CALCULATION AND ASSESSING NATURAL VENTILATION IN A SINGLE OPENING OFFICE ROOM WITH DIFFERENT WINDOWS IN THE REGIME OF HOT SUMMER AND COLD WINTER

Fang Ruan[1,2], Nianping Li[1,*], Jibo Long[1,2]

[1] College of Civil Engineering, Hunan University, Changsha, 410082, China
[2] School of Civil Engineering & Mechanics, Xiangtan University, Xiangtan, 411105, China

ABSTRACT

Driven by both wind and thermal, natural ventilation of a single opening office with three different windows, side-hung window, sliding window and a new type window, is studied by CFD simulation, where outdoor wind speeds, outdoor wind directions and outdoor temperature were all taken into account. The study demonstrates that when the area of single opening is the same, the new type of window could better adapt outdoor wind directions and induce more outdoor wind into office. Nevertheless, thermal comfort was assessed and compared on the same building conditions in the regime of hot summer and cold winter. The results can be used as a reference guideline for natural ventilation design, the improvement and popular application of the new-type window in the regime of hot summer and cold winter.

KEYWORD: Natural ventilation; CFD simulation; Single opening; The regime of hot summer and cold winter

1. INTRODUCTION

Natural ventilation can directly induce outdoor fresh air into an indoor space, to improve indoor air quality and solve health problems such as sick building syndrome (SBS). In addition the importance of natural ventilation is being more widely recognized as a means to reduce energy consumption and associated environmental pollutant emissions. Thus an increased effort is being made to increase the use of natural ventilation in modern buildings.

In fact, there are many rooms with a single opening, or rooms that have such a large depth that they should be regarded only a single opening. Moreover, as a result of the highly variable complexity of outdoor air parameters, how to better induce more outdoor air into indoor spaces is the key, especially for rooms with a single opening. Based on three patents, a new type of window, different from side-hung and sliding window, has been designed.

On the other hand, the climate of China is extremely diverse and variable with a tropical climate in the south and a sub-arctic one in the north. The design codes are also different for the five thermal zones. This paper assesses the natural ventilation cooling potential for office

[*] Corresponding author email: linianping@126.com

buildings in Changsha, the regime of hot summer and cold winter in China.

CFD simulation combines climate information and building information to perform a detailed assessment of natural ventilation. Usually, the thermal and the CFD simulation program are applied to calculate simultaneously and perform detailed indoor and outdoor airflow, therefore it is very useful and adequate for strategic natural ventilation design.

Through experimental testing and CFD simulation their characteristics under natural ventilation were studied. Based on my earlier work [2010, 2012]: a multi-sash mid-pivoted "**folio**" window with vertical deflectors was studied, and wind-driven natural ventilation for four different windows placed in a single room opening was compared, and refer to the method of Runming Yao (2009), FLUENT, a CFD software, was used to research on both wind and thermal driven natural ventilation in a single opening office room.

2. DESCRIPTION OF THREE TYPES OF WINDOWS

Three types of windows, side-hung window, sliding window and up-down Folio window, respectively called window 1, window 2 and window 3 for short in this article, were installed in the same opening and studied by CFD. The sashes of window 1 and window 2 were all made of 5mm thickness of reinforced glass, while window 3 was constructed of 8mm thickness of reinforced glass, out of bigger width than conventional windows. Their structures are as follows and shown in Table 1.

Table 1 *Figures and description of window types 1, 2 and 3*

Window types	**Side-hung window**	**Sliding window**	**Up-down folio window**
Figures			
Description	three sashes of 0.5m (Width (W)) × 1.5m (Height (H)) and all outward vertical to opening	two sashes of 0.75m (W) ×1.5m (H), and both placed in the centre of opening	four sashes of 0.75m (W) × 0.75m (H), the two top glazed sashes were opened to the right 45° and the two bottom glazed sashes were opened to the left 45°.

