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Impact of elevated outdoor MRT station towards passenger thermal comfort: A case study in Jakarta MRT

Key words: elevated MRT station, thermal comfort, computational fluid dynamic (CFD), predicted mean vote (*PMV*), predicted percentage of dissatisfied (*PPD*)

Introduction

Human comfort is affected by both physical and psychological factors. Human requires an optimum environmental condition to work effectively and efficiently. Bridger (2003) in his book mentioned several things that cause human comfort, for instance: temperature, light emitting, humidity, air circulation, odor, dust, sound and lighting. The microclimatic parameters around the MRT depend on its layout, material, size, air/wind flow through the surrounding buildings and quality of the air carried by a moving train. The British standard BS EN ISO 7730:2005 defines heat comfort as conditions and situations of the human mind that express his/her satisfaction towards the heat level of the surrounding environment. Heat comfort describes psychological conditions that indicate feeling cold or hot. Heat comfort is subjective and as the result, it is difficult to define what “comfortable” is. According to the standard ASHRAE 55-2004, thermal comfort is the level of human perception related in expressing their satisfaction towards the thermal environment and this perception depends upon subjective views. Ponni and Baskar (2015) explained that thermal performance of a building is a description of the process of modeling energy transfer between a building and its environment.

The Health and Safety Executive noted that the most suitable indicator of heat comfort is number of individuals working in a workspace who are satisfied with the temperature of the workspace. Therefore, HSE believe that a minimum of 80% of workers occupying a building should find the temperature reasonable (HSE, 2017). Höppe (2002) stated three types of thermal comfort approaches: thermophysiological, heat balance and psychological. Researchers have investigated thermal comfort for trains, both thermal comfort on the train and at the station. Jenkins, Gilbey, Hall, Glenis and Kilsby (2014) investigated the impact of thermal discomfort due to clime change in underground railways. Temperature changes due to urban development will have an impact on human thermal comfort of MRT passengers. As an addition, Li et al. (2009) used computational fluid dynamics (CFD) simulations to evaluate the level of thermal comfort through three air conditioning installation schemes. This research mainly investigated the influence of wind speed, temperature, altitude and angle from the improvement of air circulation through air conditioners. The strong majority of the research studies concerning on MRT thermal comfort inside the MRT train and inside the underground MRT station. That is no specific research which discussed thermal comfort in outdoor elevated MRT station more than 20 m above ground level. Assimakopoulos and Katavoutas (2017) discussed the thermal comfort affected by the occupation of the railroad platform, namely the depth of the railroad canal to the train station surface. Furthermore, they were investigated thermal comfort conditions at the 0 m platforms of the outdoor Athens Metro. Tropical and subtropical climates will also make a difference in the character of thermal comfort.

Geographically, Jakarta has tropical climate and therefore, the highest average temperature takes place in October (36.2°C for north-south and 37.7°C for the east-west), while the lowest occurs in November and February (approximately 32.5°C) (Maru, Ahmad, Malaysia & Malaysia, 2014). Rural Chemical Industries (Aust) Pty Ltd (n.d.) in their article mentioned that the highest relative humidity in Jakarta takes place in February (85%) and the lowest one is in August (68%). Another factor contributing to this is that the fact that Indonesia is situated between two oceans and two continents. Indonesian standard SNI 6390:2011 described the national guidelines of thermal comfort. It explains that temperature comfort of working space is 25.5°C (±1.5°C) and relative humidity (*RH*) is 60% (±5%). For semi-outdoor space such as lobby, and open-space MRT station, temperature for thermal comfort is 28.5°C (±1.5°C) with relative humidity of 60% (±10%). In general, human starts to produce sweat at the temperature of 26°C. Human productivity is degrading when the temperature is higher than 24°C (Lan, Wargocki & Lian, 2011). Working performance decreases by 2% when the temperature increases by 1°C above 25°C (Seppänen, Fisk & Faulkner, 2005). It is difficult for human to work at the temperature between 33.5 and 35.5°C. Human being cannot perform well at the temperature of over 36°C (Sugiono, Swara, Wijanarko & Sulistyarini, 2017).

