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Thermal performance of a double pane window with a solar control coating for warm climate of Mexico

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HIGHLIGHTS

- Pseudo-transient thermal performance of a double pane window (DPW) was determined.
- The DPW was analyzed each 5 s by a period from 8:00 to 18:00 h.
- 57,600 computational runs were necessary and the additive correction multigrid was implemented.
- Solar control coating (SCC) in a DPW reduces 1073.79 W/m^2 with respect to the DPW without SCC.
- SCC is highly recommended in a DPW because it reduces a 53.88% of the amount of energy gained.

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ABSTRACT

The pseudo-transient thermal performance (each 5 s) of a double pane window without and with a solar control coating was determined numerically. The study considers warm climatic conditions (Mexico) and a period from 8:00 to 18:00 h. The effect of varying the indoor air temperature (15–30 °C); and the incident solar radiation and the outdoor air temperature as functions of time is analyzed. The simulations were done with a self-developed ForTran program and it was verified with results from the literature. To obtain the results, 57,600 computational runs were necessary. From the results, the double pane window with a solar control coating allows a smaller heat flux to enter into a room than the corresponding without a solar control coating. The solar control coating in double glass window reduces the amount of 1073.79 W h/m^2 with respect to the case without a solar control coating, which represents a reduction of 53.88% of the heat gain.

1. Introduction

According with the last report by International Energy Agency (IEA), buildings represent 32% of total final energy consumption. In terms of primary energy consumption, buildings represent around 40% in most IEA countries [1]. There are two important points that all buildings must comply with, the thermal efficiency and the thermal comfort. However, the current design of buildings using large glazing facades compromises their thermal efficiency when they are not designed correctly. An incorrect design of the glass envelope causes excessive electrical energy consumption and therefore significant CO_2 emissions to the environment.

Using advanced glazing can significantly reduce the need for heating and cooling in buildings. For this purpose, there exist a wide range of glazes that can be used in buildings, particularly the double pane window (DPW) has been proposed as an alternative to the traditional single layer window. Several studies about DPW are available in the literature aiming to determine their thermal performance with different fluids, which are encapsulated in the cavity formed by the glass [2–12]. Some relevant studies about DPW are described below.

Gan [13] predicted the thermal transmittance (U) and the heat transfer coefficient of DPW. The results showed that the U vary with the width of air space between glazing panels up to about 25 mm. Ismail and Henríquez [14] presented a one-dimensional numerical model and the experimental study of the PCM filled window system. The results showed that the panels filled with PCM reduce the energy transmitted about 50%; the case of a DPW with 5 mm of spacing filled with green PCM indicates the greatest reduction. Pérez-Grande et al. [15] reported the total heat rate into the build-

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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_{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}
s_g	extinction coefficient, m^{-1}
T	temperature, K
T_g	glass temperature, K

Greek symbols

α^*	absorptivity
β	thermal expansion coefficient, K^{-1}
ε^*	emissivity
λ	thermal conductivity, W m^{-1} K^{-1}
μ	dynamic viscosity, kg m^{-1} s^{-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

ing for double glazed facades considering a height of the building L = 15 m and a width of the channel d = 0.9 m. The results show that the air velocity through the channel at 6 m/s reduced the heat load into the building by a factor larger that 1.5 compared with the free convection case. Carlos et al. [16] predicted the thermal performance of a ventilated double window; the results were compared with the results of the COMIS software and with the experimental values. The double window studied consider different combinations of glazing: single glaze at the outer window and single (system 1) or double glaze (system 2) at the inner window. The results shows that heat balance of the system 2 decreased up to 23% respect to the system 1. Ali Kara and Kurnuç [17] used a test room to study the effect of a triple glazing unit on performance of a wall with PCM. From the measurement the authors found that the solar transmittance ranged from 0.45 to 0.55 during the winter and from 0.2 to 0.25 during the summer. Thus, there were not problems of overheating for the PCM wall during the summer. Among the studies of windows with multiple glass panes (including double) that have found the optimum thickness of the fluid layer between the glass panes, Aydin have reported two works [2,18]. Aydin [2] determined the optimal width of a double glass window; the system was analyzed as a tall cavity heated differentially. The author considered four average gradients of temperatures typical for Turkey $\Delta T = 19, 25, 34 \quad \text{and} \quad 49^{\circ}C$. Optimal width 18–21, 15–18, 15–18 y 12–15 mm were obtained respectively for each ΔT. More later, Aydin [18] extended his work taking into account heat conduction on the glasses in one dimension and analyzed the effect of the exterior convective coefficient from 15 to 30 W/m^2 K. The author concluded that this increment has no significant effect on the heat transfer towards the cavity interior. Gueymard and DuPont [19] presented a compilation of 37 different glass systems: single, double and triple pane windows. In addition, the analysis was performed with and without solar control film. The authors used the software WINDOW 5.2.17 and OPTICS 5.1 for the calculation of thermal parameters (U and SHGC). Among the results, they found the SHGC in a range from 24.7% to 67.8% for systems with double glazing and low emmittance. Arici and Karabay [10] 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. The optimal gap width varies between 12 and 15 mm, according to climate zone. The results showed that it is possible achieve up to 60% of energy saving. Later, Arici and Karabay [20] extended his work taking into account double, triple and quadruple pane windows considering various gap widths. Numerical results showed that the most reasonable gap width is 12 mm for all cases considered in this study. A recent result by Arici and Kan [12] about double pane window was focused on the effect of varying the gap width between the glasses, emissivity and gas fill. Recently, Zhang et al. [21] proposed a switchable triple-glazing exhaust air window (SEA). The SEA has two air cavities, one is the ventilation channel and the other acts as a conventional double glazing unit. They showed that compared to conventional double and triple glazing windows, the SEA reduces 73.5% and 71.9% of the heat gain during summer.

Many of the above mentioned studies are conducted in steady state. However transient studies of DPW are necessary because the climatic conditions change during the day, both the air temperature and solar radiation have an important influence in the thermal performance of windows. In this way a transient analysis is a more appropriate approach than a steady state analysis.

Regarding transient studies of double glazed windows with natural convection, Álvarez et al. [22] presented a study on a double glazing unit with and without solar control film, the temperatures on the inside and outside environment considered for the study were 24 and 35 °C. The authors concluded that the glass with a solar control film increases its temperature, but it reduces 30% the gain of energy into the cavity. Among other works related to transient thermal performance of DPW is the conducted by Ismail et al. [23–25]. In the late research Ismail et al. [25] conducted a comparative study of their previous work on three different systems: (a) single glass; (b) double glazing unit filled with an absorbent gas and (c) double glass unit with natural ventilation. A mathematical model is developed for each glass window system, the cases (a) and (c) were studied in transient state and the case (b) in steady state. The authors concluded that the most effective configuration in hot climates was the double glass window filled with absorbing gas.

Gil-Lopez and Gimenez-Molina [26] presented an experimental comparison between two double glazing systems. The first one has the gap width between the glass layers filled with air and the second one has circulating water in a closed circuit. Hourly real conditions were taken to conduct the experiment for a whole day. The results showed that glazing with water in between the layers is a more efficient option than the glazing system with air in between the layers.

Scientific community has used different approaches to understand the thermal behavior of double glazing systems. However, there are scarce studies related to thermal performance in transient state of double pane window (DPW). Also, despite the great efforts realized in all previous research, monolithic clear glazing