CHAPTER 6

Predicting Studio Thermal Comfort Resulting from Window Design Using CFD Method

Ahmad MAULANA S
Department of Mechanical Engineering, Faculty of Industrial Engineering,
Universitas Trisakti, Jakarta, Indonesia
amsoedjana@gmail.com

Rosyida PERMATASARI*
Department of Mechanical Engineering, Faculty of Industrial Engineering,
Universitas Trisakti, Jakarta, Indonesia
Corresponding Author:rosyida@trisakti.ac.id
Orchid: 0000-0001-6621-0359

Popi PUSPITASARI
Department of Architecture, Faculty of Civil Engineering and Planning
Universitas Trisakti, Jakarta, Indonesia
popi@trisakti.ac.id
Orchid: 0000-0003-4143-6807

Khotijah LAHJI
Department of Architecture, Faculty of Civil Engineering and Planning
Universitas Trisakti, Jakarta, Indonesia
khotijah@trisakti.ac.id

S CAHYATI
Department of Mechanical Engineering, Faculty of Industrial Engineering,
Universitas Trisakti, Jakarta, Indonesia
sallycahyati@trisakti.ac.id
Orchid: 0000-0001-5560-896XP

Martinus Bambang SUSETYARTO
Department of Architecture, Faculty of Civil Engineering and Planning
Universitas Trisakti, Jakarta, Indonesia
bambang.s@trisakti.ac.id

Kamarul Aizat Abdul KHALID
Faculti Kejuruteraan & Teknologi Mekanikal (FKTM)
Universiti Malaysia Perlis, Perlis, Malaysia
kamarulaizat@unimap.edu.my
Orchid: 0000-0001-7220-7842

S AHMAD
Department of Manufacturing & Materials Engineering
Kulliyyah of Engineering (KOE), International Islamic University Malaysia, Selangor, Malaysia
saadahahmad@iium.edu.my
cc 0000-0002-9017-9467

ABSTRACT

Thermal comfort depends on the exposed sun's radiation, the temperature, and the wind speed around the building. In a naturally ventilated room, a method to be applied to achieve thermal comfort in a tropical area is enhancing the wind speed in the room through an opening design. An aspect capable of determining the comfort of a room is an opening design since it will affect the airflow and the natural lighting that the room will obtain. This study aims to analyze various types of windows and their opening angles in the FTSP studio at Universitas Trisakti. The CFD numerical simulation aims to predict the studio's airflow pattern and temperature by using three different window opening angles: 45º, 90º, and 135º. Then, the results are compared to those closest to the SNI 03-6572-2001 standard. Based on the results of the study, it is found that a vertical pivot window with a 135º opening angle receives the results closest to the standard at nine points of measurement with the wind speed ranging from 0.14 m/s to 0.97 m/s.
Keywords: Thermal Comfort, Wind Speed, CFD, Airflow Pattern And Temperature, Window Opening Angles.

1. INTRODUCTION

Geographically, Indonesia lies on the equatorial line, so Indonesia tends to have a high level of humidity and temperature (B. H. Sahabudin, Ihsan, 2014). This situation results in a need for ventilating a room in such a way that the room will obtain thermal comfort (P. R. Margherita Ferrucci *et al.,* 2022). Thermal comfort depends on several climate conditions such as the exposed sun's radiation and the wind speed around the building. The building's orientation will also affect thermal comfort (M. S. A. Anisa Budiani Arifah *et al.,* 2018). One method of achieving the thermal comfort of a building located in a tropical area is enhancing the wind speed in the room through the design of its window opening (S Kato, 2018). Accordingly, a window serving as a primary means of circulating the air must be meticulously designed for the sake of air control (S Omrani *et al.,* 2017). Jeffrey I. Kindagen, (2003) said that a type of window opening would affect the wind speed entering the room, so it would impact the room to a certain extent (J. I. Kindangen, 2003). Citra Amelia, (2016) also stated that an aspect capable of determining the comfort of a room was an opening design which that opening design would affect the airflow and the lighting that the room obtained.