Comfort thermal evaluation using predicted mean vote (*PMV*) is suitable for semi-outdoor building, for example elevated MRT station. Predicted mean vote will measure comfort by calculating the combination between ambient temperature and relative humidity. AREN 3050 (2005) used *PMV* scale translated from the ASHRAE thermal sensation scale guideline. Kurazumi et al. (2012) emphasized on the use of *PMV* to analyze climate change and stress level of urban community. Predicted percentage of dissatisfied (*PPD*) represents satisfaction level of residents towards thermal comfort. Based on standard ASHRAE 55-2004, the acceptable and recommended *PPD* for thermal comfort is lower than 10% of dissatisfied residents (Stanton, Hedge, Brookhuis, Salas & Hendrick, 2004). Many scholars used *PPD* to analyze thermal level, for instance Pourshaghaghy and Omidvari (2012) investigating thermal comfort in hospital building. Simion, Socaciu and Unguresan (2016) used *PPD*/*PMV* to analyze thermal comfort in vehicles. Computational fluid dynamic simulation was developed to describe airflow pattern that hit human. Studies involving CFD to predict thermal comfort were conducted by several researchers, for example Mochida, Yoshino, Takeda, Kakegawa and Miyauchi (2005), Stavrakakis, Zervas, Sarimveis and Markatos (2010), Alajmi, Baddar and Bourisli (2015).

Research theory

Thermal comfort

Höppe (2002) mentioned three approaches of thermal comfort, thermophysiological, heat balance, and psychology. Karyono (2001) defined thermal comfort as hot or cold sensation as response from our skin towards the surrounding temperature. Parsons (2014) argued that it is the thermal state of the human body that determines the thermal sensation. Standard BS EN ISO 7730:2005 stated that condition of mind expresses satisfaction with the thermal environment (Epstein & Moran, 2006) and is assessed by subjective evaluation (ASHRAE 55-2004; Bean, 2012). According to standard ISO 7730:2005 thermal (heat) balance is obtained when the internal heat production in the body is equal to the loss of heat to the environment. Boutet (1987) noted that psychological factor is an aspect to consider in thermal comfort as each individual has different perception on comfort (Purnomo & Rizal, 2000).

Heat is the main factor affecting human activities and performance. To perform well, human requires a comfortable and constant temperature. Lippsmeier (1997) stated that the suitable temperature for people living in the equator is between 19 and 26°C. The classification is as follows:

- at the temperature of 26°C, human in general starts to produce sweat;
- between 26 and 30°C, resistance and performance start to decline;
- between 33.5 and 35.5°C, human can barely adapt to the condition of the environment;
- between 35 and 36°C, human can no longer adapt to the condition of the environment.

Human body produces heat as the result of metabolism and controls it while maintaining body heat balance. Increase or decrease of internal temperature (higher or lower than the normal range) will disturb both mental and physical activities, and in an extreme temperature difference, serious physiological or health issues may take place. Human or animals increase their temperature so that their

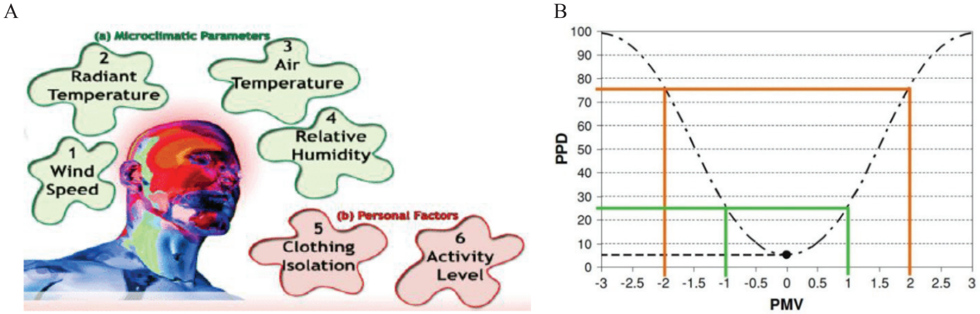

FIGURE 1. Predicted mean vote and predicted percentage of dissatisfied: A – six parameters of the *PMV* in human thermal comfort (Sugiono et al., 2017); B – *PPD* calculation based on *PMV* (ASHRAE 55-2004)

immune system can work effectively to kill bacteria or viruses.

