IOP Conference Series: Earth and Environmental Science

PAPER • OPEN ACCESS

CFD Simulation on the Natural Ventilation and Building Thermal Performance

IOP Conf. Series: Earth and Environmental Science **448** (2020) 012004 doi:10.1088/1755-1315/448/1/012004

CFD Simulation on the Natural Ventilation and Building Thermal Performance

R Widiastuti[1,3], M I Hasan[2,3], C N Bramiana[2,3], P U Pramesti[3]

[1]Faculty of Integrated Technologies, Jalan Tungku Link, Gadong, BE1410, Brunei Darussalam
[2]Department of Architecture, Faculty of Built Environment, University of Malaya, 50603, Kuala Lumpur-Malaysia
[3]Architectural Design, Vocational School, Diponegoro University, Jalan Prof. H. Soedarto S.H, Tembalang-Semarang, 50275, Indonesia

ratihw@arsitektur.undip.ac.id

Abstract. The types of window, either permanent or impermanent will influence the building thermal profiles. Natural ventilation is one of technique to create passive cooling design in the building. It can improve the quality of indoor air, thermal comfort and reduction of energy consumption for air conditioning. In this present work, a study on the type of natural ventilation and the effect to thermal building performance was conducted. There are two types of natural ventilation as main variable in this study, top hung window and jalousie window. To develop the study, a simulation used Computational Fluid Dynamics (CFD) also conducted. One natural ventilation as outlet also added in the simulation. Based on the data measurement and computer simulation, jalousie window can provide better thermal performance. The range of difference between indoor air temperature on the chamber with jalousie window and chamber with top hung window is 0.2°C to 0.5°C, showing greater heat loss. The average of amount on the indoor air flow also was found 0.0317 m/s higher in the chamber with jalousie window. Particularly in the inlet, it was clear that the velocity of incoming air flow is faster and significantly allowed greater air with lower temperature entered from outside to inside.

1. Introduction

Natural ventilation is ventilation technique without any mechanical devices [1]. It is one of strategies to improve building thermal performance by resulting air temperature changes that entering building [2]. It also reduces the amount energy consumption for air conditioning and improving indoor air quality [3-6]. Building with natural ventilation has 40% lower for energy consumption [7,8]. Especially for traditional residential building, natural ventilation can increase the exchange of indoor and outdoor air, provides internal air renewal and thermal comfort for the occupant [9]. Sick building syndrome (SBS) is easy to come when building does not have enough ventilation [10-13]. Therefore, strategies of natural ventilation should be integrated into building design.

The existence of external wind velocities, wind direction and vegetation around building become the external factors that influence the performance of natural ventilation [14]. Elshafei et al. [15] also said that temperature, air velocity and humidity have strong influence on the natural ventilation. While the types of the natural ventilation, including the window angle is the main factor that effected the quantities of indoor air velocities [16]. Especially for single-sided natural ventilation, the design of the window is very important [17].

Based on the study conducted by Gao and Lee [18], better natural ventilation performance was showed when the position of wall openings in the opposite direction or cross ventilation. It was better to place inlet in the lower position than outlet since cool air with higher air mass will enter building through inlet and stimulate the indoor air that already hot to flow outside through outlet [19]

Another theory also said that the position of opening in the cross ventilation should be arranged in the different orientations [14]. The facade opening as inlet must be placed in the high pressure zones, while the outlet in the low pressure zones. The type of opening also directly effect the performance of cross ventilation and interferes either in resistance offered to the air flow or in direction and intensity. Amount and pattern of air flow distribution also were influenced by dimension of natural ventilation [14].

However, there are some obstacles of using natural ventilation such as when the outdoor temperature is higher than the indoor temperature, the existence of pollution and dust, noise around building and conflict with construction standards [20].

A number of studies on the performance of natural ventilation have been conducted to prove the significant energy saving compared to mechanical ventilated buildings. Favarolo and Manz [21] simulated a building with single side natural ventilation with different window height and width. The result showed that the greatest impact on the effective opening discharge coefficient occurred on the window above ground. The presence of roof void also can improve the function of natural ventilation, especially for multi-storey building [22].

An experimental analysis also conducted by Appelfeld et al., [23] proved that a ventilated window can potentially contribute to energy saving and it might be most suitable for a window unit with low ventilation rates. To investigate the performance of ventilated windows, different models and calculation method already developed [24,25] since the length of outlet is the important influence that effected both indoor thermal condition and thermal behavior according to load of energy consumption [26].

