Applied Thermal Engineering 92 (2016) 8–17

Contents lists available at ScienceDirect

Applied Thermal Engineering

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

Research Paper

Modeling and thermal performance evaluation of a switchable triple glazing exhaust air window

Chong Zhang, Jinbo Wang *, Xinhua Xu, Fuxi Zou, Jinghua Yu

Department of Building Environment and Energy Engineering, Huazhong University of Science & Technology, 1037 Luoyu Road, Wuhan 430074, China

HIGHLIGHTS

- A new concept of switchable exhaust air insulation window is proposed.
- Zonal model is developed and validated by comparison with the measured data reported in a published literature.
- Temperature difference between the interior surface of window and the indoor air can be reduced.
- This window performs dramatically better than other conventional windows in both heating and cooling seasons.

ARTICLE INFO

Article history:
Received 30 October 2014
Accepted 12 September 2015
Available online 3 October 2015

Keywords:
Exhaust air window
Heat transfer
Thermal performance
Numerical modeling
Building energy efficiency

ABSTRACT

A concept of switchable triple-glazing exhaust air (SEA) window is proposed. The window is characterized by two air cavities with one being a ventilation channel for exhausting indoor air to the ambient. The other cavity is enclosed and, together with the adjacent two glass panes, acts as a conventional double-glazing unit. Venetian blinds are imbedded in the ventilation cavity which is located to the outer side in summer and is switched to the inner side in winter. Such a design makes the window able to reduce its heat loss/gain by utilizing the heat/coolth inherent in the exhaust air. An unsteady state numerical zonal model is developed and validated by comparison with the measured data reported in a published literature. The model is used to calculate the temperatures of the glass layers for evaluating the hourly thermal performance of window. Numerical simulations are carried out to investigate the SEA window, double and triple glazing window at a hot-summer and cold-winter city. Simulation results show that, in comparison with the double and triple glazing windows, the SEA window reduces 73.5% and 71.9% of the heat gain in summer, respectively, and 74% and 46.8% of the heat loss in winter, respectively. Further analysis reveals that the advantageous performance of the SEA window pertains to other orientations. A discussion on the difference of using steady state model and unsteady state model for the window is included.

1. Introduction

Window plays important roles in buildings. Its primary functions include natural lighting, outdoor view, and outdoor air supply [1]. Associated glazing separates indoor space from ambient for proper indoor environment when ambient condition is unfavorable. Large glazed windows and even glazing curtain wall are frequently designed in modern buildings. Main considerations may be the aesthetic effect of the buildings, better occupant visual comfort, and so on. However, such an architectural preference tends to result in adverse effect to building energy efficiency since the glazing is the weakest insulation of building envelope components. A study showed that up to 60% of the total energy loss through building envelope can be due to windows [2]. Efficient windows should lead to less heat gain in summer and less heat loss in winter.

An energy efficient window is supposed to have high thermal insulation and should be controllable against varying solar radiation [3]. A well insulated window reduces the unwanted conductive heat loss/gain resulting from the temperature differential across the window glazing. A reasonably controlled window allows less solar gain in summer but more in winter into building, in response to varying weather conditions and occupant preferences [4,5]. Many developers and researchers have devoted great efforts on the investigation and development of window technologies focusing on the two beneficial properties.

Typical highly insulating window technologies include vacuum glazing [6], aerogel glazing [7], and etc. While allowing visible light to pass, these windows provide extremely low U-value, and consequently, result in low heating/cooling load. At the same time there exist other approaches for load reduction, for example, the exhaust

* Corresponding author. Tel.: +86 13212756863; fax: +86 27 8779 2101.
E-mail address: jbwang@mail.hust.edu.cn (J. Wang).

http://dx.doi.org/10.1016/j.applthermaleng.2015.09.080
1359-4311/

air window [8]. Such a window is usually multiple-glazed and allows the exhaust air flow through the in-between cavity. This makes the temperature at the glass pane close to that of indoor (exhaust) air [9], and the equivalent effect is a low U-value. Similar philosophy may also be found in the water flow window, ventilated window, and mechanically ventilated double skin facade [10–12].

Several studies [13–15] have shown the advantageous energy performances and thermal comfort of the exhaust air window. Further improvement can be achieved by using tinted glass at the exterior pane for cooling season since more solar heat will be absorbed there and be removed by the exhaust air [9]. Such a window is, however, unsuitable for heating season due to the fact that more solar heat is better allowed into the building.

Mechanically ventilated double skin facade (DSF) developed in past is similar to the high performance exhaust air window. Mechanically ventilated DSF is a structure of triple glazing, with an enclosed double-glazing at the outer side [12]. The cavity between this double-glazing unit and the innermost single glazing is used for ventilating the exhaust air. Movable venetian blinds may be included in the air cavity for further performance improvement on the reduction of solar heat gain in cooling season [16]. In winter, the DSF helps to further reduce the conductive heat loss when sunlight is available [17,18]. Such a DSF of fixed glazing structure may, however, increase the cooling load in summer. When solar radiation is strong, the blinds absorb large quantity of heat and make the cavity temperature high. Due to the poor thermal resistance of the inner single glazing, the high temperature in the cavity will result in high heat flux into the room side, and thus increasing the cooling load. Water-flow window, proposed by Chow et al. [9,10], has the similar function to carry away the heat gain at the window to reduce the cooling load in building. The window can also act as a hot-water preheating device in summer. However, use of the water-flow window may be problematic in heating dominated buildings.

