Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 170 (2017) 240 – 247

Procedia Engineering

www.elsevier.com/locate/procedia

Engineering Physics International Conference, EPIC 2016

A study of thermal comfort and occupant satisfaction in office room

Jouvan Chandra Pratama Putra*

Department of Civil Engineering, Universitas Bakrie, Jl. HR Rasuna Said Kav. C 22, Jakarta Selatan, 12920, Indonesia

Abstract

This paper presents an investigation regarding the effect of indoor thermal to building's occupant satisfaction which is equipped by mechanically ventilated. The investigation is consisted of two parts, in which the first part is to visualise the indoor environmental quality of the office room in-term of air velocity distribution and indoor temperature distribution. Whereas, the second part is to obtain the perception of building's occupants regarding their satisfaction to the indoor air and thermal inside the building. An approach of modelling and simulation was carried out using COMSOL Multiphysics software to visualise indoor environmental quality and an approach of questionnaire was adopted to obtain the perception of building's occupants. The results show that the geometry model also affects to the air circulation and maintain indoor temperature distribution. This evidence occurred when the distribution of indoor air of office room didn't distributed homogeneously to the hallway as impact of the streamline, but the distribution of indoor temperature is still uniform. Additionally, the condition of temperature inside office room is not a single factor that contribute to the dissatisfaction of building's occupants. Since most of office workers are unauthorized to adjust temperature and air velocity of the air-conditioning system, this contributes to 40 % of respondents that are dissatisfaction with temperature and air velocity. Finally, this study found that the relationship amongst indoor environmental quality to produce occupant satisfaction is a complex system that need to be assessed comprehensively. Besides, it is invaluable to advance our understanding of the relationship amongst ventilation system, occupant behaviour, and building energy in tropical climate in assessment of occupant satisfaction.

Peer-review under responsibility of the organizing committee of the Engineering Physics International Conference 2016

Keywords: Thermal Comfort; Air Velocity; Occupant Satisfaction; COMSOL Multiphysics; Modelling and Simulation.

1. Introduction

In recent years, the investigation regarding energy efficiency is being studied and developed due to the limitation of fossil fuels. An excessive consumption of fossil fuels has raised the emission of carbon dioxide [1] and impacted in increasing global temperature [2]. One of the highest consumption of energy existed in office buildings, this is due to the building's occupants need to work in comfort condition. Hence, indoor thermal condition needs to be controlled in order to provide occupant satisfaction in an office building. Furthermore, the easiest and least expensive way to solve "energy problem" is not to augment energy supply, but to reduce the amount of energy needed. This is due to respond to the increased requirement for local control of indoor heat load, and to meet the thermal preferences by individuals [3].

Thermal comfort is described as state of mind which express satisfaction with the thermal environment [4]. According to ASHRAE standard 55, "Thermal Environmental Conditions for Human Occupancy" [5], people mostly feel comfort when temperature shows in the range of 70°F - 79°F (21°C-26°C). However, achieving overall thermal comfort in a building is a complex task due to its related to various aspects such as age, sex, metabolism rate, time of the year [6]. Subsequently, Al Horr et al., [7] proposed an approach to estimate indoor thermal comfort through analyze a number of discomfort complaints. It is

* Corresponding author. Tel.: +62 81288956310.
E-mail address: jouvan.chandra@bakrie.ac.id

Peer-review under responsibility of the organizing committee of the Engineering Physics International Conference 2016
doi:10.1016/j.proeng.2017.03.057

influenced of six factors namely air temperature, air velocity, relative humidity, mean radiant temperature, clothing insulation, and metabolic rate.

An initial work instrumental to estimate indoor thermal comfort was developed by Fang [8]. He developed an analytical model to predict thermal comfort by elaborating four physical parameters such as air temperature, mean radiant temperature, air velocity, and relative humidity with human variables namely clothing insulation and activity index to define the Predicted Mean Vote (PMV) index. Besides, due to the comfort of indoor thermal affects the satisfaction of building's occupant, Fanger also calculated Percentage of Dissatisfied Occupants (PPD) that is derived from PMV index [8].