Another study also performed by Ravikumar and Prakash [27] used CFD simulation by developing three dimensional (3D) building model of office room to determine the optimal window opening area and aspect ratio needed to maintain the thermal comfort. The study found out compare to the other area, the more comfortable area occurred in the area without window that close to the wall [27].

Even though, many studies already discussed the effect of natural ventilation on the building, the topic was analysed separately. A comprehensive investigation needs to be implemented for different window typologies. In this present work, a study on the type of natural ventilation and the effect to thermal building performance was conducted. To develop the study, a simulation used Computational Fluid Dynamics (CFD) also conducted.

2. Research Method

2.1. Building Model

The aim of this study is to observe the effect of natural ventilation type to building thermal performance. The object study was two identical chamber yet has different type of inlet, as seen in **figure 1a** and **figure 1b**. The dimension of each chamber is 4m x 4m x 2.5m x 2m. As detail of the chamber can be seen in **table 1**. While **table 2** explained the detail of each natural ventilation in the chamber one and chamber two.

Type of inlet and outlet is on the adjacent wall with the same high position. In order to optimize the effect of natural ventilation, during data measurement, the door in each chamber was always closed. The natural ventilation area corresponding to 7.7 % of the area of the floor (5.4% and 2.3% area of the floor).

Data measurement for both chambers was conducted during dry season at 17 July 2013 for 25 hours. Started at 06:00 p.m. to 06:00 a.m. While data collection was done at 1-hour interval for indoor air velocities and indoor air temperature.

Table 1. Detail of chamber

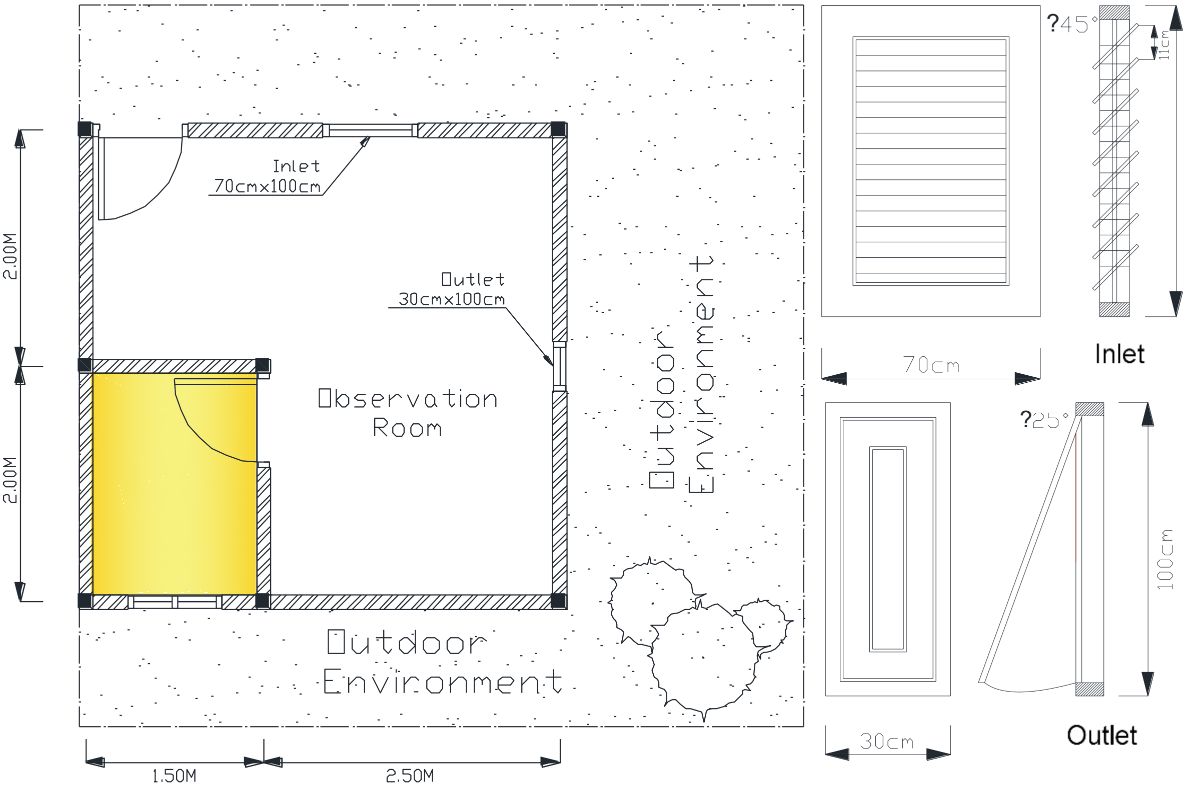
Detail of chamber	Specification
Model size	4m x 4m x 2.5m x 2m
Area of the observation room	$13m^2$
Ceiling material	Gypsum
Wall material	Brick with plaster
Inlet outlet	5.4% area of the floor
Outlet	2.3% area of the floor
Floor material	Concrete
Position of opening	Inlet in the front and outlet in the side (inlet and outlet on the adjacent wall)

