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Thermal performance of a double pane window using glazing available on the Mexican market

J.O. Aguilar [a, b, *], J. Xaman [a], G. Álvarez [a], I. Hernández-Pérez [a], C. López-Mata [c]

[a] Centro Nacional de Investigación y Desarrollo Tecnológico, CENIDET-TNM-SEP, Prol. Av. Palmira s/n. Col. Palmira, Cuernavaca, Morelos CP 62490, Mexico
[b] Universidad de Quintana Roo, Boulevard Bahía s/n, Col. Del Bosque, Chetumal Quintana Roo CP 77019, Mexico
[c] Universidad Juárez Autónoma de Tabasco, UJAT, Avenida Universidad s/n, col. Magisterial, Villahermosa Centro, Tabasco CP 86040, Mexico

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ABSTRACT

A numerical study of a double pane window (DPW) with three types of commercial glass available in Mexican market is presented. The DPW consist of two vertical semitransparent walls separated by an air gap. The effect of varying the gap width (b) between glasses, the room temperature and the incident solar radiation is analyzed. Simulations were conducted for three configurations; *case 1*: clear glass + air gap + clear glass; *case 2*: clear glass + air gap + absorbent glass; and *case 3*: clear glass + air gap + reflective glass. Optical transmittance and specular reflectance of each case were measured. Two climatic conditions were analyzed, warm and cold climate. The results showed that, in order to increase or reduce the indoor heat gains, from $b \geq 0.02$ m, the heat fluxes remains almost constant for both climate conditions. For cold climate, the *case 1* reached the highest energy savings (~10.5 and ~28.5% higher than cases *2* and 3, respectively), however in warm climate it had the worst behavior (~105 and ~177% higher than cases 2 and 3, respectively). Finally, considering the *case 1* as reference, the *case 3* had the best combined energy saving ($17.64 USD-kWh/year) and case 2 presents a combined energy saving of $7.16 USD-kWh/year. Therefore is highly recommended the use of reflective double pane window, like to *case 3*, in Mexican warm and cold climates.

1. Introduction

In regions where the climate causes large temperature gradients between indoor and outdoor ambient on buildings, the glazing are the component that have greater heat gain in these [1]. If a building has glassed facades, which is the current trend in architecture, an air conditioner is required to maintain the thermal comfort inside the building. Such equipment will consume a large amount of electricity. To overcome this problem, building's designer have used different window configurations that use a wide variety of glass (monolithic, tempered and laminated) like absorbent, reflective and low emissivity among the most used.

In other configurations, a double pane window (DPW) has a better thermal performance than the traditional single layer window. A variety of studies considering DPW have been developed over the years. For example, double glazing with air at atmospheric pressure [2,3] or with some inert gas [4,5], with water as thermal fluid [6,7], with natural convection [8], DPW with enclosed slats [9], with transparent solar cells [10], and those that use phase change materials (PCM) [11]. Among DPW mentioned above, those manufactured with air enclosed between the panes are the most commonly used because their low cost with respect to other DPW configurations.

A large number of studies related to the thermal performance of DPW have been conducted over the years. The most relevant are those conducted by Lampert [12], who carried out an extensive literature review about glass with solar control films. In other similar work, Rubin [13] developed a general procedure for calculating the net energy flux through the glazed area of multipane windows filled with air or other gases. Besides, the methodology used by Rubin to evaluate multi glazing, with or without solar control film, considering environmental variables such a temperature and wind velocity. The main finding is that with a gap width larger than 2 cm, the thermal conductance ($U = 3$ Wm^{-2} K^{-1}) for

* Corresponding author. Universidad de Quintana Roo, Boulevard Bahía s/n, Col. Del Bosque, Chetumal Quintana Roo CP 77019, Mexico.
E-mail addresses: ovidio@uqroo.edu.mx, ovidio@unam.mx (J.O. Aguilar).