It predicts the percentage of people who could be dissatisfied with a thermal environment. It predicts if a large group individual are likely to feel "too warm" or "too cold", defined by voting +3, +2, -3, -2 on the scale [9].

In this paper, an approach of Fanger's work instrumental is modified by adding modelling and simulation to visualise the distribution of air velocity and indoor temperature to assess the indoor environmental. Additionally, perception regarding occupant satisfaction in office room building is determined through questionnaire survey.

2. The model of study

2.1. Site Description

The model subjected of this study is an Office for Research, Innovation, Commercialization, and Consultancy Management (ORICC) at Universiti Tun Hussein Onn Malaysia. The selection of this office is based on its location which is situated at near the factory that frequently emits air pollutants as in Figure 1.

Fig. 1. Location of ORICC office with evergreen factory in 200 m distance

2.2. Geometry Model

The geometry model of one of ORICC's room was constructed by using COMSOL Multiphysics software and validated on previous study [10]. This selection is based on the highest temperature of indoor air recorded during the measurement period.

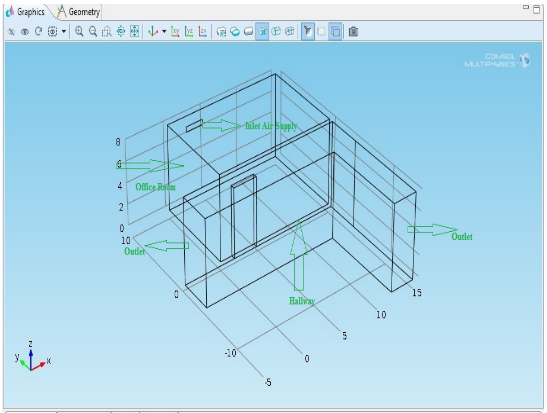

Fig. 2. Geometry model

The model dimension of office room as shown in Figure 2 was constructed with the direction of x = 15 ft, y = 10 ft, and z = 8 ft. While the dimension of hallway is consisted of 2 parts where hallway 1 was constructed with the direction of x = 20 ft, y = 4 ft, and z = 8 ft. Whereas, for hallway 2 was constructed with the direction of x = 3 ft, y = 10 ft, and z = 8 ft. In addition, inlet air supply was modelled with the direction of x = 2.2 ft and z = 0.5 ft. Subsequently, a model of door was developed with the dimension of x = 2.5 ft and z = 6.5 ft.

3. Methods

3.1. Sample collection

The measurement was carried out for eight hours during weekday. The parameters measured are inlet air supply which is measured by using Davis Anemometer and indoor air temperature by using Yes Plus LGA Meter. Davis Anemometer equipment can measure air velocity from 1 mph to 200 mph; 1 to 322 kph; 1 to 173 knots; and 0.5 to 89 m/s with accuracy of 3 % [11]. Besides, Yes Plus LGA Meter equipment can measure air temperature in the range of 5°C to 50°C and relative humidity in the range of 0 to 99 %. These two equipments are shown as in Figures 3 and 4.

Fig. 3. Davis Anemometer

Fig. 4. Yes Plus LGA Meter

3.2. Questionnaire

Questionnaire is a technique to collect data and instrument that used for data collection [12]. In addition, to obtain the perception of building's occupant regarding indoor environmental quality (IEQ), the common approach is by measuring thermal perception as one of IEQ's indicator [13]. In this study, a set of questionnaire was designed to assess the relationship between indoor thermal with the building's occupant satisfaction. The questionnaire consisted of 2 parts where the first part is to identify the demography of building's occupant and the second part is to identify the indoor thermal condition relate to building's occupant satisfaction.

Subsequently, a five points of Likert Scale was used in this questionnaire part to interpret the perception of office workers regarding their satisfaction to the existing indoor thermal as in Table 1.

Table 1. Scale used to measure occupant's satisfaction

Scale	Degree of satisfaction
1	Very dissatisfied
2	Dissatisfied
3	Neutral
4	Satisfied
5	Very Satisfied

Once the data from questionnaire surveys collected, then all the data gathered are analyzed by using descriptive statistical approach and presented into graph and bar chart.

