

THERMAL BEHAVIOR OF AIR-FILLED DOUBLE GLAZING

Comportamento térmico de vidros duplos preenchidos com ar

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Abstract

The window is an opening in the wall that allows air and light into the room. This architectural element also serves to beautify, and for the user to enjoy beautiful landscapes, which exist in the vicinity of the building. But, the window is made up of elements that do not always provide the best thermal performance, thus leading to excessive electricity expenses, with the use of air conditioners. Although there are polymeric materials used in window design with regard to the transparent zone, glass is the one that is most evident from its recurring use in most buildings. Therefore, in this study, the variation and temperature differential along the glasses will be evaluated. This element, when badly chosen, can cause high solar gains, causing thermal discomfort and the early appearance of pathologies in the building.

Resumo

A janela é uma abertura na parede, que permite a entrada de ar e de luz no interior da habitação. Este elemento arquitetónico também serve para embelezamento, e para que o utilizador disfrute de belas paisagens, que existam nas proximidades do edifício. Mas, a janela é constituída por elementos que, nem sempre, proporcionam o melhor desempenho térmico, levando, desta forma, a gastos excessivos de energia elétrica, com a utilização de aparelhos de climatização. Embora existam materiais poliméricos, usados na conceção de janelas, no que concerne à zona transparente, o vidro é aquele que mais se evidencia, pelo seu uso recorrente, na maioria dos edifícios. Assim sendo, neste estudo, será avaliada a variação e o diferencial de temperatura, ao longo dos vidros. Este elemento, quando mal dimensionado, poderá ocasionar elevados ganhos solares, provocando desconforto térmico e o surgimento, precoce, de patologias no edifício.

Key-words: *Double glazing; Fenestration; Thermal behavior; Heat transfer.*

Palavras-chave: *Vidro duplo; Fenestração; Comportamento térmico; Transferência de calor.*

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INTRODUCTION

The windows are fundamental elements to the aesthetics of a building. They have various functions ranging from light inlet permission to air renewal. For this reason, the choice of this architectural element must not only obey a visually pleasing design, but also the design of a good thermal performance element in order to reduce heat transfer and, at the same time, energy expenditure (Gomes, 2009). Increasingly, large glazed facades are being used, which provides serious problems in terms of environmental comfort inside the building (Michelato, 2007). In most cases this type of approach is never carried out, which can lead in the medium term to excessive energy expenditure on air conditioners. An energy-efficient window should provide sufficient daylight during the day without excessive thermal loss at night.

Window components include the frame, glass, plastic, hinges, latches, blinds and curtains. The glasses can be single, double, triple or quadruple, where each unit consists of multiple layers of glass. In the case of multiple glazing, these are separated by spacers and hermetically sealed by a sealant. The glass can be tinted but transparent which transmits over 85% of visible light and over 75% of incident solar radiation. It is also possible to apply coatings on the surface of the glass, which can be of low or high reflectivity, depending on their intended purpose. Tinted glass is widely used in places where privacy is desired and, due to its low emissivity, reduces the solar heat gained through the window. There are two types of coatings that can be applied to glass: those that reduce solar gain (block infrared entry) and those that reduce heat conduction. To minimize heat flow, some manufacturers are adopting low thermal conductivity spacers on the periphery of the glass. In double glazing, the first sealant is made of compressed polysulfide (PIB) and the secondary sealant may be polyurethane, polysulfide or silicone. When mounting the window, it is very common to use desiccants as a way of absorbing moisture in the glass or moisture that may subsequently arise due to the ineffectiveness of the sealant (ASHRAE, 2009a).

The window frame consists essentially of three materials: wood, metal and polymers. Wood is confined to structural integrity and is a good thermal insulator, but has low resistance to moisture, weather and warping. Metal has excellent structural characteristics but has poor thermal performance since aluminum (most windows) has a thermal conductivity of about one hundred times that of polymers or wood. Composite materials are widely used in window frame construction and have a thermal performance very similar to wood. Manufacturers often combine all these materials to improve thermal performance and aesthetics (Oravec, 2015).

1. HEAT TRANSFER PROCESSES

Heat transfer is studied in engineering and deals with the movement of energy between bodies with different temperatures (Holman 1989; Incropera & Dewitt 1990; Sukhatme 1992; Bejan 1993).

The overall driving force for these heat flow processes is the cooling (or leveling) of any thermal gradients. The heat flows that result from the cooling of the sun are the primary processes that we experience naturally. Earth's surface is also warmed by the cooling of its core, and even by radiation from the distant stars, however little those processes influence our lives (Lienhard & Lienhard, 2019, p. 4).

There are three heat transfer processes: conduction, convection and radiation (Lewis, Nitihasasu, & Seethamaru, 2004). Conduction is the heat transfer between two bodies when they are in direct contact. Convection is the heat transfer between the glass surface and a gaseous medium. Radiation is the heat transfer resulting from two bodies that are at different temperatures and emit electromagnetic waves (Moran, Shapiro, Munson, & DeWitt, 2003).

In terms of energy losses in a building, it can be said that much of it is effected through the glazing and its componentes (Grynning, Gustavsen, Time, & Jelle, 2013). In most developed and developing countries, total heat losses through windows range from 40% to 60% (Cuce, 2019). Through computer simulations, it has been found that these are, in most cases, controlled by a single component. In aluminum elements, this control is performed by the depth of the thermally breaking material in the direction of heat flow. In materials without thermal breakage, the film provides the most resistance to heat flow. Bolts that penetrate the frame can sometimes affect the thermal performance of the window as they provide small spacing, paving the way for moving air masses.

Wind speed and its orientation are fundamental to the exact determination of heat transfer. Convection heat transfer coefficients are usually determined by the temperature and air velocity conditions on either side of the window. Wind speeds may range from less than 0.2 m/s, for calm weather conditions, to 29.0 m/s for stormy conditions.

Heat transfer between the glass surface and its environment is driven, not only by the air temperature at the site, but also by the radiant temperature to which the surface is exposed. The radiant temperature indoors is generally assumed to be equal to the indoor air temperature. This is a valid assumption for large rooms where surface temperatures are the same as air temperature, but not valid in places with large areas of glass surfaces (e.g., atriums, greenhouses, etc.).