The comfort of a room in the temperature, the airflow, and the level of humidity are defined as thermal comfort. The earth's increasing temperature due to global warming affects the thermal comfort of a room. SNI 03-6572-2001 defines thermal comfort as the results of processing the air simultaneously by controlling the temperature, humidity, and distribution to achieve the occupants' comfort (Tata Cara Perencanaan Sistem Ventilasi dan Pengkondisian Udara Pada Bangunan, SNI, 2001). Thermal comfort depends on the radiation resulting from the exposed sun's radiation, the air temperature, the air humidity, and the wind speed around the building (T Wati *et al.,* 2017)

Computational Fluid Dynamics (CFD) is defined as a field using a computer resource to stimulate any problems regarding the flow of fluid (Tahang, 2016). Physics mathematics and programming tools are employed to simulate the flow of a fluid and to solve problems. Then, the obtained data will be analyzed. To give easy access, CFD provides a sophisticated interface for its user to enter the parameters of the problems and analyze the results. Therefore, all of the codes contain three main elements: (i) pre-processor, (ii) solver, and (iii) post-processor (M. Kulisz *et al.,* 2019).

Natalia Damasatuti and Ronny Durrotun Nasihien, (2017) analyzed the air profile of the second and third floors of Mosque Narotama in Surabaya, which used a natural ventilation system to know the value of the building's comfort. Their simulation results showed that the wind speed ranged from 0 m/s to 1.13 m/s and the highest speed lay in the middle of the building because the three points of the compass met (R. D. N. Natalia Damastuti, 2017).

Fitria and Thojib employed a CFD method to analyze the performance of the natural ventilation applied at the Grand Mosque Ainul Yaqin in Gresik without altering the original form of the building. They analyzed it by using an Autodesk Flow Design to engineer the opening performance. Most of the openings at Grand Mosque Ainul Yaqin were casement types theoretically capable of obtaining up to 90% of the outer air. They found out that the casement type was not suitable since the obtained wind is too strong, so it did not meet the thermal comfort standard based on the SNI standard (J. T. Nur Wakhida Fitria, 2019).

Hamzah *et al.,* identified the performance of ventilation at several classrooms in Universitas Hasanuddin, Universitas Muslim Indonesia, and Universitas Muhammadiyah Makassar. After making some simulations, they found out that the best results were obtained when the opening ratio ranged from 16.59% to 22.76%, with the opening on both sides of the adjoining walls positively impacted on the airflow in the classrooms. Those opening positions enabled a cross-ventilation. Enlarged inlet and outlet areas with a suitable ratio could also optimize air circulation (B. Hamzah *et al.,* 2017).

This study is aimed at analyzing the types of windows and the opening angles of windows in the studio located at the Faculty of Civil Engineering and Architecture at Universitas Trisakti to obtain an optimum alternative so that they achieved thermal comfort under the SNI 03-6572-2001 standard. This study employs a simulation of airflow patterns using a Computational Fluid Dynamic (CFD) method with the variables obtained from collecting data on the wind speed and the temperature. The simulation is aimed at predicting the airflow patterns and the temperature in the studio with various types of installed windows and alternative windows of the vertical pivot type with three different opening angles.

2. METHODS

This study employs an analytical method and a CFD method using ANSYS Fluent (ref) software. The analytical method is employed to calculate the coefficient value of the heat transfer that will serve as the parameter and the threshold condition of the simulation. The simulation is made to observe the occurring airflow patterns and the thermal condition of the studio. The threshold condition is made in such a way that it complies with the surrounding environment around the studio.

The data are collected from the simulation results at several points of the rooms with data in the forms of the wind speeds and the temperatures. Those simulation data for the installed windows types will be compared to the actual results of measurement to validate the simulation. The data of the simulation results and the alternative window types will be compared to the thermal comfort standard recommended by SNI 03-6572-2001. Those results will serve as the reference to determine the best alternative opening type and the best window angle.