4. Results and Discussion

Once the data collection done, the results and discussion are presented in 3 sections as follows:

4.1. Air velocity, air contour, and air streamline

The air velocity modelled and simulated are based on the highest value of air velocity which was gathered during measurement period. These input values are tabulated as in Table 2.

Table 2. Inlet air supply

No of model	Inlet air supply (m/s)
1	1.0
2	1.5

Once it done, those values are inputted as input air supply to model and simulate the distribution of indoor air of the selected room as in Figures 5 and 6.

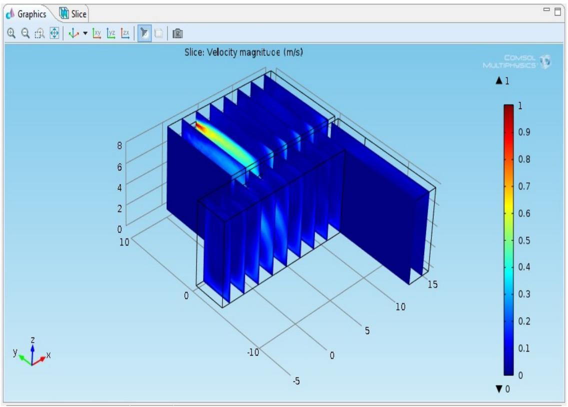

Fig. 5. Air velocity distribution of inlet air supply at 1 m/s

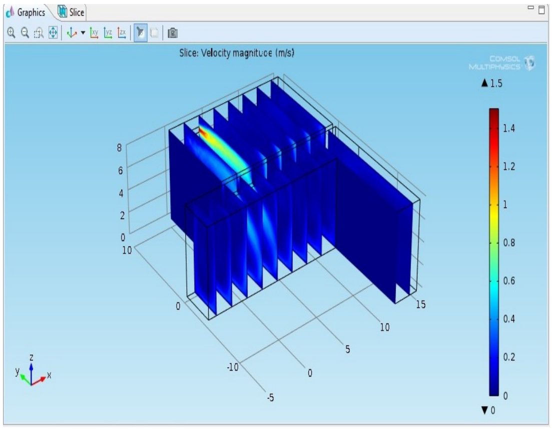

Fig. 6. Air velocity distribution of inlet air supply at 1.5 m/s

Air velocity distributed indoor is influenced by the room boundaries that lessen its value and this is considered as one of factor that trigger the consumption of energy. Additionally, the location of inlet air supply as an inlet of air velocity to discharge the air velocity to room and hallway also affected by the position of inlet and outlet. Due to the location inlet and outlet in this study is situated at in line position, then the air velocity distribution that discharged to hallway area is still in the medium value of air velocity which is in the range of 0.6 m/s to 0.3 m/s.

Subsequently, an analysis by Humphreys [14] revealed that in tropical climates, air movement is an important factor in determining comfort. In which, air velocity above 0.1 m/s and fairly constant can be equivalent for raising the comfort temperature by:

$$7 - \frac{50}{4+10v^{0.5}} \,°C \tag{1}$$

Additionally, a study regarding occupant productivity that was carried out by Al Horr et al., [7] stated that an appreciation of better occupant performance raising in line with their comfort to work. The study reports that the yearly economic benefit of US$ 13 billion by increasing minimum ventilation rates from 8 to 10 l/s per person and US$ 38 billion by increasing ventilation rates from 8 to 15 l/p per person on a US wide scale [15]. Generally, there are different ventilation systems available to control ventilation rate in building. These are naturally ventilated systems, hybrid/mix mode systems, and mechanically ventilated systems. A study that carried out by Ezzeldin and Rees [16] indicated that mixed mode HVAC systems have higher air quality satisfaction and energy savings than other HVAC systems. However, the selection of HVAC system should be based on the various local climate factors, building type, and occupant behavior pattern and expectations [17].