Predicted mean vote refers to index used to predict an overall thermal sensation that individuals in a large group experience (Stanton et al., 2004). Model of *PMV* shows that thermal sensation can be described as function of thermal load in effector mechanism of the human thermoregulatory system. In normal situation, the thermoregulatory system will automatically modify skin temperature and sweat secretion to maintain body heat balance. Predicted mean vote determines range of temperature sensation human experiences towards his or her surrounding. Predicted mean vote scale is between –3 (extremely cold) and +3 (extremely hot). Figure 1a explains six factors of *PMV* to define the human thermal comfort. According to the figure, it can be divided into two categories: microclimatic parameters (radiant temperature, air temperature, wind speed, and relative humidity) and personal factors (clothing isolation and activity level). Predicted mean vote equation can be used when activity (metabolism pace) and clothing (thermal resistance) are estimated, and some parameters of the environment, such as: temperature, mean radiant temperature, relative air velocity, and relative humidity, are measured directly (Simion et al., 2016).

Predicted mean vote can be estimated based on Equation 1 combining four microclimatic parameters and two personal factors mentioned previously (Stanton et al., 2004).

$$PMV=(0.303e^{-0.036M}+0.028)\{(M-W)-3.05\cdot10^{-3}[5733-6.99(M-W)-p_a]-0.42[(M-W)-58.15]-1.7\cdot10^{-5}M(5867-p_a)-0.0014M(34-t_a)-3.96\cdot10^{-8}f_{cl}[(t_{cl}+273)^4-(MRT+273)^4]-f_{cl}h_c(t_{cl}-t_a)\} \quad (1)$$

In which:

$$t_{cl}=3.57-0.028(M-W)-I_{cl}\{3.96\cdot10^{-8}f_{cl}[(t_{cl}+273)^4-(\bar{t}_r+273)^4]+f_{cl}\cdot h_c\cdot(t_{cl}-t_a)\}h_c=2.38(t_{cl}-t_a)^{0.25}$$

$$\text{for } 2.38(t_{cl}-t_a)^{0.25}>12.1\sqrt{\upsilon_{ar}}$$

$$h_c=12.1\sqrt{\upsilon_{ar}} \text{ for } 2.38(t_{cl}-t_a)^{0.25}<12.1\sqrt{\upsilon_{ar}}$$

$$f_{cl} = 1.00 + 1.290\ I_{cl}$$
$$\text{for } I_{cl} \leq 0.078\ \text{m}^2 \cdot {}^\circ\text{C}^{-1} \cdot \text{W}^{-1}$$

$$f_{cl} = 1.05 + 0.645\ I_{cl}$$

$$\text{for } I_{cl} > 0.078\ \text{m}^2 \cdot {}^\circ\text{C}^{-1} \cdot \text{W}^{-1}$$

Predicted percentage of dissatisfied (*PPD*) is derivation of *PMV* predicting percentage of dissatisfied individuals from a large group towards the temperature (thermal comfort) (Stanton et al., 2004). Once *PMV* has been obtained, *PPD* can be measured based on Equation 2:

$$PPD = 100 - 95 \cdot \cdot e^{-(0.03353 \cdot PMV^4 + 0.2179 \cdot PMV^2)} \tag{2}$$

