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A comparative study of naturally ventilated and gas filled windows for hot climates

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ABSTRACT

The use of absorbing gases filling the gap between glass sheets appears to be an alternative solution for thermally insulated glass windows. Fluid flow in the gap between the glass sheets either forced or natural offers other options for thermally efficient windows. In this work, the thermal efficiencies of glass windows filled with an absorbing gas exposed to solar radiation in hot climate is compared with both a simple glass window and a double glass window naturally ventilated. The two-dimensional transient energy equations with radiation absorption in the internal domain are used to model the simple glass window. The cumulative wavenumber model (CW) for real gas modeling together the discrete ordinates method is used to model double glass window filled with infrared absorbing gases. The numerical simulations were realized with three mixtures of gases, a strongly absorbing gas mixture, an intermediate absorbing gas mixture and a transparent to infrared radiation mixture. To model a double glass window naturally ventilated, a two-dimensional transient laminar incompressible flow formulation is used and the buoyancy effects are accounting for by the Bussinesq approximation. Heat transfer through the windows is calculated and the total heat gain coefficient is compared for the three types of windows.

1. Introduction

From the thermal point of view, windows are the weak link between internal and external ambients in buildings. In cold climates, windows are responsible for 10–25% of heat losses from heated ambients. In hot climates, solar heat penetrating glass windows may lead to excessive heat gain and hence increases the cooling load of ar conditioning equipments. An efficient way of reducing heating and cooling loads of internal ambients is to reduce or eliminate the solar heat gain (loss) by using windows incorporating passive mechanisms for reducing the solar heat gain without impairing the natural illumination.

Simple glass windows are inefficient in reducing the heat and thermal radiation transfer across the window system. The development of new materials, advanced window technologies led to new window products which are more efficient.

Windows having selective solar radiation characteristics are examples of thermally efficient windows. The selective properties of film deposited on glass sheets allow changing the transmittance, reflectance and absorptance of the window. These films can be designed to absorb or reflect according to the wavelength of the incident radiation. A vast review of technologies of selective films is reported by Lampert [1].

High performance is also achieved by using evacuated glass panels where heat transfer by conduction and convection is greatly reduced. Collins and Simko [2] presented an excellent review on evacuated windows.

The use of absorbing gases filling the gap between glass sheets appears to be an alternative solution for thermally insulated glass windows. The use of gases with strong infrared radiation/absorption characteristics was investigated and some simplified models for spectral radiation modeling were formulated [3,4]. One accurate model for spectral radiation modeling was applied to the case of horizontal double glass window [5]. Muneer et al. [6] presented a model for the combined modes of conduction, convection and radiation in a glass window filled with non-participant gas and determined the glass temperature at the bottom of the window. In a recent work, Ismail et al. [7] compared the thermal efficiency of glass windows filled with absorbing gas with windows filled with phase change material (PCM).

Fluid flow in the gap between the glass sheets of a double panel window offers an option for thermally efficient windows. Experimental work on ventilated windows was reported by Onur et al. [8].

Etzion and Erell [9] presented a new concept of ventilated window while Tanimoto and Kimura [10] presented a calculation procedure for ventilated windows with a curtain and venetian. Haddad and Elmahdy [11] developed a model and computational program to simulate the performance of a conventional window and a ventilated window. Zhang et al. [12] reported a study of the effect of venetian installed into a cavity formed by two glass

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sheets. Some complex models involving transient phenomena and two dimensional heat processes were presented by Larsson et al. [13].

In this work, three concepts of glass windows were investigated. A numerical model for a single glass window, a numerical model for naturally ventilated glass window and a numerical model for double glass window filled with infrared absorbing gases were elaborated, numerical simulations were realized and the results were compared and discussed.

2. Thermal performance parameters for windows

The total heat gain, the coefficient of solar heat gain and the shading coefficient are important parameters for the calculation and comparative evaluation of the performance of windows. To calculate the total heat gain one must take into consideration the solar energy which passes directly through the transparent surface and the solar energy which reaches the internal ambient after being absorbed by the glass and then redirected by the heat transfer mechanisms.