Table 2. Detail of natural ventilation in each observation room

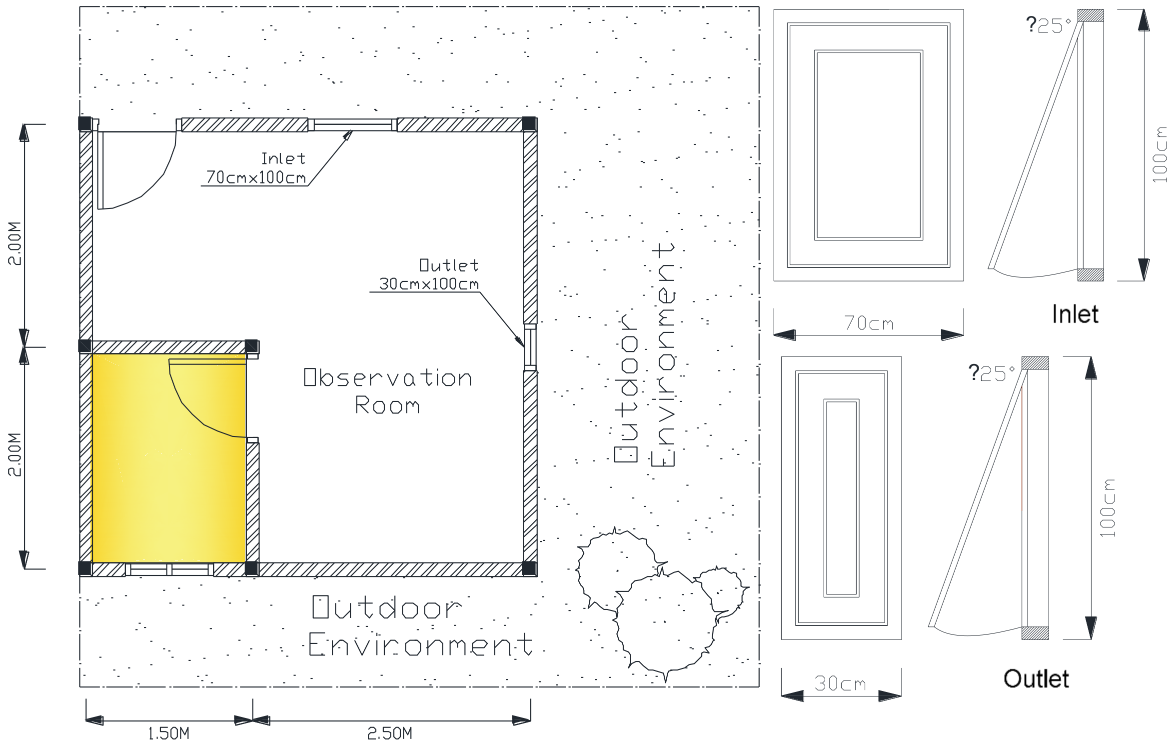
Detail of the natural ventilation	Chamber one		Chamber two	
	Inlet-Jalousie window	Outlet-Top hung window	Inlet-Top hung window	Outlet-Top hung window
Width	70 cm	30 cm	70 cm	30 cm
Height	100 cm	100 cm	100 cm	100 cm
Window sill	10 cm	10 cm	10 cm	10 cm
Area of natural ventilation	$0.7\ m^2$ (5.4% area of the floor)	$0.3m^2$ (2.3% area of the floor)	$0.7\ m^2$ (5.4% area of the floor)	$0.3m^2$ (2.3% area of the floor)
Angle of opening	45°	25°	25°	25°
WWR	5.83%	2.5%	5.83%	2.5%

2.2. CFD Simulation

In order to expand the result, a CFD (Computational Fluid Dynamics) simulation also conducted in this study. CFD (Computational Fluid Dynamics) simulation consists of the numerical simulation of physical and physicochemical processes. The software can simulate temperatures, air velocities, air pressure, pressure coefficients and other fluid characteristics [14]. The simulation is based on the principles of mass conservation, energy and momentum in the space and time domain, qualified to study the effect of natural ventilation in the building and in the urban environment [14].