3. MODEL BUILDING AND PARAMETER SETTING

3.1 Geometry Model and Effect Factors

In the model, a room of size 3m (X, length) × 6m (Y, width) × 3.6m (Z, height) was considered with an opening of 1.5m (W)×1.5m (H) square, in the middle of façade, at 1 m above the floor, and there were two adjoining office tables of 1.4m (L) × 0.7m (W) × 1m (H) in the centre of the office. Each window type was represented in this opening. In order to study the effects of opening and the interaction between different flow modes, the conditions for the opening could not be assumed beforehand. In order to correctly analyze airflow around the window and inner space, the outdoor computational domain included a space of 30m (X) ×30m (Y) × 30m(Z) around the opening (YOU Shi-jun, 2007), as shown in Figure 1. The method of grid generation was the same as the earlier work (2010, 2012).

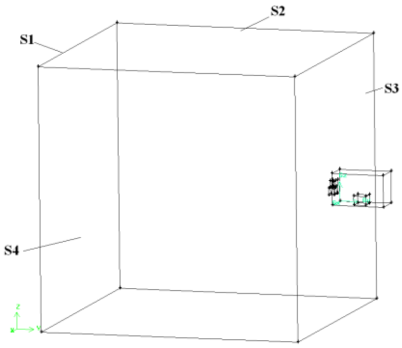


Figure 1 *Geometry Model*

In this study, natural ventilation was assumed to be forced both by wind and thermal pressure. Thus mainly outdoor wind speeds, wind directions and temperature influence on the performance of ventilation, and they were set as follows (Ruan Fang 2012): (1) The outdoor wind speed was 1m/s, 2m/s and 3m/s. (2) The outdoor wind direction, defined as *S*, was 0°, 22.5°, 45°, 67.5°, 90° (Nien-Tsu Chen, 2007). (3) Acceptable operative temperature ranges for natural conditioned spaces showed in Figure 2, is used to assess the cooling potential of natural ventilation. In the regime of hot summer and cold winter, take heat sources into account, outdoor temperature was 15℃, 20℃ and 25℃.

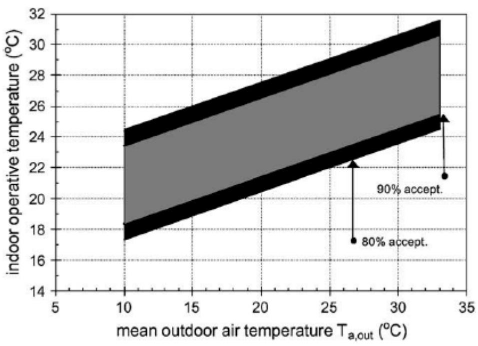


Figure 2 *Acceptable operative temperature ranges for naturally conditioned spaces.* (ASHRAE 2004)

According to the three impact factors as above, all models were simulated to calculate on all conditions.

3.2 *Basic Hypotheses and Turbulence Model*

In this research, FLUENT 6.2 was used to simulate and calculate indoor and outdoor airflows, and according to Wang Fujun (2004) some basic hypotheses were as follows: the north was the

+Y direction, and the lowest point in northwest of building was the origin; RNG *k*-ε and the Boussinesq density model; standard wall function in near-wall treatment; SIMPLE in pressure-velocity coupling of solution controls and default under- relaxation factor.

3.3 *Boundary Conditions*

All of boundary conditions applied are shown in detail in Table 2. And it is additional remarked that in the outdoor computational domain which as shown in Figure 1, S1 (when *S* was equal to 0° or 22.5°) or S2 (when *S* was equal to 45°, 67.5° or 90°) was assumed as the velocity inlet, while S3 (corresponding to S1) or S4 (corresponding to S3) of outlet was set as pressure outlet.