The radiant outdoor temperature of the environment is usually assumed to be equal to the outdoor air temperature. This design may not be entirely correct, because the additional loss of radiative heat usually occurs on clear days.

As a means of reducing the overall heat transfer coefficient, double glazed windows have been internally filled with air or gas with low thermal conductivity. In these multi-glazing systems some problems arose, namely when the gas was overheated, leading to glass fracture caused by the volumetric increase of the gas. The most effective technique to overcome this problem was to adopt double glazing with air circulation between them.

The goal is to use the window as a passive air preheating system. It can be found under the designation of “supply air window” or “air flow window”. Ventilation has also been studied under the designation “ventilated window” or “ventilated double window” where the air only flows whether on the interior side or the exterior side. That stimulates heat exchanges between interior and exterior without air exchanges (Coillot, Mankibi, & Cantin, 2017).

Ideal windows consist of thermochromic and electrochromic films. These materials are used in the form of liquid crystals, with independent internal and external photocells for control. In the presence of reasonable sunshine, the photocell emits a signal that causes the liquid crystal to darken. Unfortunately, this type of window is a mirage because of its prohibitive price for most people.

2. HEAT GAIN

Solar heat gain is managed by two components. The first is transmitted directly from solar radiation. The amount of radiation is governed by the solar energy transmission of the glass system and is calculated by multiplying the incident irradiance by the glass area and its solar transmittance. The second component is the fraction that flows into the absorbed solar radiation. Visible transmittance is the solar radiation transmitted through weighted calculations in relation to the photo optics response of the human eye. The physics underlying visible solar heat gain and transmittance can be quite complex. Solar gain also enters a building through opaque elements such as the structure or any compartment, as some of the solar energy absorbed on the surfaces of these elements is redirected to the interior by heat transfer action. The solar heat gain coefficients are calculated for the center of the glass. These coefficients are given for various angles of incidence. For angles other than usual, linear interpolation can be performed and thus the desired values can be determined (ASHRAE, 2009b).

3. EARTH ATMOSPHERE

The earth's atmosphere behaves like a filter thus preventing the transmission of ultraviolet radiation ($\lambda < 0.4 \mu\text{m}$) and infrared radiation ($0.7 < \lambda < 3 \mu\text{m}$). Ultraviolet rays degrade and age almost all types of furniture and paintings. Sunstroke can cause the building to overheat, which should be avoided without obstructing the visible range responsible for natural light ($0.4 < \lambda < 0.7 \mu\text{m}$) (Guerrero, J. 1996).

4. PHASE CHANGE MATERIAL

The phase change material (PCM), i.e., the gas to be administered in the glass spacing, in the case of multiple glass, must be chosen strictly.

The PCMs may degrade with repetition of storage cycles. A large degradation in terms of thermo-physical properties with time is not desirable for any PCM. If it is thermally, chemically and physically stable after a repeated number of thermal cycles of operation, then PCM is said to be reliable. It does not deteriorate its own properties, especially latent heat and melting point after a repeated number of thermal cycles (Rathod, 2018, p. 40).

Air is the least capable of providing good thermal comfort within the building due to its poor characteristics when compared to PCM. However, it is widely used, because the final price of the window, with air, is lower. Therefore, in this study, air will be used as the interior gas of double glazing.

5. MATHEMATICAL MODEL

In this simulation, it will be assumed that the gas that fills the cavity, between the double glazing, is air.

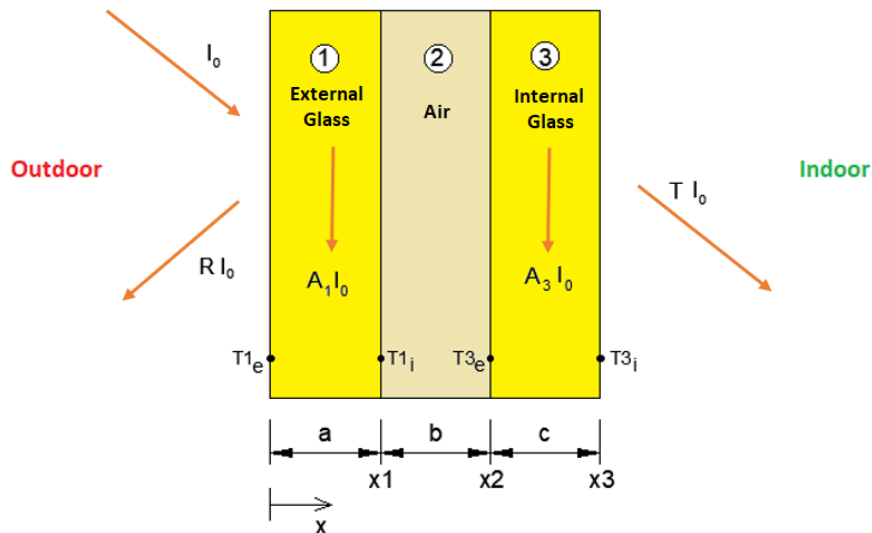
Due to its natural exposure, the outer and inner glass surfaces are crossed by shortwave radiation. Radiation values vary according to the optical properties of the glass (reflectance, transmittance and absorbance). However, wavelength radiations $\lambda > 3 \mu\text{m}$ are barred to the outer glass because it behaves as an opaque element to waves of this magnitude. After a part of this radiation is absorbed in the external glass (depends on the monochromatic absorption of the glass), the other part is transmitted indirectly through the window in the form of heat. In the glass in contact with the outside environment, there will also be heat exchange by convection with the outside and emission of infrared radiation to the outside environment (Scholze, 1980).

In short, it can be said that heat fluxes will arise by conduction through the outer glass, convection-conduction through the air and conduction through the inner glass. If the air temperature increase in the spacing between the windows is verified, radiation heat exchanges between the two windows will result. Finally, we will have convection heat exchange between the interior glass and the interior environment.