(a)



(b)

IOP Conf. Series: Earth and Environmental Science **448** (2020) 012004 doi:10.1088/1755-1315/448/1/012004

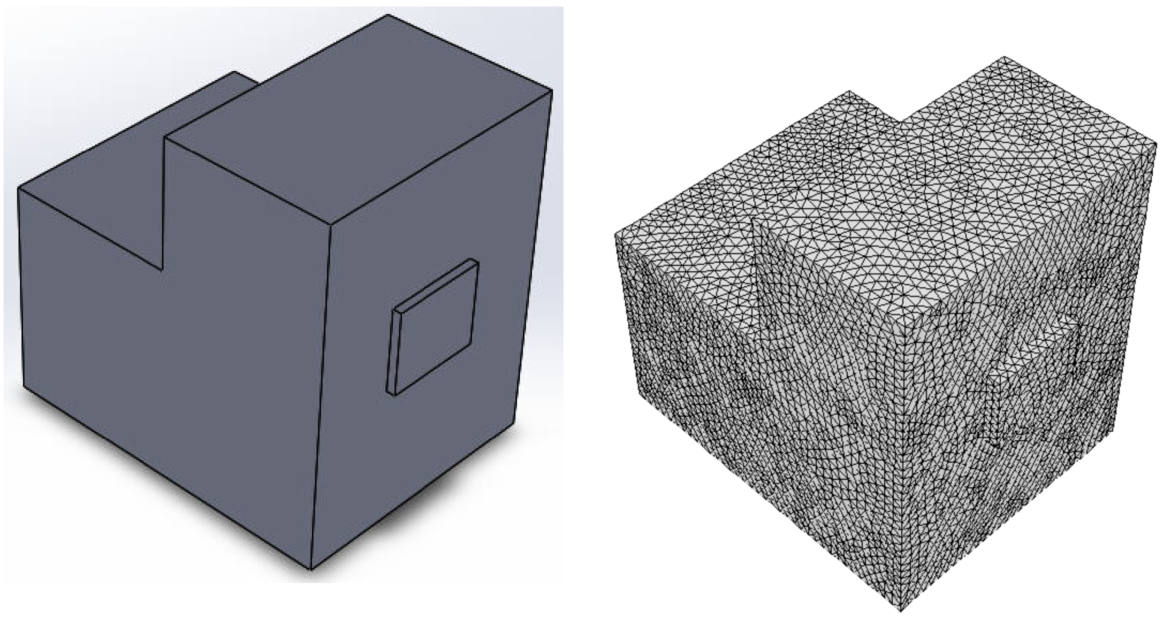
Figure 1. Object study. **(a).** Chamber one and type of natural ventilation; **(b).** Chamber one and type of natural ventilation

Modelling of the three dimensional (3D) chambers was built using SolidWorks software, can be seen in **figure 2**. The building model based on the object observation in the **figure 1**. One window act as outlet and another one act as inlet. Determination of the inlet and outlet was done based on the direction of outdoor air velocities.

All of the physical properties of building model were reflected in the calculation of thermal performance in CFD simulation as seen in **table 3**. However, the CFD modelling should identify the position of inlet, outlet, floor, roof, wall and fluid first. In the simulation, only the important characteristics for the analysis and the natural ventilations were considered for the construction of the building model. In addition, other architectural structures, physical environment, activities and other factors are controlled unchanged [28].