To measure *PPD* for room with direct sun radiation, we should make some adjustment towards the equations first. Equation 3 (Chaiyapinunt, Mangkornsaksit & Phueakphongsuriya, 2004) is the result of the adjustment. Figure 1b shows the relationship of *PMV* and *PPD* values for human thermal comfort. Environmental conditions that are too hot (+*PMV*) and too cold (–*PMV*) give a high *PPD* value (discomfort perception). According to the graph, the lowest percentage of *PPD* is 5%, it means that even in neutral condition 5% individuals will be dissatisfied

$$PPD = PPD_{\text{no solar}} + PPD_{\text{solar radiation}} \tag{3}$$

Human heat stress

Heat stress can be defined as combination of environmental and non-environmental factors that cause heat radiation to enter the body or prevent heat dissipation by the body (Bridger, 1995). Heat stress can occur when the body absorbs or produces more heat than that can be discharged through the thermoregulatory process, and illness and death can occur as a result of rising core temperatures (Stanton et al., 2004). Outdoor conditions can indicate the risk of heat stress that people who live in hot climates can experience. Heat stress can occur in unique situations, such as fire fighting. Indoor, heat stress occurs in many workplaces, such as iron and steel smelting, glass making factories, bread making factories, commercial kitchens, laundry, and power plants. Individual behavioral factors, such as wearing protective clothing can also increase risk of heat stress. Heat stress varies between individuals depending on physiological risk factors that an individual has.

Heat stress may result in several heat disorders and severe heat disorders may cause death. According to EU-OSHA (2012), some examples of heat disorders induced by heat stress are: heat stroke, heat exhaustion, heat syncope, heat cramps, heat rash, and transient heat fatigue among others. Heat stroke has several symptoms, namely hot, red, freckled or bluish dry skin, perspiration, confusion, loss of consciousness, seizure, fast pulse, and rectal temperature higher than 40°C. The cause of heat stroke is partial or overall failure of sweat mechanism and as the result, the body is unable to get rid of excess heat. Treatments for heat stroke are contacting medical professionals and reducing victim's temperature immediately. Heat stroke can be prevented by acclimation, close monitoring on the symptoms of heat stroke, medical screening, and plenty of water. Transient heat fatigue has several symptoms, such as decreasing working performance, particulary in skilled physical labor, mental labor and type of work where concentration is required. The causes of transient heat fatigue are discomfort and exposure to heat. Transient heat fatigue can be prevented by acclimation and training. Thermal comfort on trains occurs in many locations which are divided into three locations: inside the train, inside the station and locations outside to the station. Based on the initial survey, the high temperature outside the station (> 30°C) and setting the temperature inside the train at temperatures of 20–22°C is a problem that must be investigated. Furthermore, passengers were feel hot and cold in some location of Jakarta MRT.

Research methodology

As mentioned before, the main objective of this paper is to measure the existing thermal comfort of passengers in the elevated MRT station and then to give some recommendations to gain more comfort. There are seven elevated stations (outdoor) in the city so far, namely Lebak Bulus, Fatmawati, Cipete Raya, Haji Nawi, Blok A, Blok M, and Sisingamangaraja. Based on the review of related literatures, the approaches used to evaluate thermal comfort of passsengers in MRT station were *PMV* and *PPD* that involved six factors, including clothing isolation, pace of metabolism, relative wind speed, temperature, relative humidity, and a series of average temperature.

To understand design of the existing MRT stations from thermal comfort point of view is a vital aspect in this study. To achieve the goal, the study used descriptive approach. Descriptive study comprises of exploration, clarification, and interpretation of phenomena on thermal comfort. The primary data, condition of the MRT stations, were obtained from field observation, while data on the parameters thermal comfort and a 3D model of the MRT stations were obtained from direct measurement, observation and interviews. Observation was conducted to identify passenger's activities, the reference for the pace of metabolism (contact), and passenger's clothes, the reference to determine cloth insolation score (clo). Airvelometer (Alnor AVM440-A) is used to measure velocity, temperature, humidity and calculates flow and actual/standard velocity. The secondary data were readily available data or ones prepared by the MRT officials. The secondary data were the dimensions of the elevated MRT stations and its interior design.

