International Conference on Applied Energy 2019
Aug 12-15, 2019, Västerås, Sweden
Paper ID: 483

STUDY ON THE SENSITIVITY OF ZONAL MODEL FOR EVALUATING THE THERMAL PERFORMANCE OF VENTILATED WINDOW

Chong Zhang, Wenjie Gang, Liao Li, Jinbo Wang*

School of Environmental Science and Engineering, Huazhong University of Science and Technology, Wuhan, PR China

ABSTRACT

The ventilated exhaust-air window provides an approach to combine the window system with exhaust air heat recovery. This new window can act as a heat exchange to recover the heat or cold of the exhaust-air to mitigate the heating or cooling load of the window. The zonal model is a reliable method to analyze the two-dimensional heat transfer of the ventilated exhaust-air window. However, the optimal subsection number of the zonal model for evaluating the thermal performance of the ventilated exhaust-air window has not been identified. In this study, a sensitivity analysis is carried out to estimate the effect of the subsection number on the simulation results of zonal model, and to identify the suitable and recommended subsection number for the numerical modeling of the ventilated exhaust-air window. The results indicated that reducing the subsection number in vertical direction will lead to a higher calculation deviation. In current case studies, the subsection number of 10 for the zonal modeling can zonal model can predict the thermal performance of the ventilated exhaust-air window with promising accuracy, while spending less computation time.

Keywords: ventilated window, zonal model, sensitivity analysis, heat recovery, building energy efficiency

NONMENCLATURE

Abbreviations	
VEW	Ventilated exhaust-air window
VDSF	Ventilated double skin facade
Symbols	
M	Number of subdivided sections

1. INTRODUCTION

In recent years, the advanced windows have been widely investigated, in terms of increasing the thermal insulation [1], controlling the solar heat gain [2], or coupling with the natural energy [3]. In addition, there exists a heat recovery window system, which can act as a heat exchange to recover the heat or cold of the exhaust-air to mitigate the heating or cooling load of the window. Such a window system can be called as the ventilated exhaust-air window (VEW) [4-6]. The exhaust-air can flow through the gap between the glass panes, and then the conduction heat gain in summer or heat loss in winter would be removed or reduced by the flowing air. The VEW as well as the exhaust air insulation wall [7,8] can achieve the building energy-efficiency, reduce the energy demand in buildings, and provide the good thermal comfort.

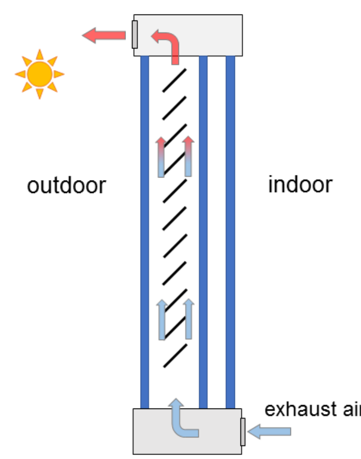

Fig 1 Schematic of ventilated exhaust air window (VEW)

The researchers conducted experimental tests and numerical simulations of the VEW and ventilated double skin façade (VDSF) and found that two-dimensional zonal model can reliably and effectively predict the thermal performance of the windows. For instant, Jiru and Haghighat [9] presented the application of zonal approach for modeling the VDSF. The model was verified by experimental measurements. A more detailed zonal model has been developed by Zanghirella et al. [10] to simulate the thermal performance of mechanically VDSF in both steady-state and unsteady-state conditions. An experimental test has been performed to validate the proposed model on a real DSF under actual operating conditions. Takemasa et al. [11] also proposed a zonal model for evaluating the thermal performance of VEW and VDSF. Results showed that such a model can reproduce the experimental measurements reasonably well.

The two-dimensional zonal modeling subdivides the VEW into several equal sections along the vertical direction, and can be treated as an intermediate method between the fully detailed CFD model and one-dimensional simplified model. However, the number of the subdivided sections may impact the accuracy of numerical simulation results. It is necessary to investigate how the simulated results are sensitive the number of the subdivided sections and to identify the minimum recommended number of the subdivided sections. In this paper, the effect of the subsection number on the simulated outlet air temperature and inner glass pane temperature of the VEW are quantitatively estimated. The optimal subsection number is recommended.

