Solar Energy 155 (2017) 354–362

Contents lists available at ScienceDirect

Solar Energy

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

Effect of design configurations on water flow window performance

T.T. Chow [a], Yuanli Lyu [a,b,*]

[a] Building Energy and Environmental Technology Research Unit, Division of Building Science and Technology, City University of Hong Kong, Hong Kong
[b] School of Energy and Environment, Inner Mongolia University of Science and Technology, China

ARTICLE INFO

Article history:
Received 23 September 2016
Received in revised form 7 May 2017
Accepted 18 June 2017

Keywords:
Water flow window
Cavity thickness
Height to width ratio
Header design

ABSTRACT

Water flow window has very good application potential in zero carbon buildings of the warm climate. In this study, the effects of water-flow window configurations were investigated, such as the water layer thickness and glazing height-to-width ratio (GHTWR). The effects of distribution header design on the thermal and flow characteristics were also analyzed. Its long-term dynamic thermal performance was examined through a self-developed simulation program, of which the FORTRAN code was previously validated through comparison with experimental data. In the current study, the one-dimensional thermal simulation modelling approach was further justified through CFD analysis. Then the overall thermal performance of the window system was evaluated from the aspects of useful water heat gain and the impact on space air-conditioning power consumptions. A water layer of thickness around 15–20 mm and a GHTWR of 0.4 were found desirable for the tested cases. While the size and distribution of the header openings would affect the localized water flow and temperature distribution, their effect on the laminar upward flow and the final temperature rise is not significant.

1. Introduction

How to make full use of solar energy in order to reduce carbon emission and its global impact on climate change has been receiving worldwide attention. Window glass, a favorable component on the building facade for daylight acquisition but a weak component in terms of heat insulation, plays a significant role. High thermal transmittance is favorable in cold climate but not the case for hot climate applications (Gasparella et al., 2011). With the adoption of advanced glazing, space thermal loads and consequently the building energy consumption could be reduced, whereas the visual comfort would not be affected (Clarke et al., 1998). Examples like reflective, electrochromic, thermochromic and photovoltaic glass panes have been well developed and widely available in the market for single glazing technologies (Gorgolis and Karamanis, 2016). For multi-glazing designs, the developments of window cavity from air-sealed to vacuum (Collins and Simko, 1998) or as the ventilating air stream (Chow et al., 2009) contribute to increase further the thermal resistance of the window system for energy efficiency enhancement. However, the adoption of renewable energy system is essential when coming to zero carbon building design.

It is for the above rationale that the novel idea of "multi-glazing water flow window" has been proposed. Since the introduction in 2010 (Chow et al., 2010), this technology is now under the development of several research teams. One current system design is illustrated in Fig. 1. By means of either natural or mechanical power, water flows in a closed circuit composed of window cavity, two headers (at the top and bottom ends of the cavity respectively), and a heat exchanger (where solar heat energy is finally transferred to the cold water stream, like one serving the domestic hot water systems).

The heat exchanger can be placed either locally within the window frame as in Fig. 1, or remotely within a centralized station that serves all windows. A centralized heat exchanger and pumping station will simplify the window structure, but will exert high working pressure on window glass and thus requires stronger glass panes; this is less favorable for large scale application.

The innovative water-flow window system is superior to the conventional multi-glazing systems from at least two aspects: (i) high reduction in solar heat transmission but low visible-light screening effect; and (ii) useful water heat gain as a renewable energy device. Gonzalo et al. found that in Spain the temperature level of a non-air-conditioned room installed with water flow window could be 17 °C lower than the one with traditional air-sealed window (Gonzalo and Hernandez Ramos, 2016). As a matter of fact, the heat extraction efficiency varies with the flow rates of both the hot and cold streams. Based on an application case in Hong Kong

---

* Corresponding author at: Inner Mongolia University of Science and Technology, Aer Ding Street 7, Bao Tou, Inner Mongolia, China
E-mail address: Lvyuanli1108@126.com (Y. Lyu).

http://dx.doi.org/10.1016/j.solener.2017.06.050

Nomenclature

C	specific heat capacity, J/(kg·K)
I	unit tensor
k	thermal conductivity, W/(m·K)
p	pressure, Pa
S	heat source, W/m^3
$\overline{\overline{T}}$	stress factor, –
T	temperature, °C
t	time, s
u	water flow velocity, m/s
x	coordinate, m
Greek	
ρ	density, kg/m^3
μ	kinetic viscosity, kg/(m·s)

