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Thermal analysis for a double pane window with a solar control film for using in cold and warm climates

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ABSTRACT

A numerical study in a double pane window (DPW) with solar control film (SCF) for warm and cold climates is presented. The DPW consists of two vertical semitransparent walls: glazing-1 facing the room, and glazing-2 facing the external environment and exposed to solar radiation; there is a SCF attached to glazing-1 for cold climate, or glazing-2 for warm climate. The effect of varying the separation distance (b) between the glasses, room temperature and the incident solar radiation is analyzed. To carry out the thermal analysis of the DPW, three cases were defined: Case C1 corresponds to the DPW with SCF; Case C2 corresponds to the DPW and Case C3 corresponds to single glazing window. It was found that in order to reduce or increase heat gains toward the inside environment, the optimal distance between the glasses was $b > 6.0$ cm for both climate conditions. For warm climate the use of a SCF is highly recommended, since the Case 1 reduces the amount of energy gained within 52% compared to Case 2. When using the SCF on the DPW for cold climate, the amount of energy gain through the system reduces 10% respect to the case C2.

1. Introduction

Among the applications of solar energy is the issue of saving and efficient use of energy in buildings, which focuses on obtaining thermal comfort and air quality with minimum consumption of energy. However, the tendency in the architectural industry during recent years has been to build tower type buildings, with large areas of windows or glaze which in some cases covers the whole building [1]. In many cases the use of these construction systems are not adequate to local climatic conditions (warm or cold). Therefore, the buildings require mechanical and electrical systems to condition the environment, which results a high cost of operation and maintenance to provide thermal comfort to people inside.

The above has motivated the study and development of new technologies focused to reduce the gains or losses of energy in tower type buildings. Among these technologies we can find the use of tinted, reflective, low-emittance coatings or high extinction coefficient (absorbent glass) glasses, and even the use of solar control films, double glazing unit or multiple facades. The SnS–Cu_xS thin films was developed to use as solar control coatings for architectural and automobile glazing applications [2–4]. The coatings were obtained by successive chemical depositions of SnS and Cu_xS thin films. Estrada-Gasca et al. [5,6], proposed a mathematical model to analyze the performance of a SuS–Cu_xS solar control coating for a 6 mm single glass. After, the foregoing model was validated by Álvarez et al. [7].

Double glazing unit are defined as open or closed systems. Closed systems encapsulate mainly a low conductivity gas (inert gas) such as krypton in order to diminish heat transfer [8]. Open systems belong to the double façade systems, in which solar radiation is used to create the chimney effect to withdraw or propitiate recirculation of the air in the buildings in order to heat or cool the interior.

Solar control films are designed to absorb or reflect the incident solar radiation, in order to diminish solar heat gains through the glass; Lampert [9] presented an extensive review on this technology. Rubin [10] presented a methodology for analyzing the heat transfer in multiple glazing with or without solar control film, considering environmental variables such as temperature and wind speed. The author determined that the overall thermal conductance (U) for a double glass unit remains constant for a separation between the windows larger than 2 cm. For a double glass with clear glass will have an approximate value of 3 W/m^{2}K and if one

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Nomenclature

b	width of the cavity (cm)
C_p	specific heat (J kg^{-1} K^{-1})
$dFdA_j - dA_k$	view factor between elements j and k
g	gravitational acceleration (9.81 m s^{-2})
G	solar radiation (W m^{-2})
H	height of the glass (m)
Nu_{conv}	average convective Nusselt number
Nu_{rad}	average radiative Nusselt number
P	Presión (Pa)
q	heat flux (W m^{-2})
q_{ext}^{conv}	convection heat flux toward the exterior of the room (W m^{-2})
q_{int}^{conv}	convection heat flux toward the interior of the room (W m^{-2})
q_{ext}^{rad}	radiation heat flux toward the exterior of the room (W m^{-2})
q_{int}^{rad}	radiation heat flux toward 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)
T_f	solar control coating temperature (K)
u,v	horizontal and vertical velocities (m s^{-1})
x,y	dimensional coordinates (m)