Table 3. Specific of thermal properties of building model [29,30]

Specification of thermal properties			
	Specific heat capacity	Thermal conductivity	Density of material
Wall (cement plaster)	840 J/kgK	0.721 W/mK	1762 kg/m^3
Wall (brick)	880 J/kgK	0.811 W/mK	1820 kg/m^3
Ceiling	1.09 J/kgK	0.19 W/mK	641kg/m^3
Floor	880 J/kgK	1.74 W/mK	2410 kg/m^3



(a) (b)

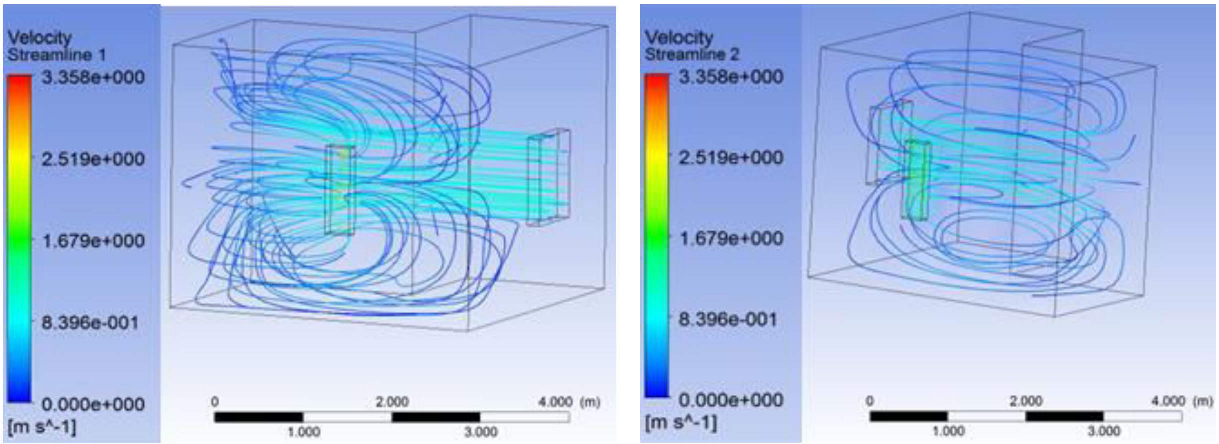
Figure ~~3~~2. Modelling of the three dimensional (3D) chambers. **(a).** Model in SolidWork software; **(b).** Meshing in CFD simulation

After determined the boundary conditions, the thermal properties were input into CFD software for geometry meshing. Each of the case studies were simulated in a steady state condition and using the application of k-ε turbulence standard model for fluid flow [31]. Constant velocity magnitude of 0.081 m/s for inlet in chamber one and 0.046 m/s for inlet in chamber two. While for outlet window was 0.06 m/s. The internal surface of the room was set at 22.02°C for chamber one and 23.98°C for chamber two. The data was based on the the average of data measurement. Before running the solver, the meshing of models, boundaries and cell zones were checked to prevent any errors or floating points occurred during the calculation. Number of iteration was 100 and convergence when conducting CFD simulation refers to previous study [14] where when a minimum of $1^{o}/_{oo}$ was reached for the scaled residual of mass, momentum, turbulent kinetic energy (k) and turbulent dissipation (ε). The effect on the natural ventilation to the rooms were investigated.

3. Analysis

Based on the simulation in **figures 3**, the angle of natural ventilation influenced the income air velocities to outlet. Furthermore, the flow of indoor air seems depend on the dimension of the opening on the natural ventilation. The average of air velocities in each chamber was 0.0753 m/s in chamber one and 0.0436 m/s in chamber two, can be seen in **figure 4**. The result was similar with previous study where the smaller natural ventilation provides better indoor air flow and smaller load loss at the inlet due to the obstruction [14]. In this case, jalousie window had smaller opening for income air from outdoor. However, the angle of the opening made easier the air to flow inside the room. For occupant, this result will provide fresh indoor air since produce of air renewal per hour is higher.

The results of simulation also showed that type of natural ventilation effected the average of indoor air pressure, especially in the outlet, can be seen in **figure 5**. The performance of the chamber one was significantly better since the angles of natural ventilation provided smaller opening and created higher air pressure. Possibility indoor air movement and better air circulation was occurred. As in chamber two, when wind hit top hung window, the velocities of indoor air flow was decreasing since the opening of inlet was smaller.



(a) **(b)**

Figure 3. Profile of air velocities in CFD simulation. **(a).** Chamber one; **(b).** Chamber two

During data measurement, the effect of indoor air velocities also recorded influencing the indoor air temperature of chambers. It showed the range of indoor temperature in chamber one was 21.9°C to 25.4°C and in chamber two was 21.7°C to 25.9°C, can be seen in **figure 6**. The averages of indoor air temperatures were respectively 23.65°C for chamber one and 23.98°C for chamber two. In chamber one, the highest indoor air temperature occurred during evening (07:00 p.m.) for one hour. While in chamber two, the highest indoor air temperature occurred during afternoon (03:00 p.m.-04:00 p.m.) for two hours. Both of the profile of indoor air temperature were decreasing during night time to morning. As important note, the highest indoor air temperature in chamber two was one hour longer than chamber one. The result can represent as time lag. Furthermore, the difference of indoor air temperature between chamber one and chamber two are at the range of -0.5°C to 1.3°C with 0.324°C as the average of the difference. The results were indicating better air circulation will provide lower range of indoor air temperature.