Nomenclature:

C - Specific heat, [kJ/kg·K]	α - Thermal diffusivity, [k/ρ·C]
I - Radiative heat flow, [W/m ²]	ρ - Density, [kg/m ³]
I_0 - Solar constant, [dimensionless]	k - Thermal conductivity, [W/m·K]
R - Optical Reflectance, [dimensionless]	t - Time, [s]
A - Optical absorbance, [dimensionless]	i - Regions 1, 2, 3
T - Optical transmittance, [dimensionless]	Δ - Increment
$h_{G,ext}$ - Overall coefficient of the external film, [W/m·K]	T_i - Temperature in the region i , [°C]

Figure 1 - Schematic diagram of double glazing filled with air and exposed to solar radiation



Source: Prepared by the author

In this resolution model we will adopt a modeling for the transient and one-dimensional heat transfer. It is also assumed that the properties of materials remain constant over time.

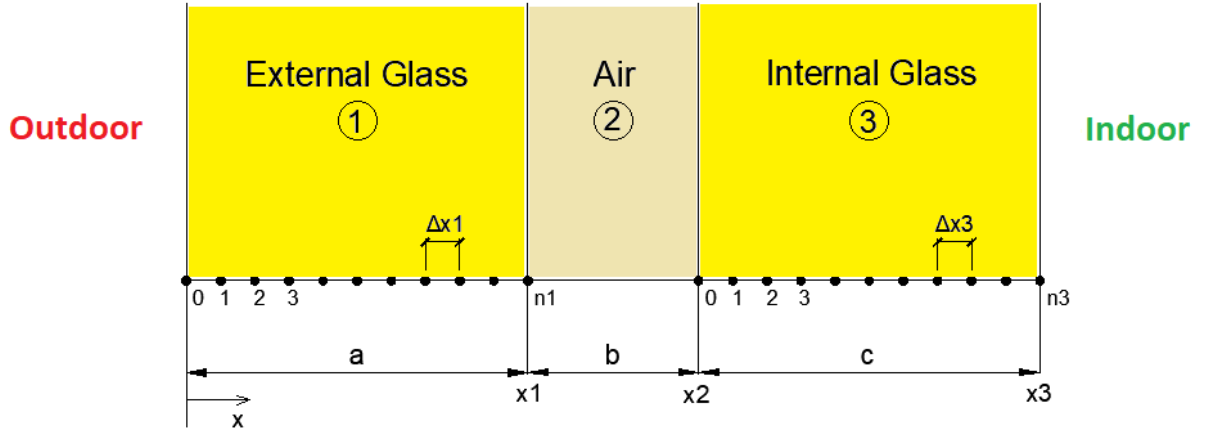
Differential equation governing this condition:

$$\frac{\partial T_i}{\partial t} = \alpha \cdot \frac{\partial^2 T_i}{\partial x^2} - \frac{1}{\rho \cdot C} \cdot \frac{\partial I}{\partial x} \quad (1)$$

6. MATHEMATICAL EQUATIONS

Then, we will expose the mathematical equations that will support the numerical study for double glazing.

Figure 2 - Fixed mesh scheme for the outer and inner glass region



Source: Prepared by the author

6.1. External Glass

To determine the temperature at the intermediate points of the glass, under study, the following equations were used:

$$T_1(i, j + i) = \left[\frac{\alpha_1 \cdot \Delta t}{(\Delta x_1)^2} \right] \cdot T_1(i + 1, j) + \left[1 - \frac{2 \cdot \alpha_1}{(\Delta x_1)^2} \right] \cdot T_1(i, j) + \left[\frac{\alpha_1 \cdot \Delta t}{(\Delta x_1)^2} \right] \cdot T_1(i - 1, j) - \frac{\alpha_1 \cdot \Delta t}{\rho_1 \cdot C_1 \cdot \Delta x_1} \cdot A_i \cdot I_0 \quad (2)$$

To determine the equation for the extreme points, the boundary conditions were considered, thus obtaining the expression for the calculation of the temperature in the first point of the mesh:

$$\begin{aligned}
T_1(0, j+1) = & T_1(1, j) \cdot \left[\frac{2 \cdot \alpha_1 \cdot \Delta t}{(\Delta x_1)^2} \right] + T_1(0, j) \cdot \left[1 - \frac{2 \cdot \alpha_1 \cdot \Delta t}{(\Delta x_1)^2} - \frac{2 \cdot \alpha_1 \cdot h_{G,ext} \cdot \Delta t}{k_1 \cdot (\Delta x_1)} \right] \\
& + \left(\frac{3}{2} \cdot A_{x=0} \cdot I_0 + h_{G,ext} \cdot T_{ext} \right) \cdot \left(\frac{2 \cdot \alpha_1 \cdot \Delta t}{k_1 \cdot (\Delta x_1)} \right)
\end{aligned} \tag{3}$$

At the last point of the mesh we have:

$$\begin{aligned}
T_1(n_1, j+1) = & T_1(n_1, j) \cdot \left[1 - \frac{2 \cdot \alpha_1 \cdot \Delta t}{(\Delta x_1)^2} - \frac{2 \cdot \alpha_1 \cdot \Delta t \cdot C}{k_1 \cdot \Delta x_1} \right] + T_1(n_1 - 1, j) \cdot \left[\frac{2 \cdot \alpha_1 \cdot \Delta t}{(\Delta x_1)^2} \right] \\
& + T_3(0, j) \cdot \left(\frac{2 \cdot \alpha_1 \cdot \Delta t \cdot C}{k_1 \cdot \Delta x_1} \right) + A_{x=x_1} \cdot I_0 \cdot \left(\frac{\alpha_1 \cdot \Delta t}{\Delta x_1} \right)
\end{aligned} \tag{4}$$

6.2. Internal Glass

Similarly, as calculated for the external glass, the expression for the intermediate points of the internal glass is as follows:

$$\begin{aligned}
T_3(i, j+i) = & \left[\frac{\alpha_3 \cdot \Delta t}{(\Delta x_3)^2} \right] \cdot T_3(i+1, j) + \left[1 - \frac{2 \cdot \alpha_3}{(\Delta x_3)^2} \right] \cdot T_3(i, j) + \left[\frac{\alpha_3 \cdot \Delta t}{(\Delta x_3)^2} \right] \cdot T_3(i-1, j) \\
& - \frac{\alpha_3 \cdot \Delta t}{\rho_3 \cdot C_3 \cdot \Delta x_3} \cdot A_i \cdot I_0
\end{aligned} \tag{5}$$