Table 2 *Boundary conditions setting*

Boundary	Parameters	Setting Value
Operating Conditions	Pressure, temperature	1atm, 20℃
Velocity inlet	Velocity	v=1, 2, 3 m/s; $v_x = v\sin S$, $v_y = v\cos S$
Wall	condition	Stationary wall, no slip, 0mm of roughness height
Opening	Face permeability	2.25m^2 (window 1 and window 3), 1.125m^2 (window 2)
Pressure outlet	Pressure	0Pa
Heat source	Thermal flux	Top of office tables, 920W/m^2

3.4 Comparison of Measured Value and Calculated Value

In order to validate the credibility of the CFD analysis, the window type 3 was installed in our laboratory, according to the same geometric size and layout as the CFD model. In the spring and summer of 2011 for a southerly wind (that was *S*=0°), wind speeds of 8~2.5m/s, and outdoor temperature of 15~22℃, velocities and temperatures (hot-wire anemometer and 16 Pt100 thermal resistors) at thirteen points (X=1.5m, Y=0~6m, Z=1.3m) were measured and compared with that of the CFD model results at 2m/s, *S*=0° and t_{out}=20℃, shown in Figure 3, where v_m was measured value while v_c was calculated value, and the subscript 3 identified window type 3. Similar trends were between measurement and calculation. Errors were caused by the accuracy of the test instrument, the uncertainty of the natural wind and outdoor air temperature, the difference of heat source distribution. However, the results of numerical calculation were supported by the study.