2.1. Material

In this study, two types of window openings namely the window type installed at the studio at FTSP Universitas Trisakti and the alternative vertical pivot type of window with three different opening angles amounting to 45º, 90º, and 135º as shown in Figure 1.

The studio at FTSP is 21.705 meters long, 16.82 meters wide, and 4 meters high. It has eight pairs of windows on the western side and eleven pairs on the northern side. The northern side serves as the vent for the air entering the classroom, and the western side serves as the exhaust air vent as shown in Figure 2.

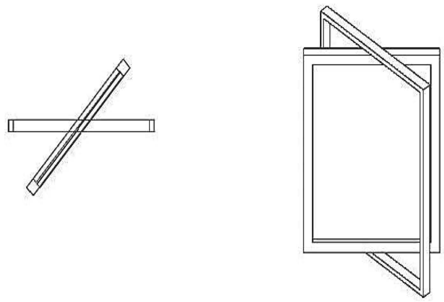

Figure 1. Vertical pivot window type

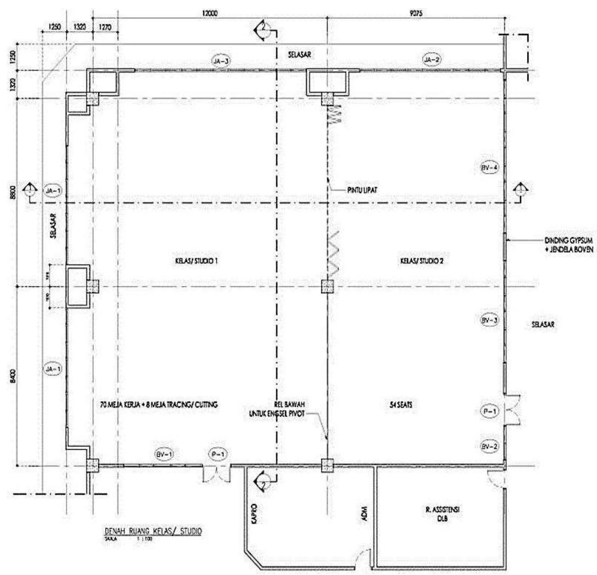

Figure 2. Studio floor plan

2.2. Methods

The actual data are collected at a height of 90 cm above the floor. Those data will be compared to the data of the simulation results to validate the simulation results. Moreover, the simulation measurement data are also collected at the height of 135 cm, the windfall point exactly above an adult's head in a sitting position. When the data are collected, several variables such as the air temperature and the wind speed are employed. The SNI standard for the speed of the wind falling overhead ranges from 0.15 m/s to 0.25 m/s, while the temperature of the room comfort ranges from 22 ºC to 27 ºC. Table 1 shows the wind speed and the outer air temperature, which serve as the simulation parameters obtained from the data measurement. Figure 3 shows the data collection points.

Table 1. Simulation parameter

Wind Speed	2.68 m/s on the X axis, 1.37 m/s on the Z axis
Outer Air Temperature	35 ºC
Time	At 12.00