The first point of the mesh is governed by the following equation:

$$\begin{aligned}
T_3(0, j+1) = & T_3(1, j) \cdot \left[\frac{2 \cdot \alpha_3 \cdot \Delta t}{(\Delta x_3)^2} \right] + T_3(0, j) \cdot \left[1 - \frac{2 \cdot \alpha_3 \cdot \Delta t \cdot C}{\Delta x_3} - \frac{2 \cdot \alpha_3 \cdot \Delta t}{(\Delta x_3)^2} \right] + T_1(n_1, j) \\
& \cdot \left(\frac{2 \cdot \alpha_3 \cdot \Delta t \cdot C}{\Delta x_3} \right) + \left(\frac{\alpha_3 \cdot \Delta t \cdot C}{\Delta x_3} \right) + \left(\frac{\alpha_3 \cdot \Delta t}{\Delta x_3 \cdot k_3} \right) \cdot A_{x=x_2} \cdot I_0
\end{aligned} \tag{6}$$

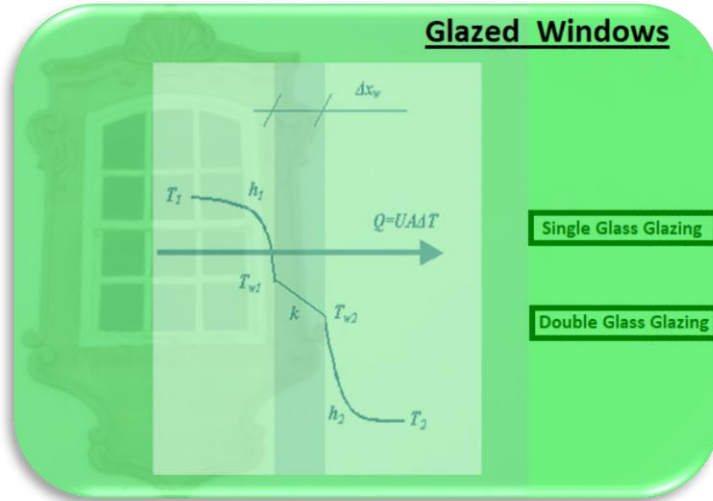
Finally, we have the expression for the last point of the mesh:

$$\begin{aligned}
T_3(n_3, j+1) = & T_3(n_3, j) \cdot \left[1 - \frac{2 \cdot \alpha_3 \cdot \Delta t}{(\Delta x_3)^2} - \frac{2 \cdot \alpha_3 \cdot \Delta t \cdot C}{k_3 \cdot \Delta x_3} \right] + T_3(n_3 - 1, j) \cdot \left[\frac{2 \cdot \alpha_3 \cdot \Delta t}{(\Delta x_3)^2} \right] \\
& + [h_{G,int} \cdot T_{int}(j)] \cdot \left(\frac{2 \cdot \alpha_3 \cdot \Delta t}{k_3 \cdot \Delta x_3} \right) + \left[\frac{\alpha_3 \cdot \Delta t}{\Delta x_3} \right] A_{x=x_3} \cdot I_0
\end{aligned} \quad (7)$$

7. CASE STUDY

For this study an application was conceived, in which the mathematical expressions, mentioned in the previous chapter, were inserted. This application has the ability to provide thermal parameters across the various glass plates.

Figure 3 - Application for the thermal calculation



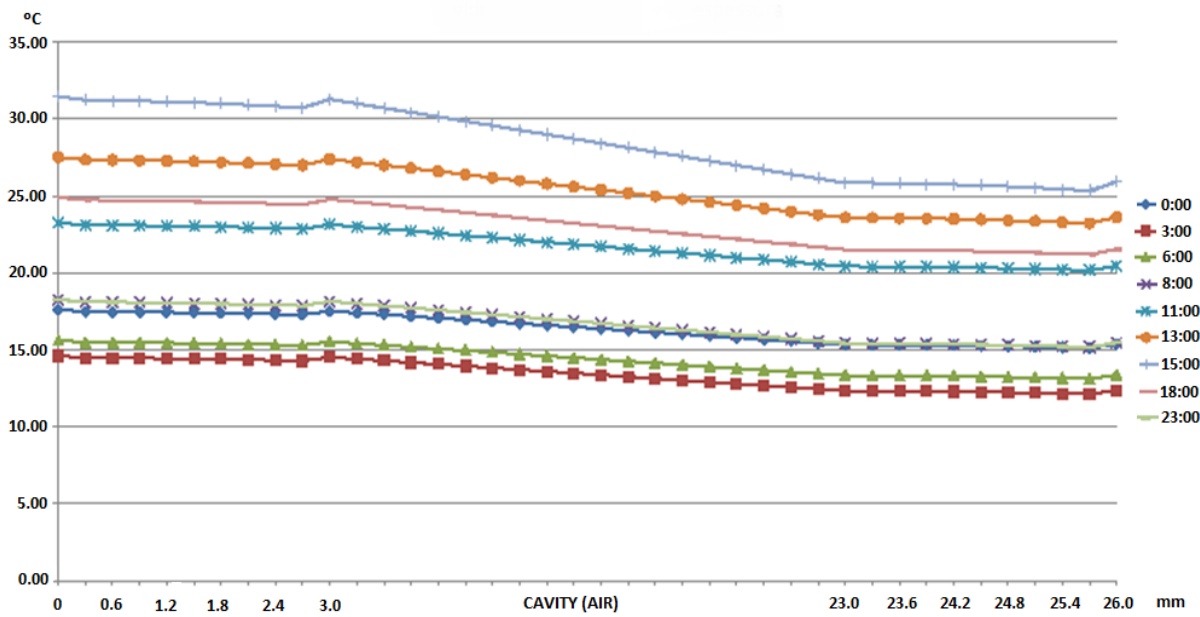
Source: Prepared by the author

In this numerical study we used clear glasses with 3, 4, 5, 6 and 8 mm. Since these are double glazing, it was decided to introduce both glasses of the same thickness in each case studied. The cavity is air filled in all cases and it is 20 mm thick.