Technologies are also being developed for the dynamic control of solar radiation to reduce solar heat gain in summer or to enhance the use of the solar energy in winter, while allowing adequate daylighting and visual comfort by modulating glass optical properties. Advanced examples include electrochromic, thermochromic, liquid crystals, and suspended-particle windows [19,20]. A relatively simple means is the use of the so-called blinds window [21,22] which includes and actively controls venetian blinds enclosed inside the double-glazing panes. The main consideration is to block solar heat gain before it enters building. But the heat trapped inside the enclosed panes may cause dramatic temperature rise, leading to the increase of convective heat gain. Compared to conventional interior shading, blinds window yields only slightly better solar heat gain rejection in summer.

Window can also be taken as a heat recovery device for good energy performance. Supply air window for winter use allows outdoor air flow into building through the cavity of a double pane window [23,24], and the incoming outdoor air is preheated by the outgoing conductive heat and part of solar heat gain absorbed by the glass. Triple-glazing dual airflow window for residential buildings, proposed by Gosselin and Chen [25], employs small supply and exhaust fans. Outdoor air incoming through one of the cavities gets preheated by the exhaust air outgoing through the other cavity. Exhaust air heat can thus be recovered, achieving excellent energy efficiency while good air quality is guaranteed.

This paper proposes a switchable triple glazing exhaust air (SEA) window (refer to Fig. 1) which utilizes the heat/coolth of exhaust air from conditioned rooms to directly reduce the temperature difference between the interior surface of window and the indoor air [26,27]. The window consists of two air cavities. One is used as exhaust air flow way, the other is enclosed acting as a commonly seen double-glazing unit. Blinds is adopted and placed in the air flow cavity. The air flow way can be switched from the outer channel (for cooling mode) to the inner one (for heating mode). The enclosed cavity is at the outer side in winter, but at the inner side in summer. Such a window design allows more solar gains into room in winter, while reject more solar heat gain in summer.

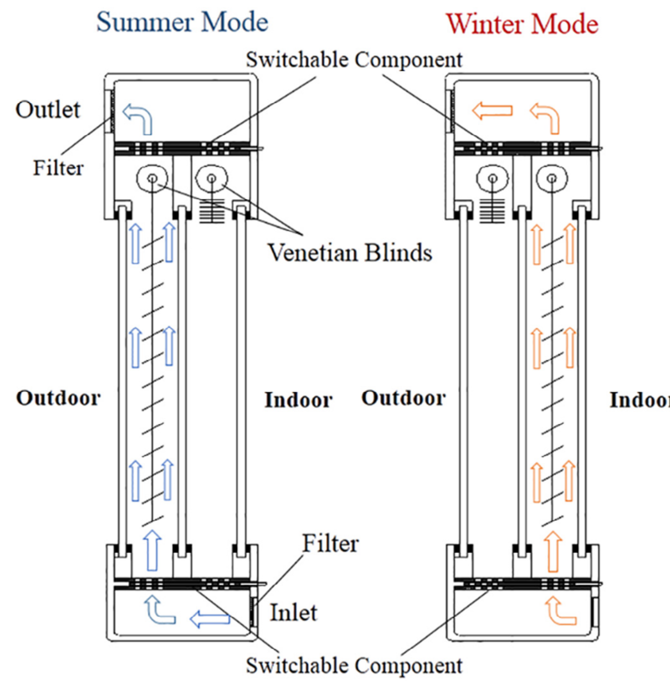

Fig. 1. Schematic of the conceptual structure of the SEA window.

An unsteady state numerical model is proposed to analyze the hour-based thermal performance of the SEA window. For validation, modeling results are compared with the experimental data from published literature and the calculation results by open software (WINDOW). Simulation is carried out to compare the thermal performance of the SEA window with that of the commonly used double and triple glazing windows.

2. Conceptual structure and insulation mechanism

Fig. 1 shows schematically the conceptual design of the proposed switchable exhaust air window. It consists of three glass panes, two air cavities, and two movable venetian blinds. One of the two cavities hosts venetian blinds and also serves as ventilation channel for exhaust air flowing to outdoor environment. The other cavity can be enclosed with appropriate switchable structure components and, together with the two adjacent glass panes, acts as a double glazing. Fig. 2 shows an example of the upper and lower switchable components that enable the exhaust air flow in different cavities. In summer mode, the airflow channel hosting the venetian blinds is at the outdoor side, and it can be switched to the indoor side in winter mode. The force driving the exhaust air through the ventilation channel may be the positive pressure due to fresh air supply system, or the differential pressure due to specifically designed mechanical exhaust system [25]. Such a window system may be considered as an exhaust air heat recovery device in HVAC system.

The enclosed cavity, the blinds and the exhaust airflow constitute the insulation function of the window. The enclosed cavity is just like the commonly employed double glazing with higher thermal resistance compared to single glazing. The blinds serve as the shading device to reduce the solar heat gain in summer and to avoid glare in winter. The insulation function of the exhaust airflow is not so strictly direct, and the detailed mechanism is different in different modes.