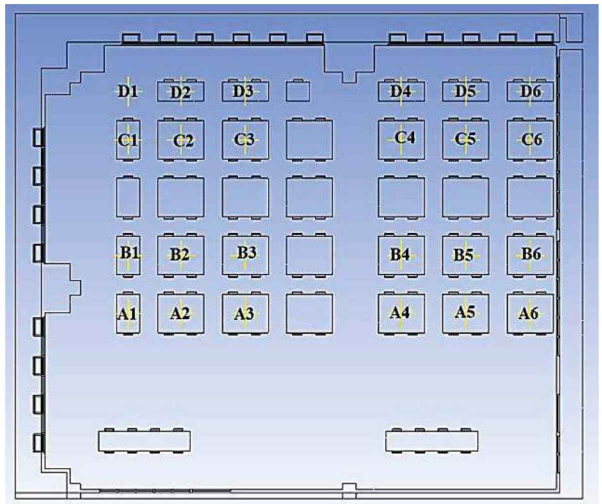

Figure 3. Data collection point

3. RESULT AND DISCUSSION

The simulation data are validated by comparing the measurement data to the simulation data in the actual condition at the height of 90 cm above the floor. Table 2 shows the validation results of the simulation. The comparative result shows that the average discrepancy between the measurement data and the measurement results is 2.34%; thus, it means that the simulation results are deemed to be valid.

Table 2. Simulation and measurement data validation

Point	Measurement Temp(ºC)	Simulation Temp (ºC)	Δ (%)
A1	32.20	32.86	2.04
A2	32.00	32.90	2.83
A3	31.80	32.88	3.40
A4	31.80	32.84	3.28
A5	31.90	33.05	3.60
A6	32.00	32.68	2.14
B1	32.20	32.85	2.03
B2	32.00	32.77	2.41
B3	31.00	32.65	5.32
B4	32.00	32.72	2.26
B5	32.00	33.12	3.51
B6	32.10	32.64	1.69
C1	32.40	32.91	1.58
C2	32.10	32.83	2.29
C3	32.00	32.68	2.13
C4	32.00	32.63	1.96
C5	32.00	33.10	3.45
C6	32.20	32.67	1.47

Point	Measurement Temp(ºC)	Simulation Temp (ºC)	Δ (%)
D1	33.50	32.94	1.67
D2	33.20	32.88	0.98
D3	33.00	32.91	0.26
D4	33.00	32.26	2.25
D5	33.00	32.92	0.24
D6	33.20	32.09	3.35

This discrepancy may take place due to the simplified modeling to facilitate the simulation, and it may also take place since several environmental conditions such as the wind speed changing at any time and or the temperature changing at any time too. Figure 4 shows that the airflow speed ranges from 0 m/s to 18m/s as shown in those various colors. The highest point lies outside of the room, while in the room the highest speed is 5.36 m/s at point D3 with the temperature amounting to 33.50 ºC.

Figure 5 shows that in the actual room condition, the thermal comfort under the SNI 03-6572-2001 standard is not achieved. Nevertheless, seven points are closing in on the wind speed stipulated by SNI 03-6572-2001 standard, namely points A1, A2, A4, B1, B4, C2, and D1. At those seven points, the wind speed ranges from 0.39 m/s to 0.89 m/s.

The highest wind speed lies at point D3 since at that point there are several wind movements gathered from several windows. The temperature from the installed window is more evenly-distributed with the average indoor temperature amounting to 33.03ºC. Figure 6 shows the temperature distribution.