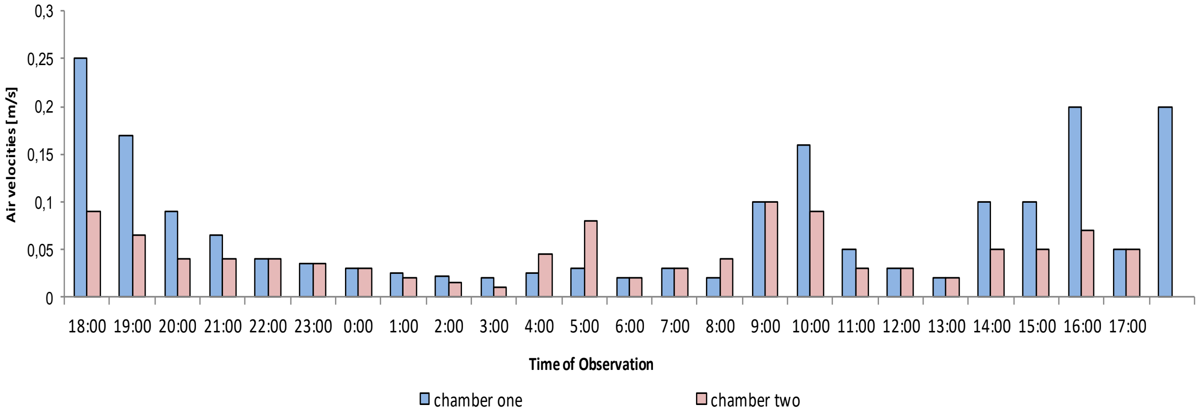
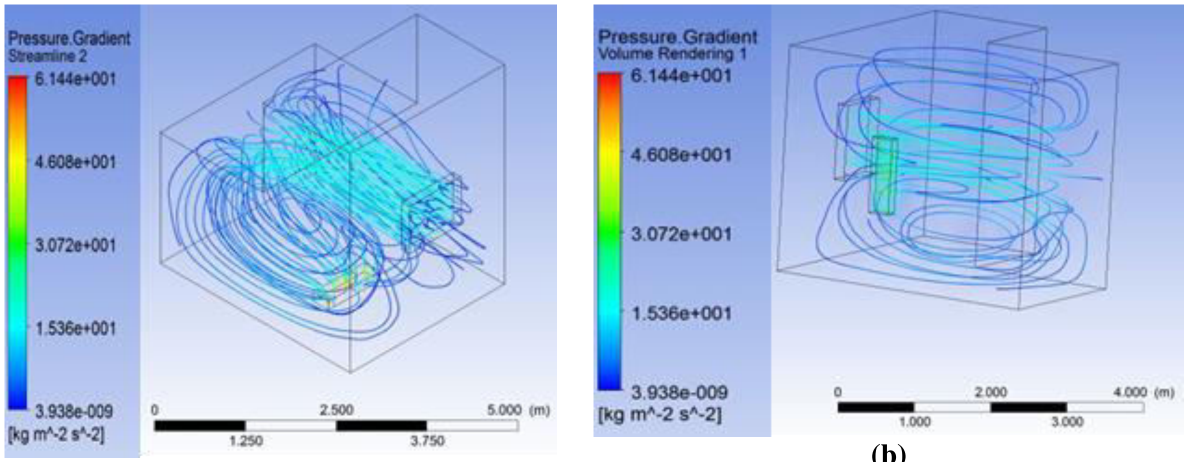


Figure 4. Profile of indoor air velocities based on the data measurement



(a) (b)

Figure 5. Profile of air pressure in CFD simulation. **(a).** Chamber one; **(b).** Chamber two

As based on the position, the hottest air temperature of chamber one started to occur at 2.65 m (25.4°C) and chamber two at 2.35 m (25.9°C). While at the same level (2.5 m) the temperature at chamber one is 24.7°C and chamber two 25.1°C. Both of the result showed that the hotter indoor air temperature occurred near ceiling. It proved that hotter air temperature had lighter air mass and easer to flow. Therefore, to accommodate indoor thermal comfort, design of outlet is better to place in higher position than inlet.