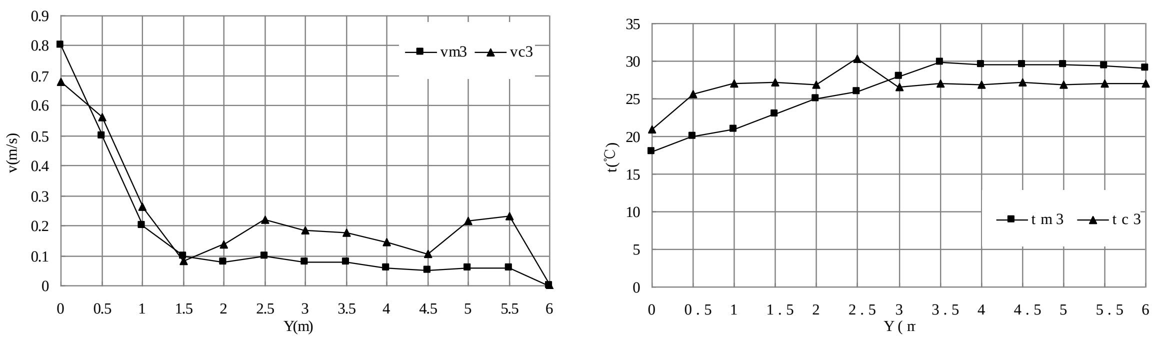


Figure 3 *Comparison of Measured Value and Calculated Value*

4. RESULTS AND DISCUSSION

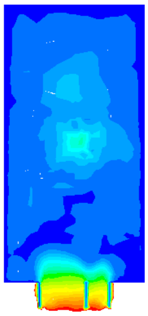
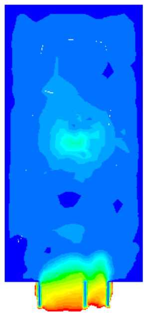
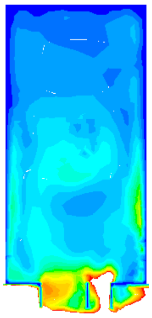
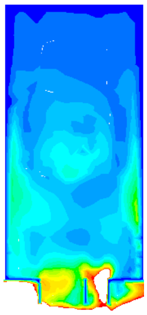
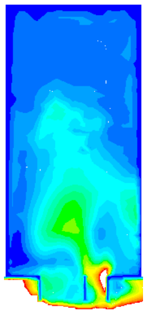
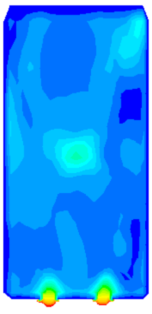
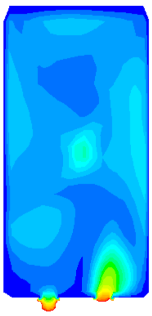
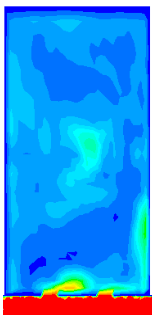
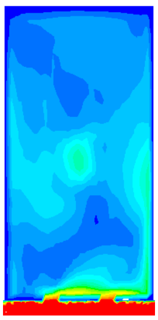
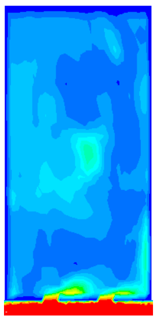
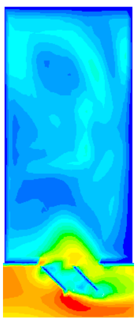
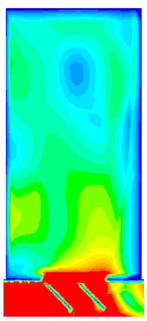
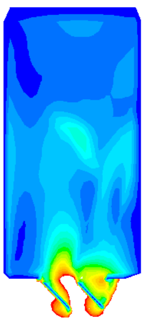
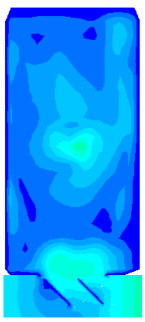
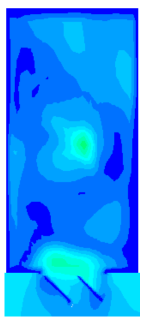
4.1 Velocity Distribution of Three Different Windows

The models with three different windows in different outdoor wind directions were simulated, calculated and compared when outdoor air temperature of 20℃ and outdoor wind speed of 2m/s. Table 3 shows the velocity fields of the opening and inner space along the section of Z=1.3m (breathing zone when sitting) for the three window types at 2m/s of outdoor wind speed, velocities ranged from 0 to 1 m/s. Refer to the results of my earlier work [2012], comparing the velocity distribution for the three types of windows for all conditions, it can be seen that:

1) Driven by both wind and thermal, the airflow in large depth was stirred by heat source, and the velocity fields was more even than that of driven just by wind, while the velocity values in the front of the office were less.

2) In the case of window type 3, out of larger width of its glazed sashes, outdoor and indoor airflows were best induced and turbulent, and great velocity airflow mainly appeared in the centre of the room, which was in favour of removing indoor heat gain.

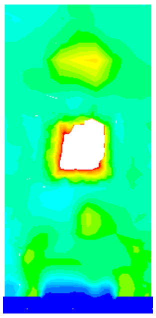
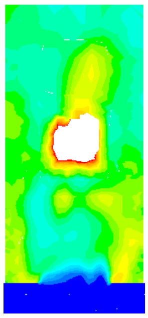
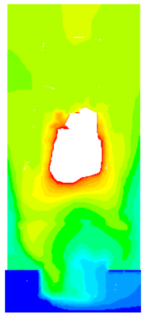
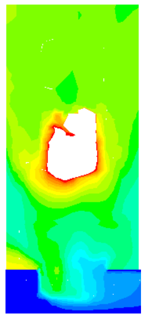
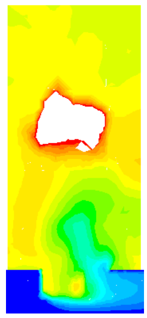
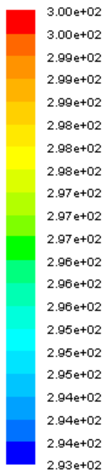
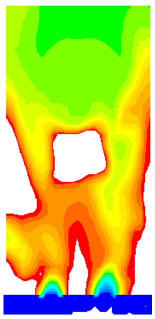
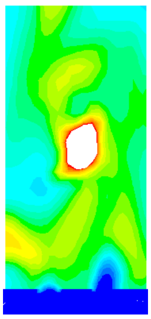
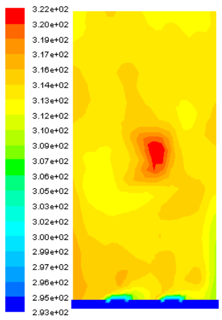
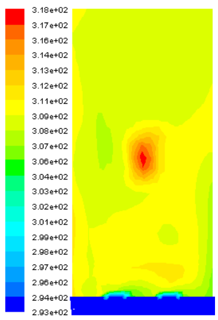
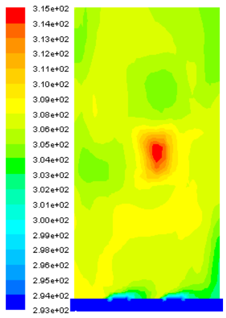
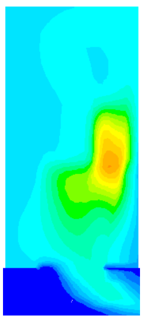
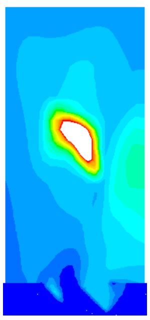
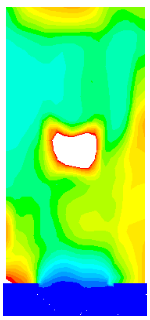
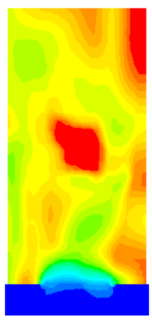
Table 3 *Velocity with different window*（v_{out}=2m/s, t_{out}=20℃, Z=1.3m）