The following graphs show the glazing temperatures throughout the day and the temperature differential between the two window panes. Temperatures were measured at a random place and time of year because what is relevant for this analysis, is the thermal behavior of the glass.

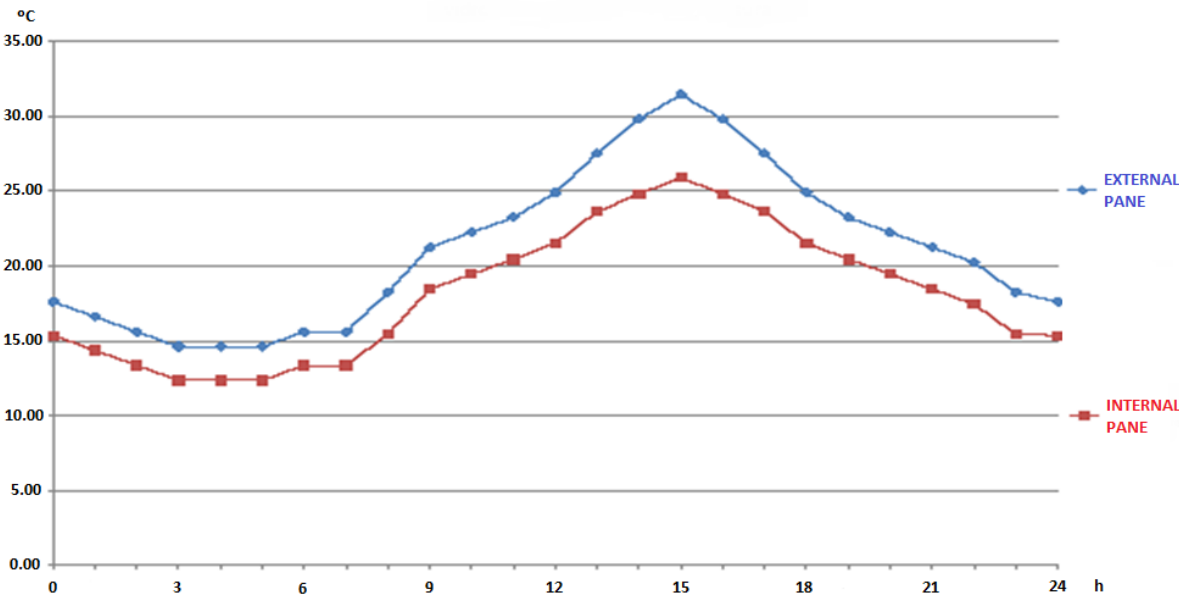
7.1. Double glazing [3-20-3] mm

Figure 4 - Temperature across 3 mm double glazing for various hours of the day



Source: Prepared by the author

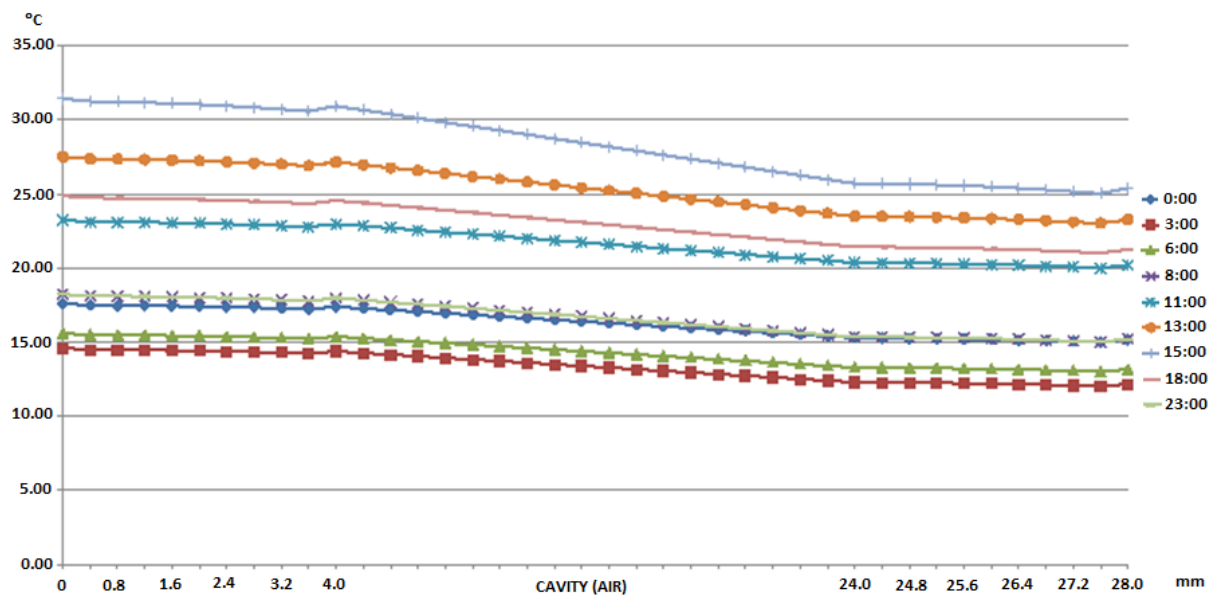
Figure 5 - Temperature on outside and inside surface of 3 mm double glazing