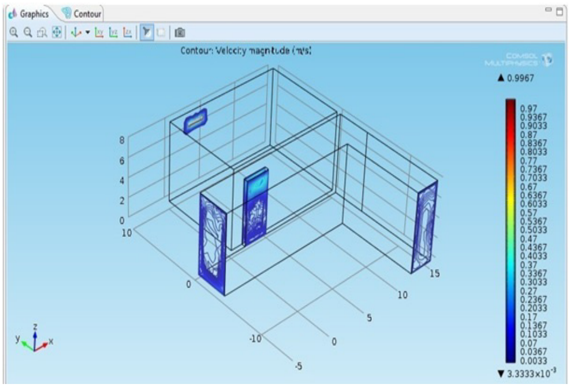

Fig. 7. Air velocity contour at 1 m/s

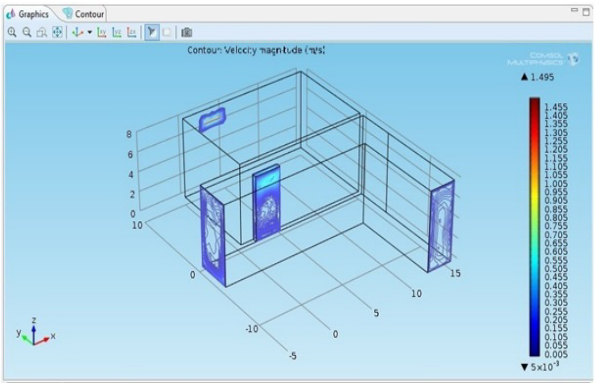

Fig. 8. Air velocity contour at 1.5 m/s

As depicted in Figures 7 and 8, the air velocity streamlines made the same pattern which shows the value at both hallway left and right is tending to zero. Subsequently, to investigate this situation it need to be simulated the streamline pattern of air velocity behaviour. The results are presented as in Figures 9 and 10.

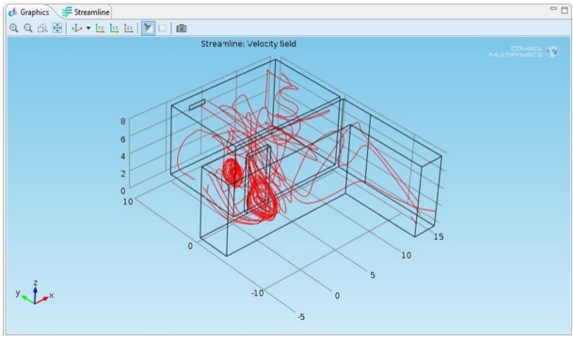

Fig. 9. Air velocity streamline at 1 m/s

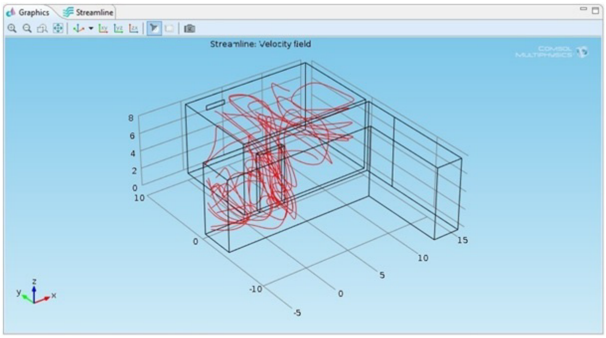

Fig. 10. Air velocity streamline at 1.5 m/s

From Figures 9 and 10, it show that the streamline pattern is frequently colliding in intersection area between room and hallway. This is considered as a factor that contributes to the condition of air velocity at both left and right of hallway is tend to zero. Additionally, imperfect mixing of air distribution is produced by a flow streamline intake in the ceiling directly to the hallway through the door, which of course would reduce the air flow to the corner of the room [18].

4.2. Indoor air temperature distribution

Indoor temperature was measured to be modelled and simulated are tabulated as in Table 3.

