performance of the building. Al-Tamimi and Qahtan [12] studied the thermal performance of six different glazing types which included single clear, single reflective, double clear, double reflective, double low-e, and double coated reflective. The results showed the advantage of using double-glazed windows for the thermal management of residential houses. Aydin [13] numerically obtained the optimal pane gap width of a double pane window for different climates. He claimed that the optimal gap width for the proposed locations is found to be in the range of 12 to 21 mm. In a study conducted by Ismail and Henríquez [14], the conduction and convection heat transfer in a double pane window with a gap of 0.5 to 10 cm was investigated. They concluded that the gap width has no significant effect on the Solar Heat Gain Coefficient. Regarding the thermal performance of double-glazed windows, Ismail et al. [15] compared the thermal efficiency of a window filled with an absorbing gas and another filled with a phase change material. Their results have shown that absorbing gas mixture, as filling material, was more efficient than the phase change material. A year later, the same Authors [16] compared the thermal performance of three different systems: a single-glass, a double-glazed filled with an absorbent gas, and a double-glazed with natural ventilation. The most effective configuration was found to be the second one. Furthermore, water was used as filling material in a double-glazed unit [17]. forced and natural flows of the water through the pane gap were used.

A comparison of double and single-glazed windows available in the Libyan market is a must to justify the extra expenses associated with double-glazed windows. This paper is expected to show which glass presents a better thermal performance and to know the optimal gap width between glasses aiming to control the energy flow towards the inside environment of the Air-conditioned space.

2. Physical Model

Figure 1 displays the schematics used in this study, W is the width of the window and H is the height of the window. The window dimensions are assumed to be 1.2×1.2 m with a glass pane area of 1×1 m and a glass thickness in the range of 6 to 12 mm. The gas gap is assumed to be in the range of 7 to 22 mm with a frame thickness of 100 mm. The previously mentioned dimensions were chosen based on what is available in the Libyan local market. Table 1 shows the thermal properties of the used materials.

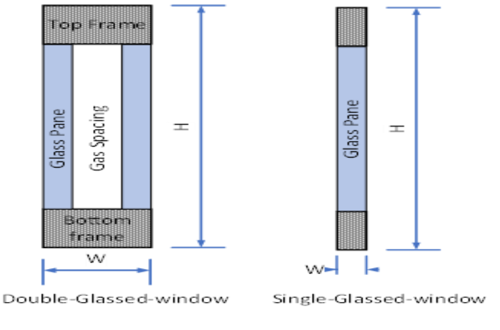

Figure 1. Window schematic and components used in the problem

Table 1. Material properties used.

	Glass	U-PVC	Air	Argon
Density (ρ) (kg/m^3)	**2800**	**1400**	**1.225**	**1.6228**
Specific capacity (C_p) (kJ/kg.K)	**750**	**880**	**1006.43**	**520.64**
Thermal conductivity (k) ($w/m^2.K$)	**0.7**	**0.16**	**0.0242**	**0.0158**
Viscosity (μ) (kg/m.s)	**NA**	**NA**	**1.784×10^{-5}**	**2.125×10^{-5}**

3. **Assumptions**

(a) no-slip conditions at all walls, (b) the frame is solid with no Air gaps, (c) natural convection is significant, (d) no radiation from/to the walls, (e) adiabatic top and bottom frame, (f) the wall's temperature is above the condensation point, (g) incompressible and Newtonian fluid [18], (h) the gas has no viscous dissipation with constant properties except for the density.

4. **Governing Equations**

Based on the assumptions mentioned, the governing equations can be written in two-dimensional Cartesian coordinates as [1,22]:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \qquad (1)$$

$$\rho(u\frac{\partial(u)}{\partial x}+v\frac{\partial(u)}{\partial y})=-\frac{\partial p}{\partial x}+\mu(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}) \qquad (2)$$

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

$$u\frac{\partial(T)}{\partial x}+v\frac{\partial(T)}{\partial y}=\propto(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}) \qquad (4)$$

1. **Boundary Conditions**

The conditions at the inner and outer of the window are:

$$\text{At } x = 0 : Q = -k\left(\frac{\partial T}{\partial x}\right) = h_o\,(T_{(0,y)} - T_o) \tag{5}$$

$$\text{At } x = w : Q = -k\left(\frac{\partial T}{\partial x}\right) = h_i\,(T_{(0,y)} - T_i) \tag{6}$$