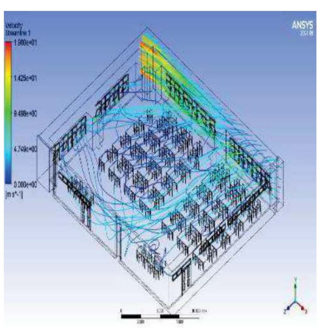

Figure 4. Existing streamline

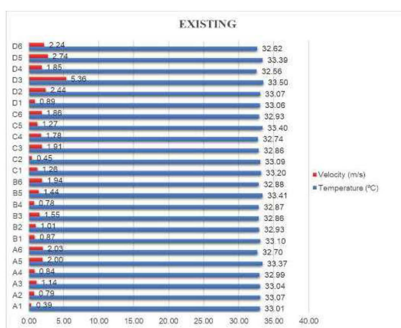

Figure 5. Existing simulation data graph

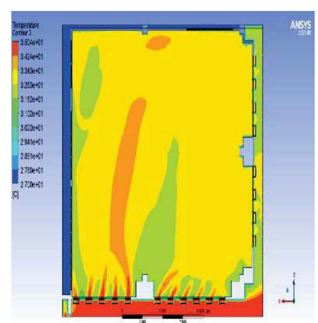

Figure 6. Temperature contour of the existing window

3.1. Simulation for the 45º - Opening Vertical Pivot

In the 45-degree-opening vertical pivot window, the airflow is not evenly distributed since the position of the window's opening angle follows the headwinds coming from outside of the room and directly heading towards the outlet window, so this situation facilitates the wind entering the room with little resistance. In this type of window, the highest wind speed amounting to 7.83 m/s lies at point D5 with the temperature amounting to 34.09 ºC as shown in Figure 7.

The simulation for the 45-degree-opening vertical pivot window also provides results suiting the standard. There are six points closer to the standard wind speed stipulated by SNI 03-6572-2001, namely points A3, A4, A6, B6, C6, and D6. At those seven points, the wind speed ranges from 0.16 m/s to 0.95 m/s. At point A4, the wind speed is 0.16 m/s, but the temperature does not still meet the standard namely 30.95ºC. Moreover, this window type cannot also meet the thermal comfort standard, either.

Based on the temperature contour, the wind in this room is observed not to be evenly distributed due to the window opening not being capable of evenly distributing the wind at a certain point. The average room temperature is 32.92ºC.

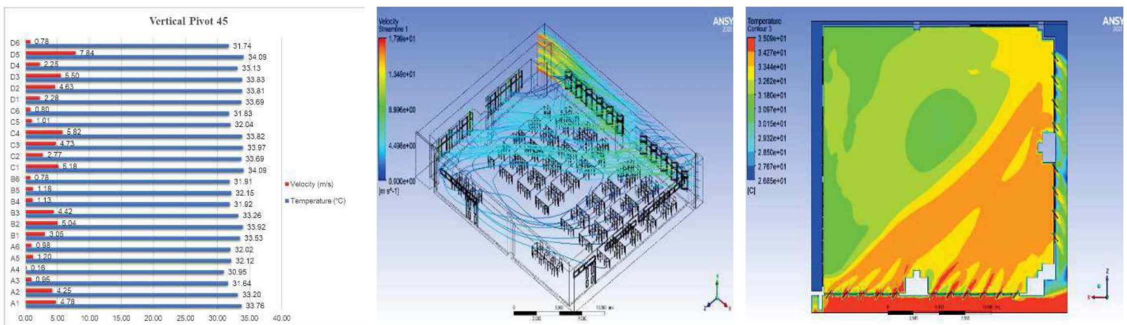

Figure 7. 45º Vertical pivot (a) data, (b) streamline, and (c) simulation graph temperature contour

3.2. Simulation for the 90º- Opening Vertical Pivot

In the 90-degree-opening Vertical Pivot window, the wind and the temperature are more evenly-distributed since that opening angle position can direct the wind into the room more optimally. In this opening angle, the highest temperature lies at point D4 amounting to 34.68 ºC with the wind speed amounting to 7.58 m/s.

The part closer to the thermal comfort standard lies at point A4 with a wind speed amounting to 0.55 m/s and a temperature amounting to 33.18 ºC and point D1 with a wind speed amounting to 0.85 m/s and a temperature amounting to 33.19 ºC. Figure 8 shows that the wind is evenly distributed in this window's opening angle taking into account the temperature contour. The temperature in this room ranges from 33.18 ºC to 34.68 ºC. Figures 8 shows that the room temperature will be affected by the temperature of the outer air entering the room. The average room temperature is 34.06 ºC.