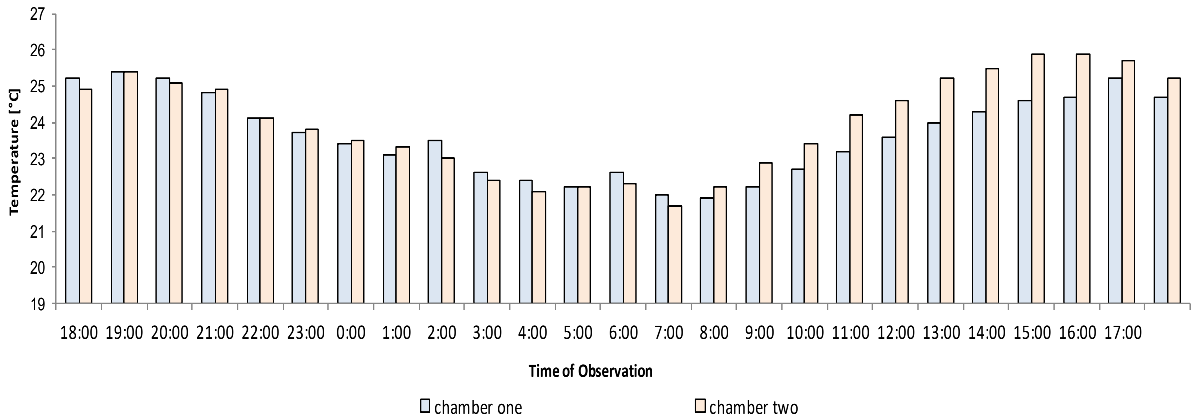


Figure 6. Profile of indoor air temperature based on the data measurement

4. Conclusion

Based on the analysis, this study proved that the type of natural ventilation will influence the profile of indoor air velocities, indoor air pressure and indoor air temperature. The average of indoor air velocity in the chamber with jalousie window was faster 0.0317 m/s than chamber two with top hang window. In this case, even though jalousie window had smaller opening yet the angle of the opening made easier the air to flow inside the room. Possibility it will effect the distribution of indoor air flow. However, further study must be conducted related to this topic.

Furthermore, data analysis also showed the performance of indoor air pressure in the chamber one was significantly better than chamber two since can provide higher air pressure. The vertical fence in the jalousie window provided direct air flow inside building.

In the end, lower range of indoor air temperature was occurred from jalousie window since allowed in better indoor air velocities. The difference between two chamber were -0.5°C to 1.3°C with 0.324°C. The average of indoor air temperature in chamber one was 0.324°C lower than chamber two. While based on the CFD simulation, at the same level (2.5 m) also showed chamber two had 0.4°C higher than chamber one.

Acknowledgments
We gratefully thank the Vocational School, Diponegoro University, for the funding to conduct this research. The authors also would like to acknowledge Putri Pujiastutik and Rizki Wahyu Romadhon for their contribution during data measurement.

5. References

[1] Schulze T, Gürlich D, Eicker U 2018 Performance assessment of controlled natural ventilation for air quality control and passive cooling in existing and new office type buildings *Energy and Buildings* **172** 265–278
[2] Alibaba HZ 2018 Heat and air flow behavior of naturally ventilated offices in a Mediterranean climate *Sustainability* **10** 3284
[3] Wang Y, Zhao FY, Kuckelkorn J, Liu D, Liu J, Zhang JL 2014 Classroom energy efficiency and air environment with displacement natural ventilation in a passive public school building *Energy and Buildings* **70** 258–270
[4] Schulze T, Eicker U 2013 Controlled natural ventilation for energy efficient buildings *Energy and Buildings* **56** 221–232