2. DEVELOPMENT OF ZONAL MODEL

The zonal model is employed to analyze the two-dimensional heat transfer of the VEW (as shown in Fig. 2). The VEW is discretized into *M* equal subsections and 7 layers in the vertical and horizontal direction, respectively. Each subsection contains 7 layers, which represents the triple glazing, venetian blinds, two airflow cavities at each side of venetian blinds, and enclosed air cavity. Therefore, a total of 7×*M* zones can be obtained for the entire VEW. Based on the energy and mass balance, the governing equation of each zone can be established by considering the effect of solar radiation absorption, long-wave radiation, and convection.

The detailed information about the development of the zonal model for evaluating the thermal performance of the VEW can be found in our previous studies [4]. It should be noticed that the subsection number in vertical direction may directly affect the calculation accuracy as well as the computation time of the zonal model. A larger subsection number will lead to a higher accuracy, but consume longer computation time. Therefore, the suitable subsection number for numerical calculation should be identified.

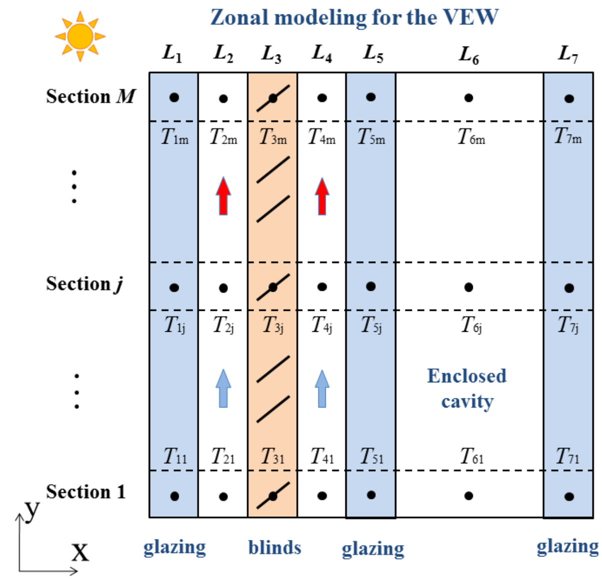

Fig 2 Developement of zonal model of VEW

3. MODEL VALIDATION

An experiment platform of the VEW was proposed for analyzing its heat transfer process and thermal performance. To validate the two-dimensional zonal model, the calculation results have been compared with the measured data in our previous study. The

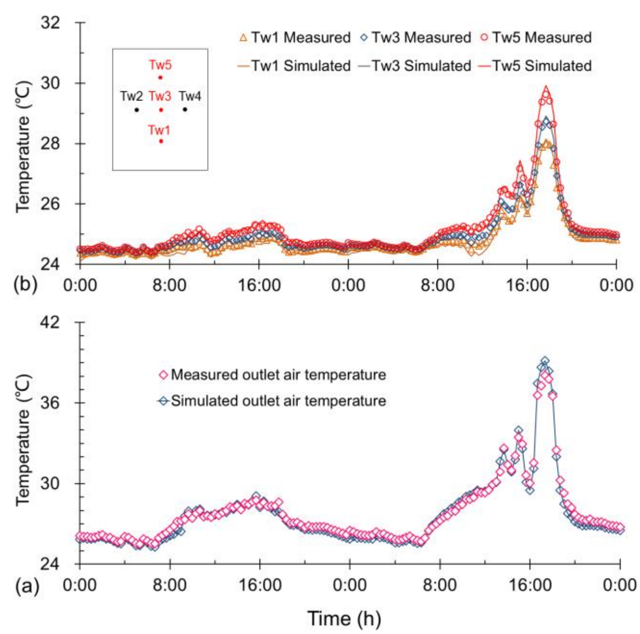

Fig 3 Comparion of zonal modeling and experiment test: (a) inner glass pane temperature; (b) outlet air temperature

experiment setup, test sample, measurement facilities, and measured boundary conditions can be found in Ref. [4]. The comparison of the numerical modeling and experiment measurement is presented in Fig. 3. It can be concluded that the two-dimensional zonal model can evaluate the thermal performance of the VEW with good accuracy.