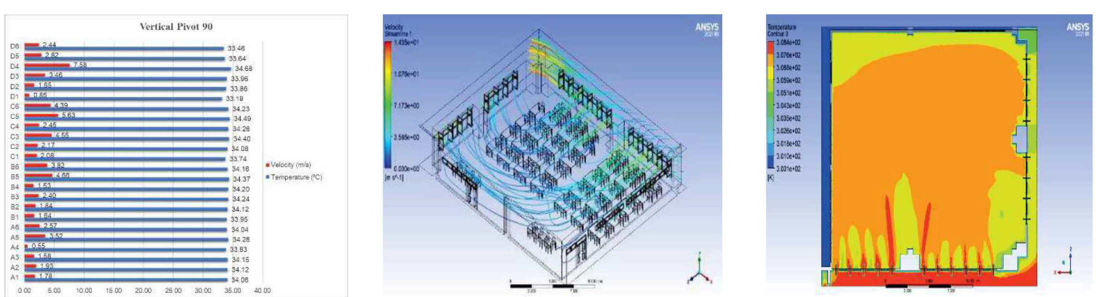

Figure 8. Streamline, and (c) simulation 90º Vertical pivot (a) data, (b) graph temperature contour

3.3. Simulation for the 135º- Opening vertical pivot

In this 135-degree-opening vertical pivot window type, due to the position of the window's opening angle leeward the outside of the room, the wind flow is reflected on the eastern side of the window, so there is an area barely exposed to the wind as shown in Figure 9 as indicated in the green color. In this window type, the highest temperature amounting to 5.32 m/s lies at point

D4 with the temperature amounting to 34.47 ºC. Moreover, the room temperature ranges from 31.456ºC to 34.469 ºC, while the wind speed ranges from 0.236 m/s to 5.322 m/s.

There are nine points closer to the standard wind speed namely points A3, B3, B4, C2, C3, C4, C5, D1, and D2. At those points, the wind speed ranges from 0.14 m/s to 0.97 m/s, while the temperature ranges from 31.46 ºC to 32.65 ºC.

The temperature is not evenly distributed since the opening angle only heads towards one side of the room. Based on the temperature contour, the highest temperature is in the eastern part of the room which is also confirmed by the wind lines as shown in FIGURE 9. The figure shows that the wind entering the room directly heads towards the eastern part of the room before going to the outlet. The average temperature in this type of opening is 33.05 ºC.

Based on the results of the simulations for the three types of alternative window openings, and a simulation for the installed window, the temperatures at several points are close to the standard temperature stipulated by SNI 03-6572-2001 (Table 3).

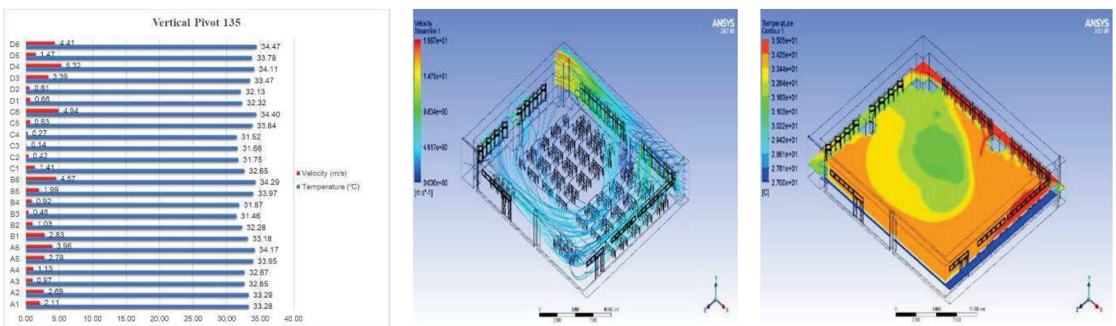

Figure 9. 135º Vertical pivot (a) data, (b) streamline, and (c) simulation graph temperature contour

Table 3. Simulation result

No.	Window Condition	Number of Points Close to the Standard	
		Velocity	Temperature
1	Installed Window Condition	7	0
2	45-º VP	6	0
3	90-º VP	2	0
4	135-º VP	9	0

4. CONCLUSION

Based on the results of the study, IT is recommended that a 135º- opening-angle vertical pivot window type be applied and developed. The best average temperature amounting = -2\to 32.92ºC is found at a 45º- opening-angle window type.