Source: Prepared by the author

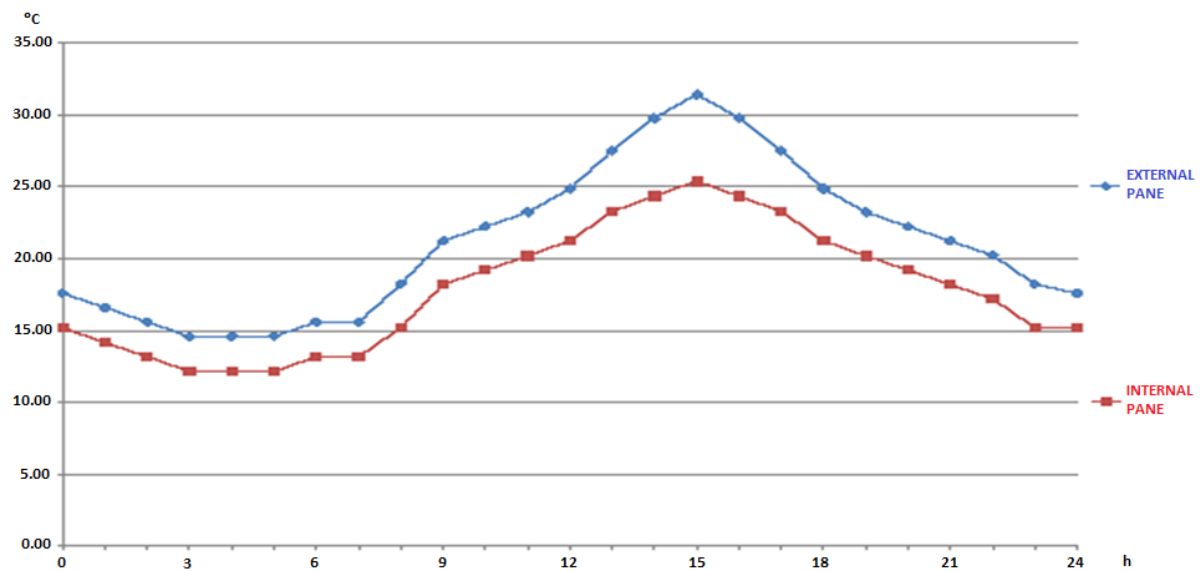
7.2. Double glazing [4-20-4] mm

Figure 6 - Temperature across 4 mm double glazing for various hours of the day



Source: Prepared by the author

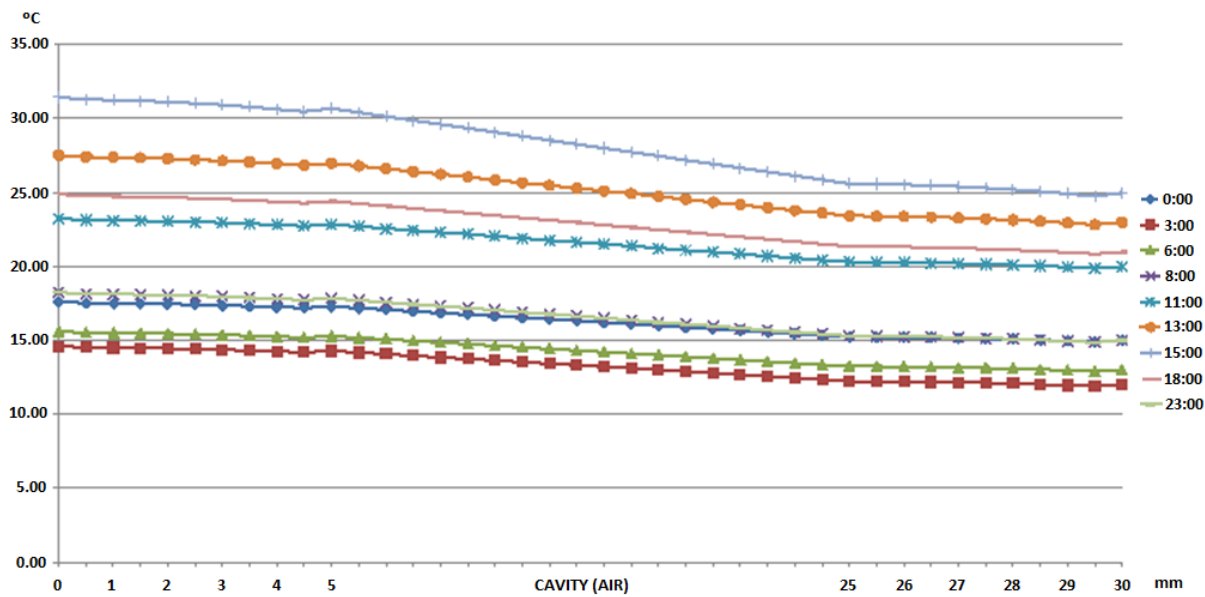
Figure 7 - Temperature on outside and inside surface of 4 mm double glazing