Table 3. Indoor air temperature measured

No of model	Indoor air temperature (K)
1	302.25
2	302.15

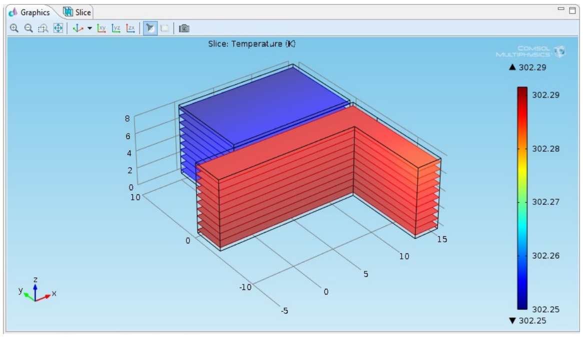

Fig. 11. Indoor air temperature distribution at model 1

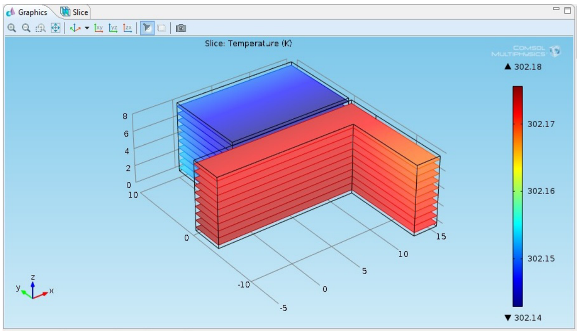

Fig. 12. Indoor air temperature distribution at model 2

Figures 11 and 12 indicate that the indoor temperature distribution between room and hallway is quite same. Since the value of air velocity in both left and right at hallway is tend to zero as in Figures 5 and 6. Then, the indoor temperature distribution should be tend to zero, However, this finding is shows conversely. It is considered that the effect of air distribution in the hallway is not only affected by the condition of the air velocity from the room. The potential possibility to make this things happen is the geometry model of this office building in terms of its height.

4.3. Occupant satisfaction

The questionnaire survey was performed to assess the strength of association between indoor thermal and occupant satisfaction. A total of 20 sets of questionnaire were distributed to the office workers of the ORICC office building in UTHM. All the distributed questionnaires were returned back. The data from the questionnaires were descriptively analyzed and the findings are presented and discussed as follows:

Out of 20 workers participated in this survey, 7 are males and 13 are females. Besides, in-term of their academic qualification, 60 % of the office workers hold diploma and 40 % with bachelor degree. Practically, the office workers in this office building are quite capable and competent to participate in the survey. In addition, the duration staying/working in the office building is very important to determine whether the occupant's perception to describe their satisfaction is correct. The demography of worker's duration staying/working in the office building is presented as in Figure 13.

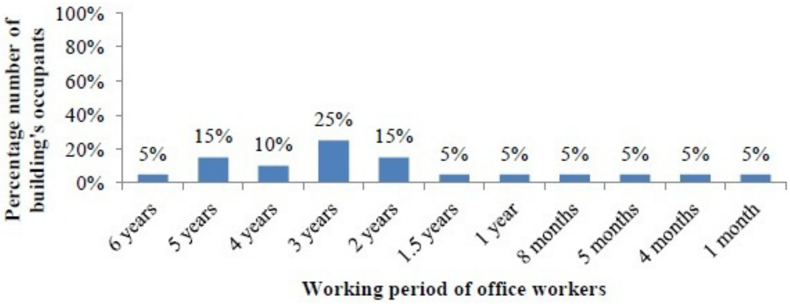

Fig. 13. The percentage of working period of occupants in the office building

The highest percentage of office workers working in the office is 25 % (5 persons) which means majority of the workers had been working for 3 years in the office. However, for the workers who had been working for 1 month, 4 months, 5 months, 8 months, and 6 years are surveyed as the lowest percentage of office workers working in this office with the value of 5 %.

Moreover, the building's occupants were requested to give their perception regarding satisfaction level and the perceived of thermal and air velocity. The results of occupant's perception are presented as in Figures 14 and 15.

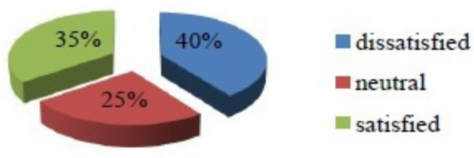

Fig. 14. Occupant satisfaction regarding temperature

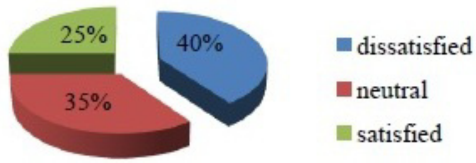

Fig. 15. Occupant satisfaction regarding air velocity

The findings revealed that 40 % of buildings occupant dissatisfied on thermal condition due to its hot condition. Additionally, the air velocity perceived by the building's occupant is low and resulted to the 40 % dissatisfaction amongst the building's occupant.

