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A steady heat transfer model of hollow double glazing under entire wave length heat radiation

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ABSTRACT

This paper presents a mathematical model of heat transfer between inside room surfaces and the outside environmental surface through hollow double glazing. It includes convective heat transfer on the inside and outside surfaces of hollow double glazing, the conduction heat transfer between the two glass sheets, and the radiation heat transfer (solar and long-wave radiation) through the sheets. Based on the total heat transferred through hollow double glazing, effective transmittance is identified as an important parameter for indicating the effect of the transparence radiation of hollow double glazing. The model evaluated the effects of three different combinations of hollow double glazing on the overall heat flux, the effective transmittance and the solar heat gain coefficient. The heat flux increment due to the long-wave transparence radiation of glass cannot be ignored in the overall heat flux. When a single low-E film is positioned on the outer surface of the indoor-side sheet of glass, it contributes to efficient heat preservation in winter. When positioned on the inner surface of the sheet on the outdoor side, the low-E film is more effective for heat insulation and the shading of sunshine in summer.

1. Introduction

Where solar radiation and temperature difference between the inside and outside environments exist, glazing is typically a room's weakest barrier against heat transfer compared with the solid outside walls. Frequently windows are fitted with a single clear sheet of glass. Ordinary single glass sheets have little thermal resistance and consequently induce large heat gain or heat loss in hot or cold climates respectively. In order to improve energy saving, hollow double glazing has been widely used due to its excellent thermal insulation characteristics. As a result, the heat transfer characteristics of hollow double glazing have become an important area for study over the years. Most studies on hollow double glazing focus on three aspects, as described below.

The material used to make the glass is the first key aspect. Ordinary clear sheets of glass have been replaced with wave absorbing glass, low-emissivity glass, glass sheets with films or wave selective layers, and so on. The use of these special types of glass aims to reduce the levels of radiation heat transfer. Granqvist [1] has provided an overview on various transparent conductors which include applications based on spectral selectivity, angular selectivity and temporal variability (chromogenics). Leftheriotis and Yianoulis [2] conducted an experimental analysis of the characteristics and stability of different low-emissivity multiple coatings for glazing applications. Optical properties such as reflectivity, transmittance and the absorption of various selective coatings for glazing in visible and near-infrared ranges were compared and optimized by Mohelnikova [3]. Chaiyapinunt et al. [4] studied the thermal comfort offered by and the heat transmission of window glass covered with different types of films. Genaro et al. [5] presented results showing a reduction of solar heat gain using copper based thin films; a total 18% annual energy saving was obtained. Alvarez et al. [6] characterized the optical properties of coated glass in the visible and solar spectra regions, and a heat transfer model was developed to evaluate the convective heat transfer coefficient and solar heat gain coefficient (SHGC). Saeli et al. [7] performed a simulation study to reduce energy consumption in building by thermochromic glazing coatings. A combination of anti-reflection coated glass and ethylene tetrafluoroethylene (ETFE) film was introduced as a novel glazing system for greenhouses and similar buildings by Max et al. [8]. The energy saving potential of plastic profile mounted Glass–film-combination versions was 50% and 64% for the double