Source: Prepared by the author

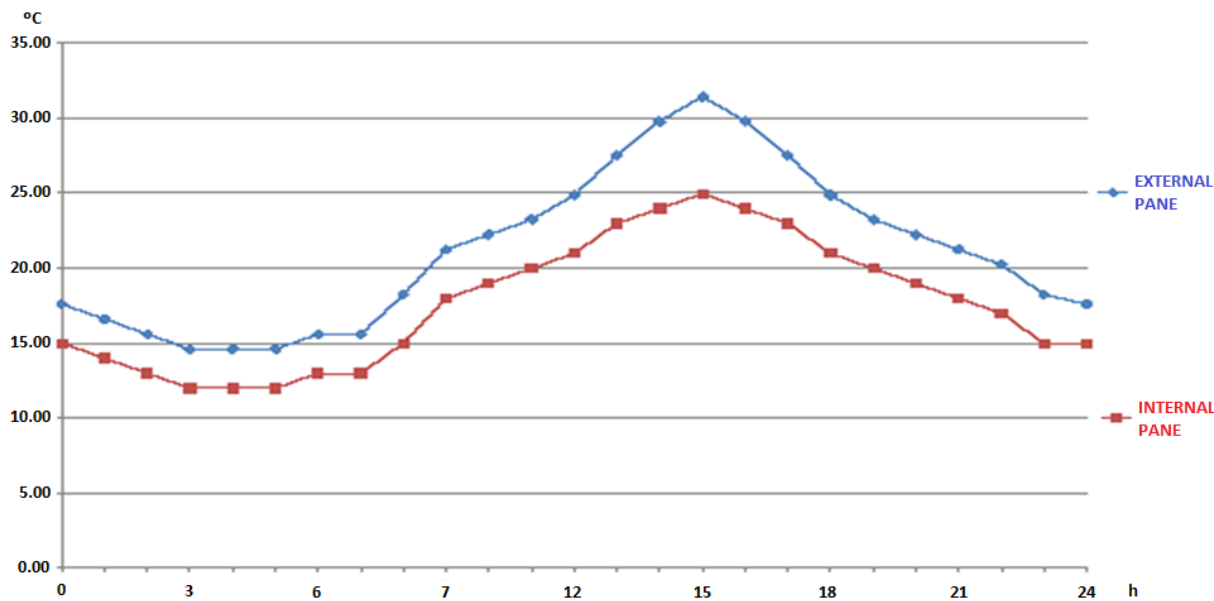
7.3. Double glazing [5-20-5] mm

Figure 8 - Temperature across 5 mm double glazing for various hours of the day



Source: Prepared by the author

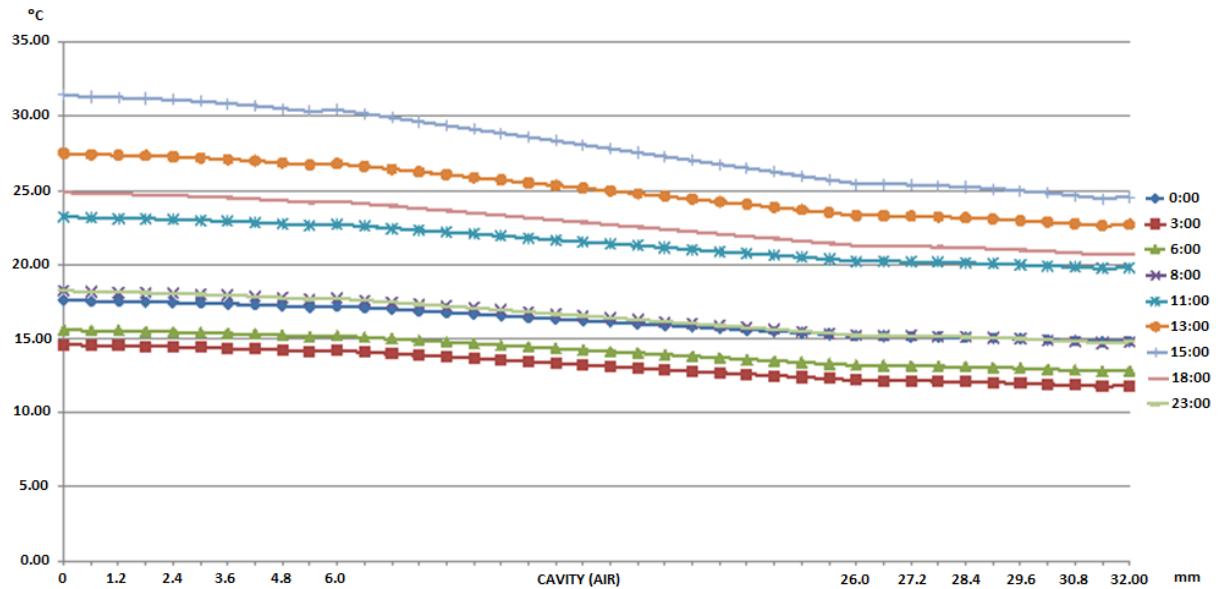
Figure 9 - Temperature on outside and inside surface of 5 mm double glazing