2. The adiabatic top and bottom frame assumption leads to

$$\text{At } y = 0: \frac{\partial T}{\partial x} = 0 \tag{7}$$

$$\text{At } y = H: \frac{\partial T}{\partial x} = 0 \tag{8}$$

The no-slip condition at the glass and the frame results in the following boundary conditions: (9)

$$\text{At } x = 0 : u\,(0,\ y) = v\,(0,\ y) = 0$$

$$\text{At } x = w : u\,(w,\ y) = v\,(w,\ y) = 0 \tag{10}$$

$$\text{At } y = 0 : u\,(x,\ 0) = v\,(x,\ 0) = 0 \tag{11}$$

$$\text{At } y = H : u\,(x,\ H) = v\,(x,\ H) = 0 \tag{12}$$

The ambient temperatures and heat transfer coefficients (h) for the outside surfaces of the window are displayed in Table 2 [19].

Table 0. Ambient temperatures and heat transfer coefficients.

Season	Temperature (K) and heat transfer coefficient (h)			
	Min Temperature (K)	h (W/m^2.K)	Max Temperature	h (W/m^2.K)
Summer	288	18.33	320	29
Winter	279	22	299	15.33
Room	295	20.667	295	20.667

5. **Mesh**

The mesh was made to be very fine near the glass walls to precisely define the surface and consequently ensure greater accuracy in the gained results. The mesh properties used are displayed in Table 3 [20].

Table 03 Mesh properties.

	Number of divisions (x)	Number of divisions (y)	Bias Factor
Top frame	50	50	4
Bottom frame	50	50	4

Inner glass pane	**50**	**500**	**4**
Outer glass Pane	**50**	**500**	**4**
Spacing	**50**	**500**	**4**

6. **U-value**

The U-value or the overall heat transfer coefficient is defined as the rate of heat transferred through a structure divided by the difference in temperature across that structure [21]. The U-value of the glass and the window's frame can be calculated from Equations (13) and (14).

$$U_g = \frac{Q_g}{A_g \times (T_H - T_C)} \tag{13}$$

$$U_f = \frac{Q_f}{A_f \times (T_H - T_C)} \tag{14}$$

Where Q_g, Q_f, T_H, and T_C are the total heat transferred through the glass, the total heat transferred through the frame, the hot glass temperature and the cold glass temperature respectively. Then, the overall U-value of the window can be calculated as:

$$U_w = \frac{U_g \times A_g + U_f \times A_f}{A_w} \tag{15}$$

A_w, A_g, A_f are the areas of the window, the glass, and the frame.

7. Results

7.1. Thermal Performance of Single-Glazed Windows.

Figure 2 shows the heat flux through a single-glazed window at maximum and minimum temperatures for summer and winter. As can be seen that glass thickness has an insignificant effect on the heat transfer through the window, this could be due to the fact that glass is a poor thermal insulator [21].

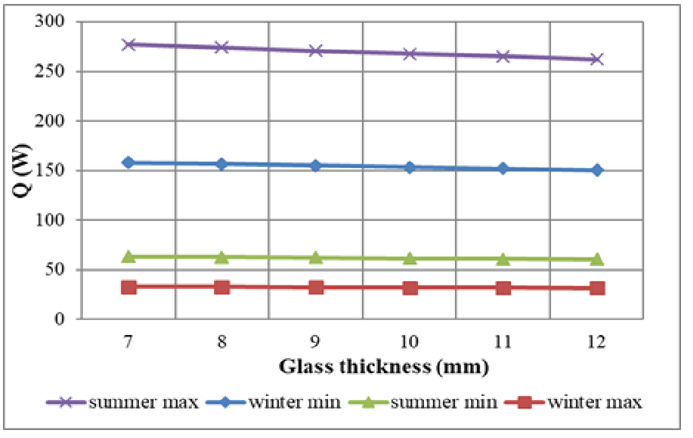

Figure 2. Heat flux through a single-glazed window with different glass thicknesses at different temperatures.

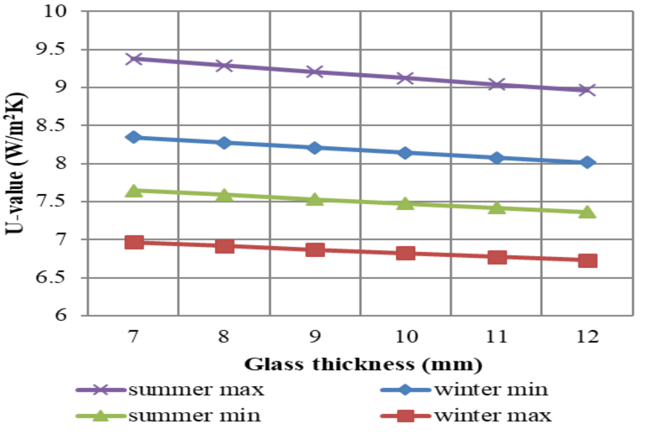

Figure 3. U-vale for a single-glazed window at different glass thicknesses and different temperatures.