Greek symbols

α^*	absorptivity
α	thermal diffusivity (m^2 s^{-1})
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
τ_{ij}	tensor stress

Subscripts

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

of the glasses adheres solar control film of plastic (polyester film) the value is reduced to 2 W/m^{2}K. Álvarez et al. [11] presented a one-dimensional study on a double glass with and without solar control film. The temperatures on the inside and outside environment considered for the study were 24 and 35 °C with convective coefficients of 8.3 and 22.7 W/m^2 K respectively. For the energy exchange of the air enclosed between the sheet glasses the convective coefficient was taken as 5.75 W/m^2 K. The authors concluded that the glass with a control solar film increases its temperature, but reduces the energy passing through it by 30% toward the interior of the cavity.

Aydin [12] presented a study to determine the optimal width of a closed double glass; the system was analyzed as a tall cavity differentially heated. Four values of temperature differences for Turkey were considered: ΔT = 19, 25, 34 and 49 °C and the temperature of the cold wall was fixed at 21 °C. Optimal widths of 18–21, 15–18, 15–18 and 12–15 mm were obtained respectively for each ΔT. Aydin [13] 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 toward the cavity interior. Ismail and Henríquez [14] carried out a study on the conduction and convection heat transfer in a double glass. Which consisted of two glasses with 8 mm thick and 1.0 m high, considering a separation distance (b) between 0.5 and 10 cm. The two-dimensional vertical channel has 12.5% of the upper and lower part of the glasses insulated and receives a solar radiation of 600 W/m^2 on one of the glasses Based on the results, the authors concluded that the separation distance between glasses has no significant impact on the *SHGC* neither on the shading coefficient, the first remain constant at 77%.

Ismail et al. [15] carried out an analysis on a double glazing unit (DGU). In order to compare two different substances between the glasses, an absorbent gas and a substance with change of phase. The *SHGC* for the gas was reported to be between 55 and 65% and for the change of phase substance was 60–80%. Ismail et al. [16], recently carried out a comparison on their own previous works on three different systems: single glass, double glazing unit filled with an absorbent gas and a DGU with natural ventilation; they concluded that the second configuration was the most effective. Gueymard et al. [17] presented a compilation of 37 different glass systems: single, double and triple glass. In addition, the analysis was performed with and without solar control film. The authors used 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.

Chow and Lin [18], presented a compilation and comparison for different systems of double and single glass. At the same time they proposed a closed double glass unit for application on places with high cooling thermal loads demand, consisting of two sheet glasses enclosing water. Three different configurations are analyzed: clear glass/water/clear glass, clear glass/water/reflective glass and tinted glass/water/clear glass. The results demonstrated that the last configuration proved to be the best configuration for energy saving. Yin et al. [19], recently carried out an analysis of energy savings from applying solar window films in a commercial building with large, curtain wall areas in Shanghai, China. eQUEST software was used to simulate the annual building performance with and without the solar window film. The authors concluded that the solar control film can decrease the shading coefficient and solar heat gain coefficient by 44 and 22% if applied on the outside and inside of the existing windows, respectively.

In México, in addition to the work of Alvarez et al., there are some other studies that consider solar control films, these are: Messina et al. [20], Aguilar et al. [21], Chávez-Galan and Almanza [22]. The latter for applications in buildings, the authors used the Energy-10 software to simulate the energy consumption of a department with a simple glass window and the glass with solar control film. The energy consumption is reduced up to 16% annual for the room to that considering the window with a solar control film.

From the literature review can be concluded that studies have been developed for systems of single and multiple glasses with and without solar control films. The studies carried out with solar control films using software such as WINDOW (Gueymard et al., 2009), Energy-10 [22], which used a standard for the calculation of thermal parameters (ISO-15099, [23]). For the analysis of multiple windows systems is necessary to use correlations for convective and radiative heat transfer coefficients for convection and radiation between the glass and fluid.