S	0°	22.5°	45°	67.5°	90°	levels
Window1						
Window2						
Window3						

4.2 Temperature Distribution of Three Different Windows

Table 4 shows the temperature fields of the opening and inner space along the section of Z=1.3m for the three window types at 2m/s of outdoor wind speed, temperatures ranged from 293.16K to 300K. From the simulation results we can summarize the following: The whole inner space with window type 1 and window type 3 in each outdoor wind direction were acceptable in the same conditions, while that of window type 2 mainly could be unacceptable except *S*=22.5° . When S=45° , the cooling effect of window type 3 perform very well.

Table 4 *Temperature distribution with different windows*（v_{out}=2m/s, t_{out}=20℃, Z=1.3m）

S	0°	22.5°	45°	67.5°	90°	levels
Window 1						
Window 2						
Window 3						

4.3 Air Mass Flow Rate of Three Different Windows

The same method as my earlier work [2012], air mass flow rates of three different windows in each outdoor wind direction and outdoor wind speed of 2m/s were reported as Table 5. Through calculation, when the air mass flow rate was more than 0.18kg/s, the inner heat gain could be promptly removed and get a comfortable environment. Table 5 was obvious to tell us:

1) For the same wind speeds, when with window type 1 and 3, the air mass flow rate peaked at a wind angle *S*=45° while that of window type 2 was S=22.5° .

2) The new types of windows could induce more outdoor airflow into the office and bring about comfortable working environment in each outdoor wind direction, while window type 1 performed well when S was from 0° to 45° and window type 2 performed well when S was from 0° to 22.5° , especially in window type 2, when S was from to 45° to 90° , there was hardly natural ventilation. Moreover, the new type of window was more flexibility to outdoor natural wind than the two conventional windows.

Table 5 *Air mass flow rate (kg/s) into the Room through the Opening*（v_{out}=2m/s, t_{out}=20℃）

Window type \ *S*	**0°**	**22.5°**	**45°**	**67.5°**	**90°**
Window 1	0.326	0.287	**0.903**	0.157	0.141
Window 2	0.246	**0.323**	0.044	0.048	0.068
Window 3	0.247	0.551	**0.662**	0.245	0.204

5. CONCLUSIONS AND SUGGESTIONS

The CFD analysis and spot monitoring results presented in this paper compares the both wind and thermal driven natural ventilation performance of two types of conventional windows and the new window type when placed in a single opening room. The new window design was shown to be more effective at inducing airflow into the space. It thus offered improved scope for ventilation in rooms with different indoor layout. Indoor air velocities and temperature were found to be more comfortable, more air volume flow rates, and more flexibility to outdoor natural wind and the regime of hot summer and cold winter for the new window design when compared to the conventional windows for the same wind conditions.