Figure 2a shows the research procedures which are starting from data collection, *PMV* and *PPD* calculation and probing ideas on solutions of the passengers' heat stress. The first step was to collect data on *PMV* factors from several MRT locations. Predicted mean vote was used to predict *PPD* using Equation 2. The following steps were to develop a 3D model of the MRT using the CAD and test it using the CFD simulation to describe the real situation from the distribution of air velocity, temperature and relative humidity contour. Computational fluid dynamics (CFD) is a computational method used to identify dimension, area and volume of fluid media; it shows calculation for each denominator. The advantages of CFD software are it is time and cost-efficient. The CFD can

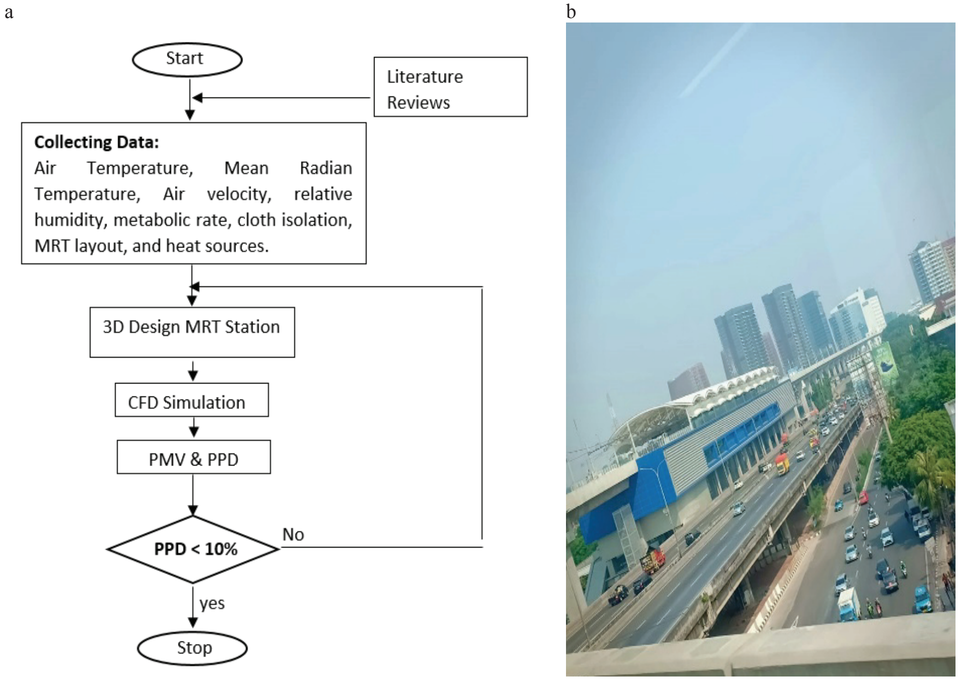

FIGURE 2. Research methodology and object: a – steps for identifying the best MRT station design in terms of thermal comfort; b – Fatmawati station

also be used to measure the parameters of airflow such as velocity, relative humidity, temperature, and average radiant temperature. The CFD can reduce design engineering process. These are the importance of CFD simulation to understanding characteristics of flow of fluid in studies on heat. This simulation provides graphic, vector, contours and animated videos. Validation was conducted by making comparison between *PMV* score from the primary data and one from CFD simulation. When average *PPD* is higher than 10%, changes should be made on the condition of the MRT station. In this case, CAD model and CFD simulation were the key factors to improve heat comfort of the warehouse workers.

The object of the study was Fatmawati MRT station, the highest elevated MRT station in Jakarta. Other considerations to select the MRT station as the object were its building complexity and the flyovers nearby (Fig. 2b). The length of Fatmawati MRT station is 175 m, width is 22.3 m, and height reached 34.3 m (from the surface of the road to the roof of the station) and 25.6 m (from the surface of the road to the passenger platform). The station roof adopted natural ventilation system allowing air circulation freely. Measurement of the environment (temperature, air velocity, and relative humidity) was conducted on the ground, the first and the second floor (platform). The researchers selected several locations in which a lot of passengers passed by or conduct their activities. There are four locations for collecting the environmental data: ticket purchase queue, MRT station entrance, passenger waiting room and cafe. Data collection was conducted between 7:00 a.m. to 8:00 p.m. based on the ASHRAE. The highest temperature occurred between 11:00 a.m. to 3:00 p.m on the dry season (June, July and August). Passenger's metabolism was evaluated based on how much they sit down and walk, while clothing isolation data were obtained based on casual or working attires the passengers wore.