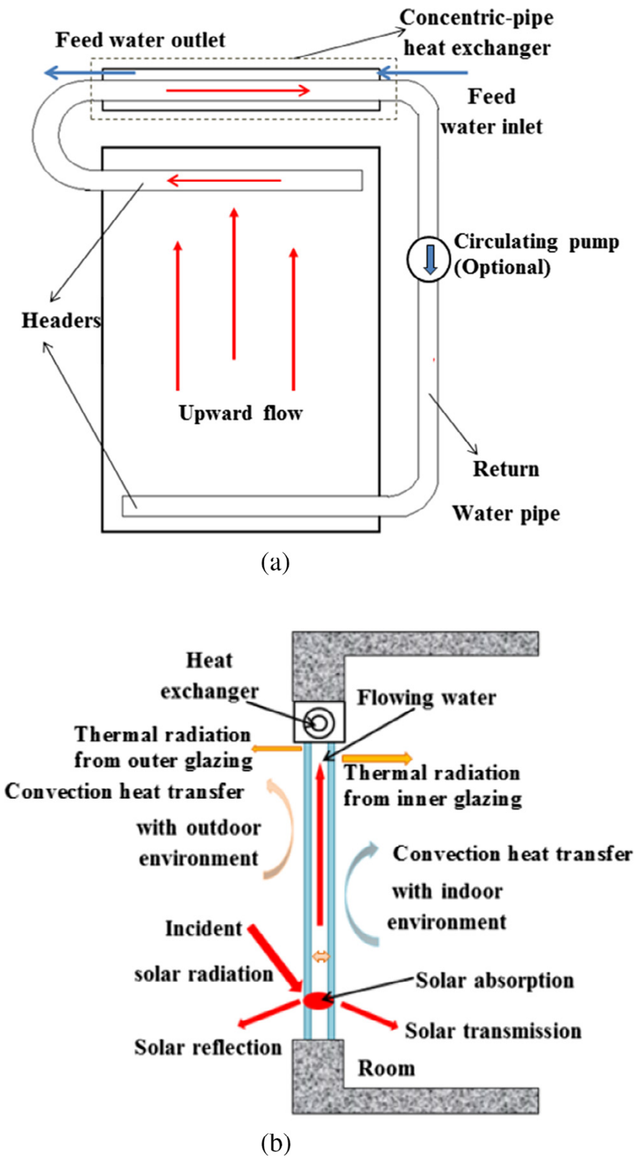

Fig. 1. Water flow window: (a) front view showing the water circuit; (b) side view indicating the energy flow paths.

(Chow et al., 2012, 2011a; Li and Chow, 2011), the heat gain efficiency was found in the range of 20–37% with the change in water flow rate, and the reductions in annual cooling loads reached 32% and 52% respectively as compared to the traditional double and single glazing systems. Based on an application in Spain, Tomas and Carmen found that the energy consumption for heating and cooling was reduced by 18% and a more stable room temperature was achieved by circulating warm water in the water cavity (Tomas and Carmen, 2013a, 2013b). All these show that this innovative technology highly favors the development of zero carbon buildings.

In fact, there can be further advancement of this new technology to suit different applications. For example, the presence of the water-filled tubing and liquid volume increases the overall weight of the window. This adds difficulties to the construction site installation and future replacement tasks, as well as increases the imposed loads on the building structure and the overall investment costs. The importance of proper window structure design for good energy performance has been pointed out in related research articles (Ma et al., 2015; Goia, 2016). On the other hand under the forced flow scheme, the water flow velocity in cavity affects much the thermal efficiency, especially at low flow rates (Chow et al., 2011b). The solar heat gain coefficient (g) of the glazing system is related closely to the water flow rate. While a stagnant water layer will result in maximum g value, adequate water flow is able to reduce the energy transfer both inwards and outwards (Sierra and Hernández, 2017). Accordingly, an active multi-glazing liquid flow window module with an adjustable central liquid layer was proposed, in that the liquid flow rate and layer thickness were controlled to maintain the visual transparency but minimize the thermal transmission (Villasante et al., 2013). Besides, geographical factors like the sun path and solar intensity are amongst the key influencing factors on thermal performance, so are the major dimensions of the window components (Lampert, 1998; Pérez-Grande et al., 2005; Persson et al., 2006).

From the above, one can observe that the research works in the past were more or less focusing on studying the impact of external influencing factors or major operating parameters on the window system performance. Very few were evaluating the window component design and configuration in details. Presented in this article are our investigations on the effects of a number of window configurations based on the buoyant flow design principle.

2. Research methodology

The thermal performance of the window system was evaluated numerically considering three influencing configurations: (i) water layer thickness, (ii) glazing height-to-width ratio (GHTWR), and (iii) distribution header design. Generally speaking, the thermal and environmental performances of the glazing systems can be investigated by means of both experimental and numerical methods. Computer simulation has been widely adopted in the related performance prediction and analysis. In the work of Pal et al. (2009), FORTRAN computer code was developed to determine global radiation components and thermal response at window surfaces. The simulation results were found in good agreement with experimental measurements. In this current study, one-dimensional water flow in the window cavity was assumed in developing our thermal simulation model, since laminar flow was expected under the buoyance driven force. The same as before,