4. SENSITIVITY ANALYSIS OF ZONAL MODEL

4.1 Simulation condition

In this study, a sensitivity analysis is carried out to quantitatively estimate the impact of the subsection number (*M*) on the calculated outlet air temperature and inner glass pane temperature of the VEW under a typical summer day. The thicknesses of the three glass panes and two air cavities are 6 mm and 30 mm, respectively. The angle is kept at 45 degree for the venetian blinds. The exhaust-air rate in the ventilation channel is set to 0.3 m/s. The indoor temperature is 25 ^{o}C, and the outdoor weather conditions are presented in Fig. 4. In this paper, six different subsection numbers are considered for sensitivity analysis (*M* = 1, 3, 5, 10, 20, 50).

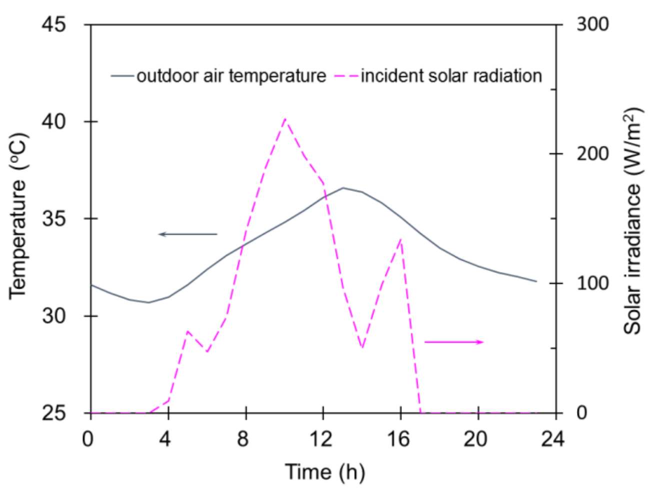

Fig 4 Outdoor weather conditions for sensitivity analysis

4.2 Results and Discussion

The zonal model can be treated as an intermediate method between the fully detailed CFD model and one-dimensional simplified model (*M*=1). Such a model can therefore provide information on flow and heat transfer characteristics of the VEW faster than CFD model, but with more accuracy and detail than one-dimensional simplified model (*M*=1). But, the number of subsections (*M*) in zonal model may directly affect the calculation accuracy and the computation time.

Fig. 5 and Fig. 6 show the effect of the subsection number on the simulated inner glass pane temperature and outlet air temperature of the VEW, respectively. It can be found that the differences between the simulated inner glass pane temperatures and outlet air temperatures for zonal model with different subsection numbers are very apparent. Reducing the number of subsection will increase the calculation deviation. When the subsection number is increased from 1 to 3, or from 3 to 5, an evident variation of the simulated inner glass pane and outlet air temperatures of the VEW can be observed. Moreover, further variation of the simulation inner glass pane and outlet air temperature is very limited as the subsection number is increased from 10 to 20. In current case studies, it seems that when *M*=10,

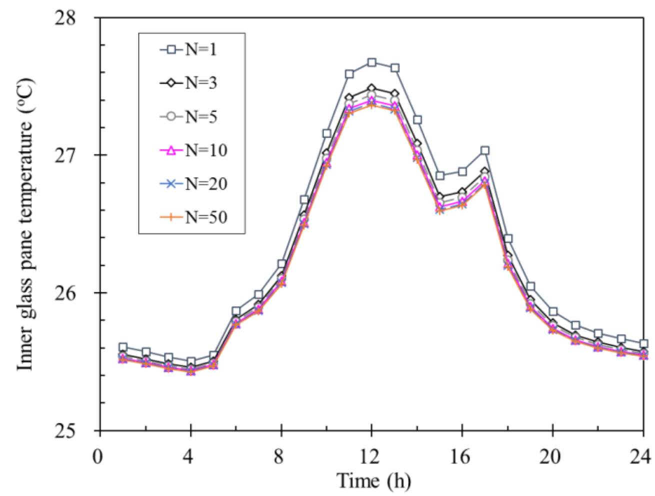

Fig 5 Effect of subsection number on the simulated inner glass pane temperature of the VEW