To calculate the total heat gain, the temperatures of the glass sheets have to be calculated iteratively from energy balances on each sheet. The total heat gain (THG) or the total solar heat transmittance is the heat passing over to the internal ambient by convection and radiation in addition to the total incident solar radiation which reaches the internal ambient.

$$\mathrm{THG} = Ah_{int}(T_{internal\ glass} - T_{room}) + \varepsilon A\sigma(T^4_{internal\ glass} - T^4_{room}) + \tau A Q_{solar} \quad (1)$$

where τ is the coefficient of solar transmittance of the window, ε is the glass wall emissivity, σ is the Stefan–Boltzman constant, h_{int} is the convective coefficient, Q_{solar} is the incident solar radiation and A is the glass area. The solar heat gain coefficient F is calculated from:

$$F = \frac{\mathrm{THG}}{Q_{solar}} \quad (2)$$

3. The mathematical models

3.1. Simple glass window

Fig. 1 shows details of the model where the incident solar radiation over the external surface is partially reflected, transmitted

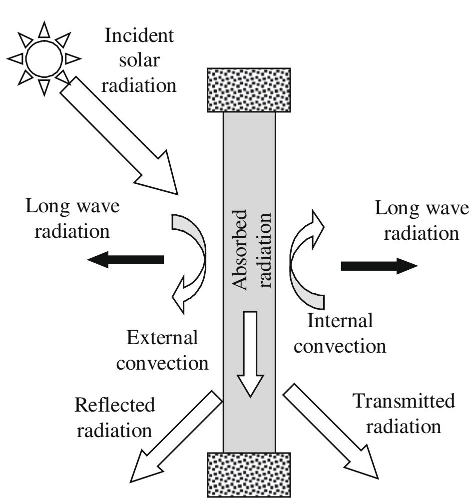

Fig. 1. Heat flux over a sample glass window.

and absorbed by the glass sheet. The absorbed radiation increases the internal energy of the glass sheet and consequently its temperature. Additionally the glass window looses or gains heat from the internal and external ambients by conduction, convection and long wave radiation. Fig. 2 shows the scheme adopted for computing the energy absorption along the glass sheet cross section.

The mathematical model of the two-dimensional transient energy equation for the glass sheet is written as in [15]

$$\frac{\partial T}{\partial t} = \frac{k}{\rho c}\left[\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2}\right] - \frac{1}{\rho c}\frac{\partial I_q}{\partial y} \quad (3)$$

where k is the glass conductivity, ρ is the glass density and c is the glass heat capacity. The glass thermal properties are considered constants. The term $\partial I_q/\partial y$ is the solar radiation absorbed in the glass per unit volume and can be written in terms of the radiation attenuation across the glass sheet characterized by its extinction coefficient as

$$dI_q = -\beta I_q dy \quad (4)$$

where β is the extinction coefficient. Eq. (4) can be integrated and the result can be written in a form to represent the radiation absorbed by the material along the ray path

$$\frac{I_{q_{y=0}} - I_q}{I_{q_{y=0}}} = 1 - \exp[-\beta y] \quad (5)$$

The boundary conditions on the glass sheet are:

The horizontal boundaries, that is, the top and bottom extremities ($x = 0$ and $x = L = 1.0$ m) are considered adiabatic.

The boundary conditions for the vertical boundaries in contact with the internal and external ambients are obtained by an energy balance. One can write for the external side of the glass sheet

$$q_{y=0} = -k_g\frac{\partial T}{\partial y}\bigg|_{y=0} = h_{ext}(T_{ext} - T_{y=0}) + \sigma\varepsilon(T^4_{ext} - T^4_{y=0}) \quad (6)$$

Similarly for the boundary in contact with the internal ambient can be represented by

$$q_{y=b} = -k_g\frac{\partial T}{\partial y}\bigg|_{y=b} = h_{int}(T_{y=b} - T_{int}) + \sigma\varepsilon(T^4_{y=b} - T^4_{int}) \quad (7)$$

The indoor and outdoor convection heat transfer coefficients are assumed as 8.3 and 16.7 W/m K, respectively [6]. In the case of transient conditions, the total heat gain can be calculated by the following energy balance as

$$\mathrm{THG} = \frac{1}{n\Delta x}\sum_{i=1}^{n} h_{int}\Delta x(T_{i,m+1} - T_{int}) + \sigma\varepsilon_i\Delta x(T^4_{i,m+1} - T^4_{int}) + \tau I_q \Delta x \quad (8)$$

where the subscript i refers to a given element of the grid in the x-direction of the internal surface of the glass sheet. The sum of the energy balances over each element permits calculating the total heat gain (THG).

3.1.1. The numerical solution

The mathematical model represented by the two-dimensional transient energy equation with radiation/absorption in the internal domain is solved by the finite difference approximation and an implicit scheme. The discretization domain involving the glass sheet is divided into n intervals along the x-direction and m intervals along the y-direction. The equations for the internal points of the domain are obtained by discretizing Eq. (3). While the equation for the points on the frontier are obtained by energy balance involving the point on the frontiers and its neighbours. The discretization of the system of equations utilizes the alternating direction implicit (ADI) scheme in which the equations are discretized at the