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Nomenclature

b	width of the cavity, cm
C_p	specific heat, J kg^{-1} K^{-1}
G	solar radiation, W m^{-2}
H	height of the glass, m
q	heat flux, W m^{-2}
q_{ext}^{conv}	convection heat flux towards the exterior of the room, W m^{-2}
q_{int}^{conv}	convection heat flux towards the interior of the room, W m^{-2}
q_{ext}^{rad}	radiation heat flux towards the exterior of the room, W m^{-2}
q_{int}^{rad}	radiation heat flux towards the interior of the room, W m^{-2}
q_τ	transmitted heat flux through the double pane window, W m^{-2}
s_g	extinction coefficient, m^{-1}
T	temperature, K
T_g	glass temperature, K
x, y	dimensional coordinates, m

Greek symbols

α^*	absorptivity
ε^*	emissivity
λ	thermal conductivity, W m^{-1} K^{-1}
ρ^*	reflectivity
ρ	density, kg m^{-3}
τ^*	transmissivity

Subscripts

conv	convection heat transfer
ext	external ambient
g	glass
int	internal ambient
rad	radiation heat transfer
1, 2	glass number

double glass unit remains constant, while adhering a solar control coating on polyester film the U value reduces a 33%.The above results provided the basis for further research to find the optimal air gap width in double glazing. Related works are presented below.

Aydin [14] presented a numerical study of the heat transfer through a double pane window to determine the optimal gap width between two panes for different climates. The study consider several climate conditions for Turkey locations, with Δt ranging 19–49 °C and a cold wall temperature fixed in 21 °C. The optimal gap width was found to be in the range of 12–21 mm for the locations proposed. Years later, Aydin [2] extended his work to a conjugate conduction and natural convection heat transfer in double pane windows. The author's conclusion are that variation of heat flux through the inner pane in all cases analyzed is constant for air gap ≥20 mm. Ismail and Henríquez [15] conducted a study of conduction and convection heat transfer in a double pane window with gap with from 0.5 to 10 cm. The authors concluded that with the boundary conditions proposed, the gap width has no significant impact on the SHGC (Solar Heat Gain Coefficient) neither on the SC (shading coefficient).

Arici and Karabay [16] determined the optimal gap width of a double pane window using the degree-day method. The study was conducted for four different climates zones of Turkey and the heating cost was calculated for five types of fuels. The base temperatures were 18, 20 and 22 °C and the optimal gap width varies between 12 and 15 mm, according to climate zone, fuel type and base temperature. The results showed that it is possible achieve up to 60% of energy saving.

Referent to thermal performance of double windows glazing, reported works like Ismail et al. [17] conducted an analysis to compare thermal efficiency for two types of double pane window, one filled with an absorbing gas and the other filled with a phase change material (PCM) and exposed to solar radiation. They found that double pane window filled with absorbing gas mixture and using reflective glass is more efficient and has an SHGC between 55 and 65% meanwhile the double pane window filled with PCM has an SHGC ranging 60–80%.

Ismail et al. [18] conducted a comparative study of their previous work on three different systems: single glass, double glazing unit filled with an absorbent gas and double glass unit with natural ventilation. The authors concluded that the most effective configuration was the second one. In similar works and after conduct a brief overview of state of the art on solar window technology, Chow and Li [8] proposed a double glass unit with enclosed water. Three different configurations, for forced flow (5×10^{-3} m/s) and natural flow (1×10^{-3} m/s), were used: clear/water flow/clear, clear/water flow/reflective on clear, and tinted/water flow/clear. The results demonstrated that the best configuration for both cases were those that use tinted glass.

Gueymard et al. [19] studied the SHGC and the behavior of the visible transmittance in vertical and inclined glazing as function of spectral solar radiation. They used 37 type of glass, single, double and triple, with and without solar control film. The thermal evaluation was conducted with commercial software window 5.2.17 and Optics 5.1. The obtained results show SHGC values from 0.247 to 0.678 for double glass windows with low-e solar control films, presented the better behavior.

Chow and Li [7] extended their previous works to analyze the thermal characteristics of double glass unit with enclosing water considering outdoor and indoor temperatures, solar irradiance, beam angle as well as flow velocity on the heat flow. In other work [6], report the integrative thermal performance of a double glass unit with enclosing water as compared to the conventional single and double pane absorbing glazing. In both work, authors concluded that double pane window with enclosing water is suitable for applications in warm climates. The most recent results reported about double pane window are focused on the effect of varying the gap width between the glasses, indoor temperature, solar radiation [3], emissivity and gas fill [20] and entire wave length heat radiation [21].

From the literature review it can be concluded that there are plenty studies related to thermal performance of double pane windows with and without solar control films. However, several works use correlations for convective and radiative heat transfer coefficients for convection and radiation between the glass and fluid.

The objective on this paper is to evaluate three types of glass available in the Mexican market in a double pane window configuration for using in cold and warm climates. The results will allow one to know which glass presents a better thermal performance and to know the optimal gap width between glasses aiming to