Energy and Buildings 117 (2016) 33–43

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

The effects of transparent long-wave radiation through glass on time lag and decrement factor of hollow double glazing

Tian-Peng Wang[a,c], Liang-Bi Wang[b,c,*]

[a] School of Architecture and Urban Planning, Lanzhou Jiaotong University, Lanzhou, Gansu 730070, PR China
[b] Department of Mechanical Engineering, Lanzhou Jiaotong University, Lanzhou, Gansu 730070, PR China
[c] Key Laboratory of Railway Vehicle Thermal Engineering (Lanzhou Jiaotong University), Ministry of Education, Lanzhou 730070, PR China

ARTICLE INFO

Article history:
Received 8 May 2015
Received in revised form
11 December 2015
Accepted 5 February 2016
Available online 10 February 2016

Keywords:
Time lag
Decrement factor
Long-wave radiation transmittance
Surface combined heat transfer coefficient
Hollow double glazing

ABSTRACT

Time lag (TL) and decrement factor (DF) for a hollow double glazing have been investigated numerically with considering the long-wave radiation transmittance of glass that is small and is usually ignored according to “greenhouse effect”. The long-wave radiation transmittance of ordinary soda-lime silicate glass is selected as 0.1, the combined surface heat transfer coefficients (including convection and radiation heat transfer) of the outside and inside glazing surfaces are included in the boundary conditions of the numerical model, in which the increment of the surface radiation heat transfer coefficient of the inside and outside surfaces of the glazing ranges from 1.1 to 3.7 W/(m^2 K). By this way the transmittance effects on TL and DF shift to the effects of the combined heat transfer coefficients on TL and DF. The results show that when the transmittance is 0.1, TL and DF decrease about 3–17% comparing TL and DF without considering the transmittance; and the transmittance effects are stronger in summer than in winter. Furthermore, compared to TL and DF of thick solid walls TL of hollow double glazing is far smaller, and DF is relatively larger. Increasing air layer thickness and glass thickness can effectively increase TL and decrease DF.

1. Introduction

In order to improve energy saving of building, 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 glass material is the first key aspect. Ordinary clear sheets of glass have been replaced with wave absorbing glass sheets, low-emissivity glass sheets, glass sheets with films or wave selective layers, and so on [1–5]. The use of these special types of glass aims to reduce the levels of radiation heat transfer. Leftheriotis [1] 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 [2]. Chaiyapinunt et al. [3] studied the thermal comfort offered by and the heat transmission of window glass covered with different types of films. Genaro and Rafael [4] presented results showing a reduction of solar heat gain using copper based thin films, and a total 18% annual energy saving was obtained. Alvarez et al. [5] 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).

The configurations of the hollow glazing are 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. Inert gases and phase change material (PCM) et al. 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 [6–15]. Rosenfeld et al. [6] developed an experimental approach to measure the light transmittance and solar energy transmittance of a double glazed window system separated by argon-filled space and solar controlling film at any incidence angle. Ismail and Henríquez [7] numerically analyzed the heat transfer coefficient (*k*-value), the SHGC and the shading coefficient (SC) of double glazed panels filled with PCM. Later, Ismail et al. [8] numerically compared the thermal characteristics of glass

* Corresponding author at: Department of Mechanical Engineering, Lanzhou Jiaotong University, Lanzhou, Gansu 730070, PR China. Fax: +86 931 4956556.
E-mail address: lbwang@mail.lzjtu.cn (L.-B. Wang).

http://dx.doi.org/10.1016/j.enbuild.2016.02.009
0378-7788/

Nomenclature

A	Amplitude of periodic temperature variation (°C)
c_p	Specific heat capacity (kJ/(kg K))
h_i	Inside surface combined heat transfer coefficient (W/(m^2 K))
h_o	Outside surface combined heat transfer coefficient (W/(m^2 K))
I_s	Solar radiation heat flux (W/m^2)
q	Heat flux (W/m^2)
t	Time (s)
T	Temperature (°C)
$T_{f,i}$	Indoor air design temperature (°C)
$T_{f,o}$	Outdoor air temperature (°C)
x	Cartesian axis direction (m)
δx	The distance between control volume boundaries(m)
Δx	The distance between grid nodes (m)
Δt	Time step (s)