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Nomenclature

A	area (m^2)
E	emissivity of radiation heat flux on surface (W/m^2)
G_{g1in}	incident radiation heat flux to inside surface of glass sheet on indoor side (W/m^2)
G_{g1out}	incident radiation heat flux to outside surface of glass sheet on indoor side (W/m^2)
G_{g2in}	incident radiation heat flux to inside surface of glass sheet on outdoor side (W/m^2)
G_{g2out}	incident radiation heat flux to outside surface of glass sheet on outdoor side (W/m^2)
G_{in}	incident radiation heat flux to inside room surfaces (W/m^2)
G_{out}	incident radiation heat flux to outside environmental surface (W/m^2)
h_{in}	convective heat transfer coefficient of inside surface of glass sheet on indoor side ($W/(m^2\,K)$)
h_{out}	convective heat transfer coefficient of outside surface of glass sheet on outdoor side ($W/(m^2\,K)$)
I	solar radiation heat flux (W/m^2)
J_{g1in}	effective radiation heat flux of inside surface of glass sheet on indoor side (W/m^2)
J_{g1out}	effective radiation heat flux of outside surface of glass sheet on indoor side (W/m^2)
J_{g2in}	effective radiation heat flux of inside surface of glass sheet on outdoor side (W/m^2)
J_{g2out}	effective radiation heat flux of outside surface of glass sheet on outdoor side (W/m^2)
J_{in}	effective radiation heat flux of inside room surfaces (W/m^2)
J_{out}	effective radiation heat flux of outside environmental surface (W/m^2)
k	heat transfer coefficient ($W/(m^2\,K)$)
Nu	Nusselt number (dimensionless)
Ra	Rayleigh number (dimensionless)
q	overall heat flux with the area of double hollow glazing as the reference area (W/m^2)
q_{cg1}	conduction heat flux from inside surface to outside surface of glass sheet on indoor side (W/m^2)
q_{cg2}	conduction heat flux from inside surface to outside surface of glass sheet on outdoor side (W/m^2)
q_{cin}	convective heat flux between indoor air and inside surface of indoor-side glass sheet (W/m^2)
q_{cout}	convective heat flux between outside surface of outdoor-side glass sheet and outdoor air (W/m^2)
$q_{r\,in,g1}$	net radiation heat flux from inside room surfaces to inside surface of glass sheet on indoor side (W/m^2)
$q_{r\,g1,g2}$	net radiation heat flux from outside surface of indoor-side glass sheet to inside surface of outdoor-side glass sheet (W/m^2)
$q_{r\,g2,out}$	net radiation heat flux from outside surface of outdoor-side glass sheet to outside environmental surface (W/m^2)
$q_{\tau 1}$	net radiation heat flux through indoor-side glass sheet (W/m^2)
$q_{\tau 2}$	net radiation heat flux through outdoor-side glass sheet (W/m^2)
Q	net heat (W)
τ_{eff}	effective transmittance of hollow double glazing (dimensionless)
T	temperature (K)
X	view factor (dimensionless)

Greek symbols

α	absorbance (dimensionless)
α_{s1}	solar absorbance of indoor-side glass sheet of hollow double glazing (dimensionless)
α_{s2}	solar absorbance of outdoor-side glass sheet of hollow double glazing (dimensionless)
β	thermal expansion coefficient of gas (1/K)
γ	thermal diffusivity of gas (m^2/s)
ν	kinematic viscosity of gas (m^2/s)
ρ_s	total solar reflectance of hollow double glazing (dimensionless)
δ	glass thickness (m)
δ_f	thickness of hollow gas space (m)
τ	long-wave transmittance of glass (dimensionless)
τ_s	total solar transmittance of hollow double glazing (dimensionless)
ε	emissivity (dimensionless)
σ	Stefan–Boltzmann constant ($W/(m^2\,K^4)$)
λ	thermal conductivity of glass ($W/(m\,K)$)
λ_f	equivalent thermal conductivity of gas enclosed in hollow double glazing ($W/(m\,K)$)
λ_{gas}	thermal conductivity of dry air ($W/(m\,K)$)

Subscripts

fin	indoor air fluid
fout	outdoor air fluid
g1	indoor-side glass sheet
g2	outdoor-side glass sheet
gc1	conduction of indoor-side glass sheet
gc2	conduction of outdoor-side glass sheet
g1in	inside surface of indoor-side glass sheet
g1out	outside surface of indoor-side glass sheet
g2in	inside surface of outdoor-side glass sheet
g2out	outside surface of outdoor-side glass sheet
in	inside room surfaces
out	outside environmental surface
s	solar radiation

(ETFE-film on single side of the glass pane) and triple layer system (ETFE-film on both sides of the glass pane), respectively.

Hollow double glazing is the second key aspect. The technologies used in the hollow space between the two glass sheets have led to a change in the heat transfer characteristics of double glazing. Xamán et al. [9] carried out a numerical study in a hollow double glazing with solar control film for warm and cold climates, and the results indicated that it can reduce obviously the amount of energy gained comparing to single glazing. Noh-Pat et al. [10] analyzed and found that energy gain of a double glazing unit with a solar control film (SnS–Cu_xS) on its surface was reduced by 55% compared to a double glazing without the film. Gan [11] predicted the heat transfer coefficient of multiple glazing and the convective heat transfer coefficient of hollow space by computational fluid dynamics (CFD) technology. Ismail and Henríquez [12,13] presented a heat transfer study on windows formed by double glass sheets with natural or forced air flow between them under incident solar radiation. A conjugate heat transfer analysis based on finite difference methods was made by Orhan [14] to determine the performance of hollow double glazing taking both the conduction and convection processes into account. Inert gases and phase change material (PCM) have been used to fill the hollow space in order to reduce convective heat transfer or to realize the goal of storing and releasing heat intelligently. Rosenfeld et al. [15] developed an experimental approach to measure the light transmittance and solar energy transmittance of a double glazed window system separated by