Source: Prepared by the author

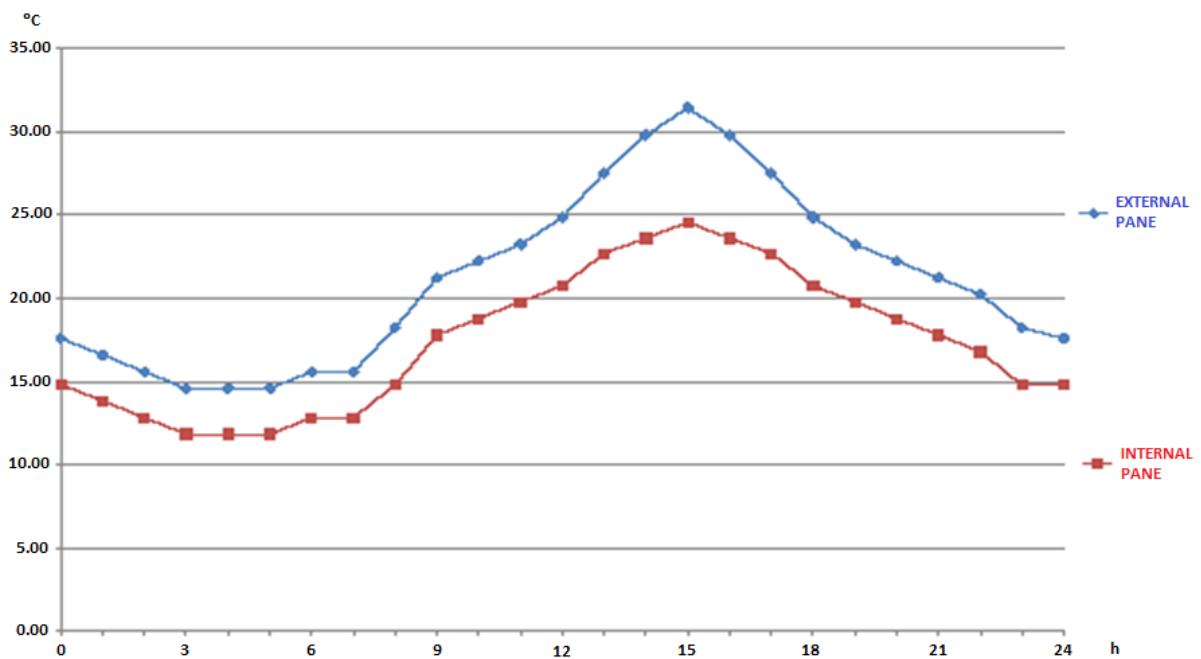
7.4. Double glazing [6-20-6] mm

Figure 10 - Temperature along 6 mm double glazing for various hours of the day



Source: Prepared by the author

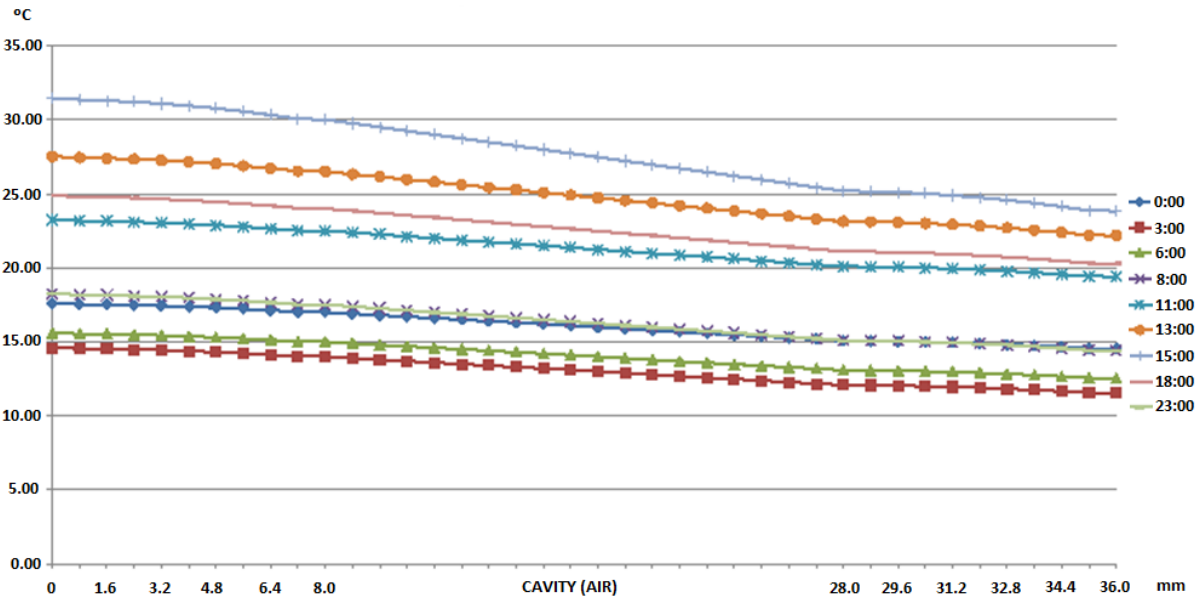
Figure 11 - Temperature on outside and inside surface of 6 mm double glazing



Source: Prepared by the author

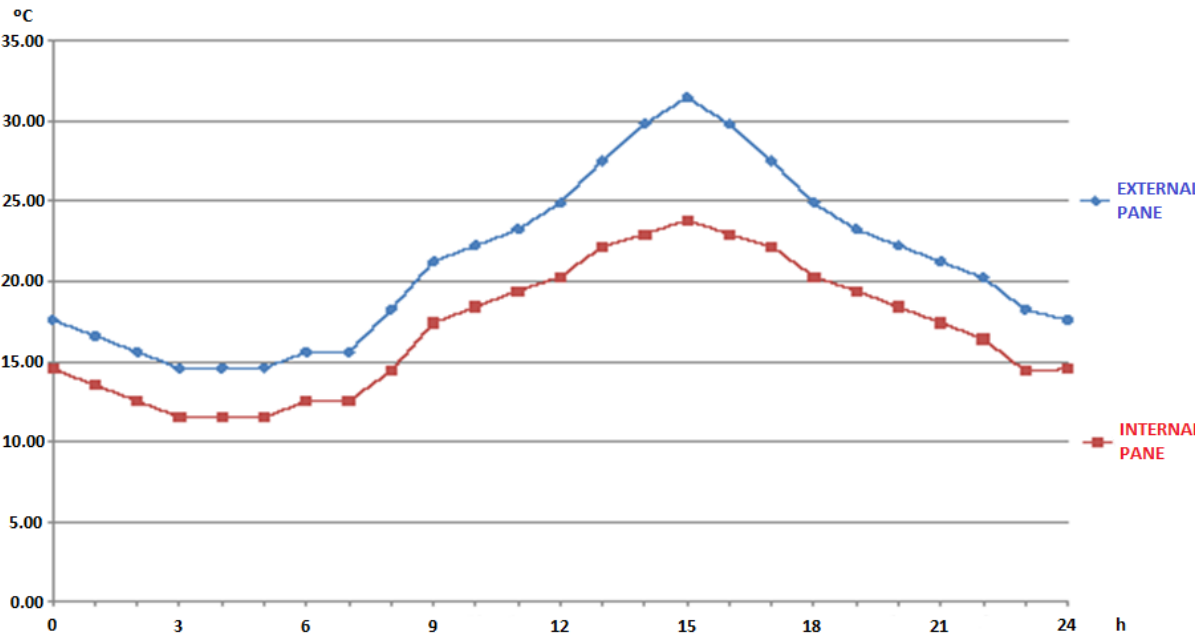
7.5. Double glazing [8-20-8] mm

Figure 12 - Temperature along 8 mm double glazing for various hours of the day



Source: Prepared by the author

Figure 13 - Temperature on outside and inside surface of 8 mm double glazing



Source: Prepared by the author

9. CONCLUSIONS

It is concluded that the surface temperature of the interior glass is low when the glass thickness is high. That is, the heat flux decreases with increasing glass thickness.

The maximum outside temperature is reached at 3 p.m. and it is at this time that the largest temperature differential between the outer and inner glass is observed. This temperature differential is higher when window glass is thicker. Therefore, it is found that the thicker glass reduces the thermal load more efficiently.

By increasing the thickness of the air cavity it has been found that there is no reduction in the heat load.

Regarding the radiation transmittance, we can say that the increase of the thickness of the glass only produces slight decreases of the same. Therefore, the application of thicker elements is not justified. Increasing the spacing between pcm-filled glass plates results in reduced transmittance, thus eliminating infrared radiation and keeping the band visible. The introduction of colored gases only affects the visible range, causing no changes in the infrared range.

In terms of reflectance, increasing the thickness of the double glass, filled with air, reduces it.

Absorbance is increased in the case of double glazing. If the fill is pcm, the highest absorbance is in the wavelength range 750 to 1750 nm and smaller values outside this range.

The transmitted energy is lower when the thickness of the assembly is high. If the incident radiation is inclined to the glass surface, the transmitted energy value is even lower.

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