This was the second step analysis and further studies are proposed to confirm the performance of these windows. It is proposed that these should focus on:1) Further optimization of window angles; 2) Resultant design guidance for improving ventilation should be disseminated to encourage the take-up of these window types for application in different types of buildings and for different climatic regions.

ACKNOWLEDGMENTS

The study was supported by two National Natural Science Foundations of China (ID: 50778064 and 51178169) and the Scientific Research Fund of Hunan Provincial Education Department (12C0411), and the authors would like to thank them and all participants for their contributions.

REFERENCES

Ruan Fang, Li Nianping, Wei Xiaoqing. Numerical Simulation of Natural Ventilation of a Folio Multi-Sash Mid-Pivoted Window with Vertical Deflectors in a Room. *The 2nd International Conference on Energy and Environment Technology (ICEET2010).* Changsha, China, Dec 04-06, 2010, Volume II: 717-720

Ruan Fang, Li Nianping. Comparison of Wind-driven Natural Ventilation for Different Windows Placed in a Single Room Opening. *The International Journal of Ventilation, Sept. 2012 (Special Edition: Towards Low Energy Buildings - Exploiting Ventilation),* Volume 11(2): 193-203

Graca G, Chen Q, Glicksman LR, Norford LK. Simulation of wind-driven ventilative cooling systems for an apartment building in Beijing and Shanghai. Energy Build 2002; 34:1-11.

Yao R, Steemers K. Strategic design for natural ventilation in buildings. In: Proceedings of ninth international conference on air distribution in rooms, 58 September 2004, Coimbra, Portugal.

Yao R, Steemers K, Li B. Climatic suitability analysis for natural ventilation cooling in office building in China. In: PLEA2005 The 22nd conference on passive and low energy architecture, Beirut, Lebanon; 1316 November 2005.

Runming Yao, Baizhan Li, Koen Steemers, Alan Short. "Assessing the natural ventilation cooling potential of office buildings in different climate zones in China". *Renewable Energy*. 2009 (34): 2697-2705.

YOU Shi-jun, WANG Lei-lei, ZHANG Huan, LIU Li, "Assessment of Performance of Wind Catcher System Using Numerical Method," *Journal of Tianjin University*, Vol. 40(8), Aug. 2007, pp. 936~940.

Chiang C.M., Chen N.T., Chou P.C., Li Y.Y., Lien I.C, A study on the influence of horizontal louvers on natural ventilation in a dwelling unit. *The 10th International Conference on Indoor Air Quality and Climate*, Beijing, China, 2005.

Chiang C.M., Li Y.Y., Chou P.C., Lai C.M, "CFD simulation to predict natural ventilation efficiency in a dwelling bedroom with the central horizontal pivot window," *The 8th International Conference on Indoor Air Quality and Climate*, Edinburgh, UK, 1999.

Nien-Tsu Chen, Che-Ming Chiang, Po-Cheng Chou, Yi-Ping Lin, Cheng-Lin Chen. "A Study on the Influence of Vertical Wind Deflectors on the Natural Ventilation of a Dwelling" , *Journal of Architecture*, No.61, Sep. 2007, pp. 63~78. (in Chinese)

Chinese National Standard JGJ 134-2001. Design standard for energy efficiency of residential buildings in the hot summer and cold winter zone. Beijing: Chinese Architectural Publication House; 2001.

ANSI/ASHRAE 55-2004. ASHRAE standard: thermal environmental conditions for human occupancy. Atlanta, USA: *ASHRAE;* 2004. ISBN 1041-2336.

Chen, Q., Jiang, Z, "Significant questions in predicting room air motion, "*ASHRAE Trans*. 98(1), 1992, pp. 929-939.

Wang Fujun, "Analysis of Computational Fluid Dynamics-Theory and Application of CFD Codes [M]," Beijing, Tsing-hua University Press, 2004. Ch.2~Ch.5.