5. ACKNOWLEDGMENTS

We thank you for the support and funding of the Directorate of Resources of the Ministry of Education and Culture, Research and Technology in accordance with the Research Contract for the Implementation of the Research Program Number 520/A/LPPM-P/USAKTI/V/2023.

REFERENCES

Autodesk Flow Design. (2018). Autodesk

B. H. Sahabudin (2014). Ihsan Pengaliran Udara Untuk Kenyamanan Termal Ruang Kelas dengan Metode Simulasi Computational Fluid Dynamics, **Sinektika,** vol. 14, no. 2, pp. 209-216.

B. Hamzah, M. R. Rahim, M. T. Ishak, and S. Sahabuddin. (2017). Kinerja Sistem Ventilasi Alami Ruang Kuliah, **Jurnal Lingkungan Binaan Indonesia**, vol. 6, no. 1, pp. 51-58, doi: 10.32315/jlbi.6.1.51.

C. Amelia. (2016). Kajian Sistem Bukaan Kamar Tidur Asrama Beiyuan Gxnu terhadap Kenyamanan Termal dan Pencahayaan Alami Ruangan, Serat Rup. **Journal of Design**, vol. 1, pp. 325-342, September.

J. I. Kindangen. (2003). **Pengaruh Tipe Jendela terhadap Pola Aliran Udara dalam Ruangan Dimensi Teknik Arsitektur,** vol. 31, no. 2, pp. 158-162.

J. T. Nur Wakhida Fitria. (2019). **Kinerja Sistem Ventilasi Alami pada Masjid Besar Ainul Yaqin Sunan Giri Gresik.**

M. Kulisz *et al*., (2019) Computational fluid dynamics simulation of thermal comfort in a naturally ventilated room, **MATEC Web of Conferences,** vol. 252, p. 04007, doi: 10.1051/matecconf/201925204007.

M. S. A. Anisa Budiani Arifah, Agung Murti Nugroho. (2018). **Pengaruh Bukaan terhadap Kenyaman Termal pada Ruang Hunian Rumah Susun Aparna Surabaya.**

P. R. Margherita Ferrucci, Fabio Peron, Mauro Strada. (2022). Computational Fluid Dynamic Study with Comfort Analysis in Large Atrium of the Angelo Hospital in Venice, **Energies**, vol. 15.

R. D. N. Natalia Damastuti. (2017). Simulasi Keceptan Angin dengan CFD untuk Mengetahui Tingkat Kenyamanan Termal Masjid Narotama. **Prosiding SENTIA,** vol. 9, no. 2085-2374, pp. II1 - II4.

S. Kato. (2018). Review of airflow and transport analysis in building using CFD and network model, Japan **Architectural Review,** vol. 1, no. 3, pp. 299-309. doi: 10.1002/2475-8876.12051.

S. Omrani, V. Garcia-Hansen, B. R. Capra, and R. Drogemuller. (2017). Effect of natural ventilation mode on thermal comfort and ventilation performance: Full-scale measurement, **Energy and Buildings,** vol. 156, pp. 1-16, doi: 10.1016/j.enbuild.2017.09.061.

T. Wati and F. Fatkhuroyan. (2017). Analisis Tingkat Kenyamanan Di DKI Jakarta Berdasarkan Indeks THI (Temperature Humidity Index). **Jurnal Ilmu Lingkungan,** vol. 15, no. 1, p. 57, doi: 10.14710/jil.15.1.57-63.

Tahang. (2016). Teknik Sistem Simulasi Termal Bangunan dengan Menggunakan Perangkat Computating Fluid Dynamic (CFD). **Jurnal Ilmiah Tecno Entrepreneur Acta**vol. 1, no. 1, pp. 49-54.

Tata Cara Perencanaan Sistem Ventilasi dan Pengkondisian Udara pada Bangunan, **SNI.** (2001).