5. Conclusion

This study gave a perspective that thermal comfort is rely on individual of occupant and their mind perspective regarding comfort. This consequence leads to the discrepancy result from the direct measurement and perception of building's occupant. Subsequently, the adoption of standard to design air-conditioning must conform with the existing climate to create optimum comfort and energy efficiency as well.

Besides, the utilization of modelling and simulation techniques are an exact approach. This strategy is more beneficial if added with social behaviour approach such as questionnaire technique to solve problems that involve human perception.

References

[1] Harimi, D., Ming, C. C., Kumaresan, S. "A generalized thermal perception approach for indoor thermal comfort assessment in the humid tropics of Malaysia," Energy Build., vol. 88, pp. 276–287, Feb. 2015.

[2] Solomon, S., Plattner, G., Knutti, R., Friedlingstein, P. "Irreversible climate change due to carbon dioxide emissions," PNAS Environ. Sci., vol. 4, pp. 1704 – 1709, 2009.

[3]Bauman, F. S., Arens, E. A. "TASK / AMBIENT CONDITIONING SYSTEMS : ENGINEERING AND APPLICATION GUIDELINES FINAL REPORT," 1996.

[4] American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) "ANSI/ASHRAE 55-2004. Thermal environmental conditions for human occupancy," Atalanta, USA, 2004.

[5] ASHRAE Standard 55, "Thermal Environmental Conditions for Human Occupancy," 2003.

[6] Cena, K., Dear, D. R. "Thermal comfort and behavioural strategies in office buildings located in a hot-arid climate," J. Therm. Biol., vol. 26, no. 4–5, pp. 409–414, Sep. 2001.

[7] Al Horr, Y., Arif, M., Kaushik, A., Mazroei, A., Katafygiotou, M., Elsarrag, E. "Occupant productivity and office indoor environment quality: A review of the literature," Build. Environ., vol. 105, pp. 369–389, Aug. 2016.

[8] Fanger P. O., “Moderate Thermal Environments Determination of the PMV and PPD Indices and Specification of the Conditions for Thermal Comfort,” 1984.
[9] Olesen, B. W., Parsons, K. C. “Introduction to thermal comfort standards and to the proposed new version of EN ISO 7730,” vol. 34, 2002.
[10] Rahman, I. A., Putra, J. C. P., Asmi, A. “MODELLING OF PARTICLE TRANSMISSION IN LAMINAR FLOW USING COMSOL MULTIPHYSICS,” vol. 11, no. 10, pp. 6630–6637, 2016.
[11] Davis Instruments, Standard Anemometer Installation Manual. pp. 1–8.
[12] Brown, Using Surveys in Language Programs. Cambridge: Cambridge University Press, 2001.
[13] Chuen, L. K. “The Concept of Safe Indoor Air Quality for The Management of Indoor Environment in Immune Buildings,” Hong Kong Polytechnic University, 2010.
[14] Humphreys, M. A. “A simple theoretical derivation of thermal comfort conditions,” J. Inst. Heat. Vent. Eng., no. 33, pp. 95 – 98, 1970.
[15] Fisk, W. J., Black, D., Brunner, G. “Changing Ventilation Rates in U . S . Offices : Implications for Health , Work Performance , Energy , and Associated Economics,” Build. Environ., vol. 47, pp. 368 – 372, 2012.
[16] Ezzeldin, S., Rees, S. J. “The potential for office buildings with mixed-mode ventilation and low energy cooling systems in arid climates,” Energy Build., vol. 65, pp. 368–381, Oct. 2013.
[17] Kim, J., Dear, D. R. “Impact of different building ventilation modes on occupant expectations of the main IEQ factors,” Build. Environ., vol. 57, pp. 184–193, Nov. 2012.
[18] Tichenor, B. A. Characterizing Sources of Indoor Air Pollution and Related Sink Effects. West Conshohocken, USA: ASTM 100 Barr Harbor Drive, 1996.