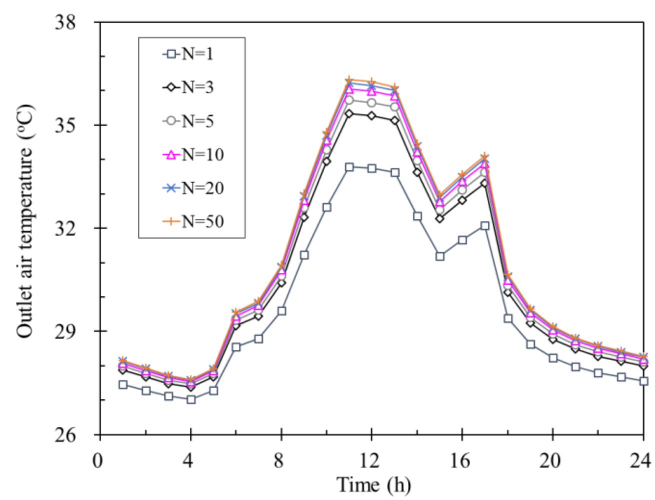

Fig 6 Effect of subsection number on the simulated outlet air temperature of the VEW

the zonal model can predict the temperatures of the VEW with promising accuracy, while spending less computation time. However, it should be noticed that such a recommended *M* may be affected by several factors, such as the exhaust-air rate in ventilation cavity and size of the VEW.

5. CONCLUSIONS

The zonal model is a reliable approach to simulate the two-dimensional heat transfer of the VEW. However, the number of the subdivided sections along the vertical direction may affect the accuracy of numerical simulation results. In this study, a sensitivity analysis has been carried out to estimate the effect of this subsection number on the simulated results the VEW. The results show that reducing the subsection number along the vertical direction will lead to a higher calculation deviation. In current case studies, the subsection number of 10 is recommended which can guarantee the calculation accuracy and also reduce the computation time.

ACKNOWLEDGEMENT

The study in this paper is funded by the research grants of the National Natural Science Foundation of China (Grant No. 51808239) and China Postdoctoral Science Foundation (Grant No. 2018M640702).

REFERENCE

[1] Chen YM, Xiao YL, Zheng SQ, Liu Yang, Li YP. Dynamic heat transfer model and applicability evaluation of aerogel glazing system in various climates of China. Energy 2018; 163: 1115-1124.

[2] Baetens R, Jelle BP, Gustavsen A. Properties, requirements and possibilities of smart windows for dynamic daylight and solar energy control in buildings: A state-of-the-art review. Sol Energy Mat Sol Cells 2010; 94: 87-105.

[3] Shen C, Li XT, Yan S. Numerical study on energy efficiency and economy of a pipe-embedded glass envelope directly utilizing ground-source water for heating in diverse climates. Energy Convers Manag 2017; 150: 878-889.

[4] Zhang C, Gang WJ, Wang JB, Xu XH, Du QZ. Experimental investigation and dynamic modeling of a triple-glazed exhaust air window with built-in venetian blinds in the cooling season. Appl Therm Eng 2018; 140: 73-85.

[5] Zhang C, Gang WJ, Wang JB, Xu XH, Du QZ. Numerical and experimental study on the thermal performance improvement of a triple glazed window by utilizing low-grade exhaust air. Energy 2019, 167: 1132-1143.

[6] Zhang C, Wang JB, Xu XH, Zou FX, Yu JH. Modeling and thermal performance evaluation of a switchable triple glazing exhaust air window. Appl Therm Eng 2016; 92: 8–17.

[7] Wang JB, Du QZ, Zhang C, Xu XH, Gang WJ. Mechanism and preliminary performance analysis of exhaust air insulation for building envelope wall. Energy Build 2018; 173: 516-529.

[8] Zhang C, Gang WJ, Xu XH, Li L, Wang JB. Modelling, experimental test, and design of an active air permeable wall by utilizing the low-grade exhaust air. Appl Energy 2019; 240: 730-743.

[9] Jiru TE, Haghighat F. Modeling ventilated double skin façade-A zonal approach. Energy Build 2008; 40: 1567–1576.

[10] Zanghirella F, Perino M, Serra V. A numerical model to evaluate the thermal behaviour of active transparent facades. Energy Build 2011; 43: 1123–1138.

[11] Takemasa Y, Togari S, Miura K, Katoh M, Hiraoka M, Owada J. Evaluation of calculation models for predicting thermal performance of various window systems. ASHRAE Trans 2013; 119: 22–42.