The U-value for the single-glazed window at different thicknesses and temperatures are shown in Figure 3. The lower U-value means better thermal performance and vice versa. As is obvious from Figure 3, the U-value is proportional to the temperature difference and inversely proportional to the glass thickness. Therefore, the maximum heat load, and the higher U-value, will occur during the maximum temperature difference in the summer. As is evident from Figure 3, the U-value of a single-glazed window at 7mm is approximately 9.38 W/m^2 K while at 12mm is approximately 8.96 W/m^2 K. These figures are considerably high given the fact that glass is a poor thermal insulator.

7.2. Thermal Performance of Double-Glazed Windows.

Figure 4 shows the heat transfer through the double-glazed window with an Air-filled gap at maximum and minimum temperatures for summer and winter. The results have shown that the thickness of the spacing in double-glazed windows has an obvious effect on the heat transfer through the window. Specifically, for summer conditions the heat flux through the window decreased by 38 % if the gap thickness doubled. This decrease is due to the poor thermal conductivity of the filling gas. Figure 4 also shows that once the thickness of the spacing reaches 14mm, for maximum temperature in summer, and 16mm, for minimum temperature in winter. This could be due to the gas in the gap having more space to develop convective currents which increases the heat transfer rates in the spacing. Consequently, a spacing thickness of 14 mm is considered to be the optimum thickness under the climatic conditions of Libya.

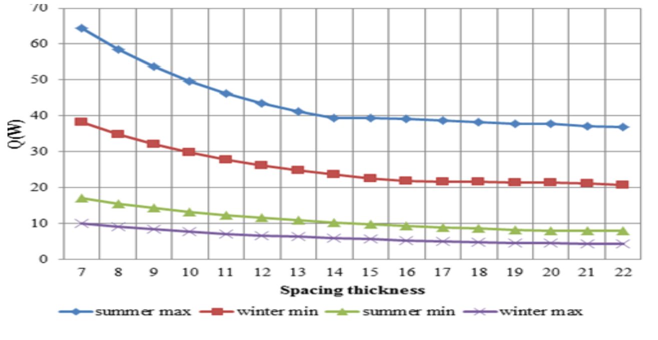

Figure 4. Heat flux through a double-glazed window with an Air filling at different spacing thicknesses and temperatures.

To study the effect of the filling gas on the thermal performance of the window, Air and Argon have been adopted as filling gases, and their corresponding heat fluxes have been compared. It was found that Argon has much better thermal performance than Air, this is due to Argon having lower thermal conductivity than Air as well as having a higher density which makes it harder for convective currents to occur. Figures 5 and 6 show the comparison between Argon and Air at maximum loads for winter and summer respectively. As can be seen in Figures 5 and 6, an Argon-filled double-glazed window with a spacing thickness of 9 mm has approximately the same thermal performance as a 14 mm Air-filled one. This shows that using Argon as a filling not only increases the thermal performance of the window but also decreases the spacing thickness needed. In addition, the optimum spacing thickness for the Air-filled window was found to be 16mm in winter and 14mm in summer while for the Argon case was found to be 15mm in winter and 13mm in summer.

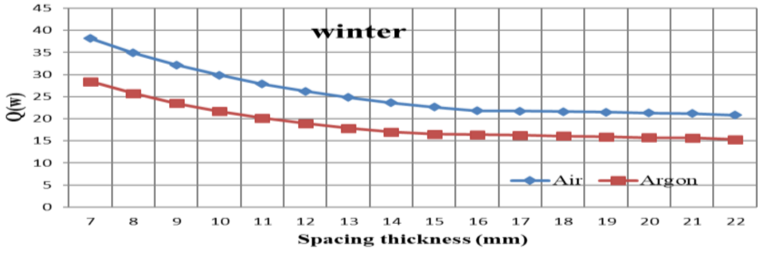

Figure 5. Heat flux through a double-glazed window with different spacing thicknesses and different gas fillings (winter).