[5] Bayoumi M 2017 Energy saving method for improving thermal comfort and air quality in warm humid climates using isothermal high velocity ventilation *Renewable Energy* **114** 502–512
[6] Lei Z, Liu C, Wang L, Li N 2017 Effect of natural ventilation on indoor air quality and thermal comfort in dormitory during winter *Building and Environment* **125** 240–247
[7] Alloca C, Chen Q, Glicksman LR 2003 Design analysis of single-sided natural ventilation *Energy and Buildings* **35 (8)** 785–795
[8] Energy Consumption Guide 19, Energy Use in Offices <http://www.cibse.org/getmedia/7fb5616f-1ed7-4854-bf72-2dae1d8bde62/ECG19-Energy-Use-in-Offices-(formerly-ECON19).pdf.aspx> (accessed on 17 August 2019).
[9] Shen JM 2002 Strategies and measures for improving indoor air quality in China *Journal of HV&AC* **32** 34-37
[10] Sundell J 2004 Indoor Air Uncertainty and the environment implications for decision-making and environmental policy **14** 51-58
[11] Saeed A 1993 *Subjective assessment of indoor air quality in office buildings* Master Thesis (The Dhahran: Kind Fand University)
[12] Wargocki P, Sundell J, Bischof W 2002 Ventilation and health in non-industrial indoor environments: report from a European multidisciplinary scientific consensus meeting (EUROVEN) *Indoor Air* **12 (2)** 113-128
[13] World Health Organization 1983 *Indoor air pollutants exposure and health effects* (Copenhagen: EURO Reports and Studies) no 78
[14] Sacht H and Lukiantchukib MA 2017 Windows size and the performance of natural ventilation *Procedia Engineering* **196** 972-979
[15] Elshafei G, Negm A, Bady M, Suzuki M, Ibrahim MG 2017 Numerical and experimental investigations of the impacts of window parameters on indoor natural ventilation in a residential building *Energy and Buildings* **141** 321–332
[16] Lukkunaprasit P, Ruangrassamee A, Thanasisathit N 2009 Tsunami loading on buildings with openings *Science of Tsunami Hazards* **28(5)** 303
[17] Wang J, Wang S, Zhang T, Battaglia F 2017 Assessment of single-sided natural ventilation driven by buoyancy forces through variable window configurations *Energy and Buildings* **139** 762–779
[18] Gao CF and Lee WL 2011 Evaluating the influence of openings configuration on natural ventilation performance of residential units in Hong Kong *Building and Environment* **46 (4)** 961-969
[19] Lippsmeier G 1994 *Tropenbau Building in the Tropics. In Bahasa: Bangunan Tropis by Syahmir Nasution* 2nd ed. Indarto PW ed. (Jakarta: Erlangga)
[20] Masooda OA, Guirguisb NM, Abd Al-Hadyc, MI, Fahmia AA Windows factors impact on air speed and quality inside architectural spaces 2018 *International Journal of Applied Engineering Research* **13 (15)** 12146-12156
[21] Favarolo P and Manz H 2005 Temperature driven single-sided ventilation through a large rectangular opening *Building and Environment* **40 (5)** 689-699
[22] Muhsin F, Yusoff WFM, Mohamed MF, Sapian AR 2016 The effects of void on natural ventilation performance in multi-storey housing *Buildings* **6** 35
[23] David A and Svend S 2011 Experimental analysis of energy performance of a ventilated window for heat recovery under controlled conditions *Energy and Buildings* **43 (11)** 3200-3207
[24] Carlos JS, Corvacho H, Silva PD, Castro-Gomes JP 2010 Real climate experimental study of two double window systems with preheating of ventilation air *Energy and Buildings* **42** 928-934
[25] EN 15099 November 2003 Thermal performance of windows, doors and shading devices-Detailed calculations

[26] Moosavi L, Mahyuddin N, Ghafar NA, Ismail MA 2014 Thermal performance of atria: An overview of natural ventilation effective designs *Renewable and Sustainable Energy Reviews* **34** 654–670
[27] Ravikumar P and Prakash D 2009 Analysis of thermal comfort in an office room by varying the dimensions of the windows on adjacent walls using CFD: A case study based on numerical simulation *Building Simulation* **2 (3)** 187-196
[28] Köhler M 2000 Green facades-a view back and some visions *Urban Eco-System* **11** 423–36
[29] Balaji NC, Monto M, Venkatarama RBV 2013 Thermal performance of the building walls (Free University of Bozen-Bolzano: 1st IBPSA Italy conference) *Building Simulation Applications* pp 1-7
[30] Rahmanian I and Wang Y 2009 Thermal conductivity of gypsum at high temperatures a combined experimental and numerical approach *Acta Polytechnica* **49 (1)** 16-20
[31] Chen Q 1995 Comparison of different k-ε models for indoor air flow computations *Numerical Heat Transfer, Part B: Fundamentals* **28 (3)** 353-369