Greek symbols

α	Absorbance (–)
α_{s1}	Solar absorbance of inside glass sheet of hollow double glazing (–)
α_{s2}	Solar absorbance of outside glass sheet of hollow double glazing (–)
γ	Thermal diffusivity of dry air (m^2/s)
ε	Emissivity of glass surface (–)
λ	Thermal conductivity (W/(m K))
ν	Kinematic viscosity of dry air (m^2/s)
ρ	Density (kg/m^3)
σ	Stefan–Boltzmann constant, 5.67×10^{-8} (W/(m^2 K^4))
τ_g	Long-wave radiation transmittance of glass (–)

Subscripts

air	Air gap
c	Convection
d	Conduction
f	Fluid
g1	Inside glass sheet of hollow double glazing
g2	Outside glass sheet of hollow double glazing
i	Inside surface of hollow double glazing
in	Inner surface of the room
max	Maximum
min	Minimum
o	Outside surface of hollow double glazing
out	Outdoor environmental surface
r	Radiation
τg1	Long-wave transparent radiation of inside glass sheet
τg2	Long-wave transparent radiation of outside glass sheet
w, e	Control volume boundaries
W, E, P	Grid nodes

windows filled with PCM and absorbing gas. To further reduce conductive heat transfer of the hollow space, the hollow space has been emptied, and vacuum glazing has emerged. Fang et al. [9–11] have presented numerical heat transfer models for vacuum glazing and have performed experimental validation. Gan [12] predicted the heat transfer coefficient of multiple glazing and the convective heat transfer of hollow space by computational fluid dynamics (CFD) technology. Ismail et al. [13,14] 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 [15] to determine the performance of hollow double glazing taking both the conduction and convection processes into account.

The spectral characteristic of radiation is the third key aspect. Most studies have focused on controlling solar radiation heat transfer with a wave length of 0.2–3.0 μm through hollow double glazing [16–20]. A study was performed by Feuermann and Novoplansky [16] using a double glazed and tinted glass window for reducing solar heat gain. A triple glazed glass window system was adopted by Askar et al. [17], in this study the direct solar radiation heat gain from the surrounding atmosphere was reduced while allowing adequate visible light to enter the building. For energy-efficient glazing that could control the solar radiation heat gain, optical parameters, *k*-value and emissivity of different types of advanced glazing materials were studied by Clarke et al. [18]. Xian [19] proposed useful empirical correlations for calculating the *k*-value of single and double glazed windows using high long-wave reflectivity venetian blinds. Gijón-Rivera et al. [20] assessed the thermal performance of different glazing configurations including double glazing with solar control coating in cold and warm weather conditions. While, the long-wave radiation (with a wave length from 3 to 50 μm) heat transfer between the inside room surfaces and outside environmental surfaces through hollow double glazing comprises a comparatively high proportion in terms of total heat transfer, especially where there are wide differences in temperature between the inside and outside environments. Wang et al. [21,22] presented steady heat transfer models of a single sheet of glass and a hollow double glazing considering the long-wave radiation transmittance of glass.

Above mentioned reports indicate that the studies on the long-wave radiation heat transfer through glazing are limited and mainly focused on the static thermal characteristics instead of dynamic ones. The dynamic thermal parameters mainly include the time lag (TL) and the decrement factor (DF). The definitions of TL and DF can be seen in Fig. 1. They are usually expressed as followed [23,24].

$$\mathrm{TL} = t_{i,max} - t_{o,max} \tag{1}$$

$$\mathrm{DF} = \frac{A_i}{A_o} = \frac{T_{i,max} - T_{i,min}}{T_{o,max} - T_{o,min}} \tag{2}$$

Comparing to the thick solid outside walls, TL of hollow double glazing is relatively short and DF of hollow double glazing is large due to small heat storage capacity. It is believed that although long-wave radiation transmittance of the glazing is small and usually ignored according to "greenhouse effect", the transmittance should lead the changes of TL and DF. In order to evaluate the quantities of TL and DF and effect factors on them, this paper studies TL and DF of the ordinary hollow double glazing using one dimensional numerical model based on finite volume method under periodic boundary conditions.

2. Numerical methodology

The heat transfer is a periodic heat transfer process through a hollow double glazing curtain wall as the external wall of a room shown in Fig. 2. To build up the physical model, the following assumptions are made. (1) The inter surfaces of the glazing with the walls, the roof, the floor are considered adiabatic. The glazing is made up of only hollow double glass and glazing frame is ignored. (2) The sheet of glass is assumed to be a transparent diffused-gray sheet and has a uniform surface temperature. (3) The inside room surfaces are assumed to be non-transparent diffused-gray surfaces and have a single isothermal surface T_{in}. (4) The indoor air temperature is uniform $T_{f,i}$. (5) The outdoor air temperature and total