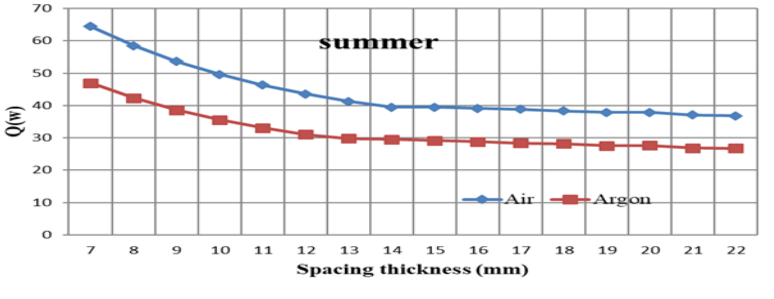

Figure 6. Heat flux through a double-glazed window with different spacing thicknesses and different gas fillings (summer).

The U-value for Argon and Air-filled double-glazed windows with different spacing thicknesses at maximum summer loads is shown in Figure 7. As it was expected, Argon has a lower U-value than Air, approximately 20% lower.

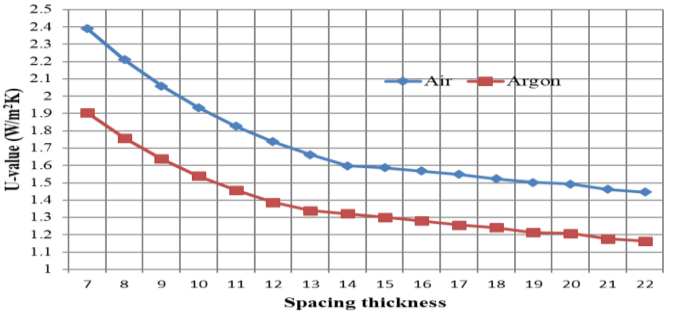

Figure 7. U-value for double-glazed windows with Air and Argon gases.

7.3. Comparing Single and Double-Glazed Windows

To compare the performance of the single and double-glazed windows, the percentage of heat saved Q_{save}, was introduced and can be defined as [21]:

$$Q_{save} = \frac{Q_{single} - Q_{double}}{Q_{single}} \times 100 \quad (16)$$

Where Q_{single} is the total heat transferred through the single glazed window and Q_{double} is the total heat transferred through the double glazed window.

By using Q_{save}, the percentage of heat that was saved when a double-glazed window was used instead of a single-glaze window, can be observed and therefore their performance can be compared. For instance, and as shown in Figure 8, when an Argon-filled double-glazed window is used, the amount of heat passing through the window was reduced by 90.5% for a window with a 22mm gap and by 83.3% for a window with a 7mm gap. This is a significant decrease in heat transfer, which shows the superiority of double-glazed windows over single-glazed windows in terms of thermal performance. The same result was observed for an Air filled double-glazed window, with a percentage of heat reduction of 86.9% for a window with a 22mm gap and 77% for a window with a 7mm gap. The above reductions of heat transfer confirm the superiority of double-glazed windows over single-glazed windows

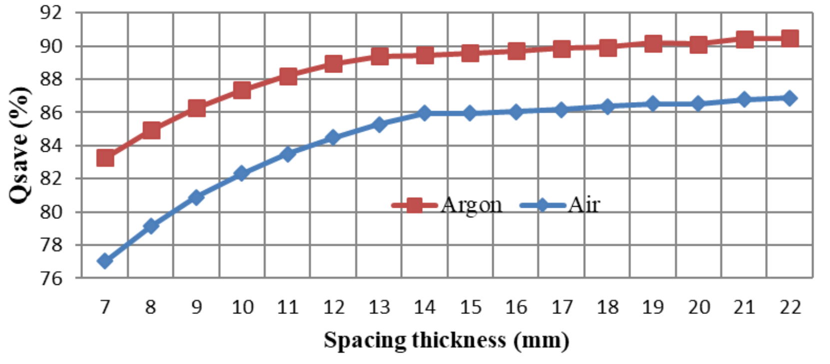

Figure 8. Heat saved when a double glaze window was used instead of a single glaze window.

8. Conclusion

Based on the obtained results the following conclusion can be drawn: (a) Double-glazed windows have a maximum amount of heat reduction of about 90.5%, (b) The glass thickness had a negligible effect on the thermal performance, (c) The optimum gap spacing was 14mm and 13mm for the Air and the Argon gas, respectively, (d) Significant increase in the thermal performance of double-glazed windows was achieved when a heavier gas such as Argon is used instead of Air.

9. References

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