Results and discussions

Investigation of parameters thermal comfort in elevated MRT station worked in three conditions: train arriving, train departing, train arriving and departing.

Comparison of six factors (relative wind velocity that hit the passengers, metabolism rate, relative humidity, mean radiant temperature, air temperature and cloth insolation), represented in *PMV* score, at four seats in the station (right/ /left of the train) are the basis for identifying and improving the elevated MRT station design. Figure 3 shows a 3D model of the highest elevated MRT station – Fatmawati station. Unlike the other stations, this MRT station has an intermediate area located under the concourse area. For easy access from the road to the intermediate area, passengers can choose one among the three staircases, two escalator, and one elevator. The MRT officials will add another escalator later. To get to the concourse area from the intermediate area, passengers can select one of the two staircases, two escalators, and one elevator. The best roof for the three stations it is working on is the U-650. This roof mounting system does not require any bolt and therefore, causes no damage to the roof and reduces the risk of leakage in the overlap. The advantage of this system is its seaming technology on the overlap between the sheets. Wave height of 100 mm makes the U-650 roof very effective for buildings with a small degree of slope, up to 2°. Roofs with high waves can drain rainwater more effectively. U-650 roof can be installed for buildings with very wide spans. U-650 is a product that has been obtained FM APPROVED certification under FM APPROVAL Standard Class 4471 with a mixture of zinc and aluminum.

First step investigation is to compare the *PMV* scale between real condition and CFD simulation results. The input parameters of the *PMV* calculation that need to be considered in comparison are microclimate parameters in the form of ambient temperature, relative humidity and wind speed. Based on the comparison, it can be concluded that a 3D model is valid with level of error of 0.95%. Both *PMV* and *PPD* were employed to describe thermal comfort or discomfort of passenger at Fatmawati MRT station. The data shows that the highest temperature was 34.8°C with the relative humidity of 63.28% and the wind velocity of 0.32 $\mathrm{m \cdot s^{-1}}$. The analysis was conducted at the height of 100 cm from the floor level (passenger chest area when sitting position) (Piasecki, Fedorczak-Cisak, Furtak & Biskupski, 2019). Types of clothing MRT passengers are divided into two: casual wear (t-shirt, shorts and sandals) and formal wear (suits/shirts and shoes). Based on the cloth insola-

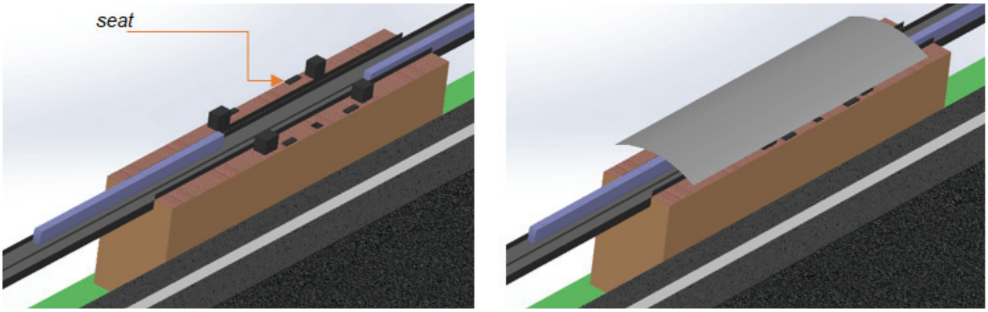

FIGURE 3. Elevated MRT station (Fatmawati station) in a 3D CAD model

tion table ASHRAE 2004:16, insolation of each condition is 0.3 and 1.1 clo. Furthermore, the metabolism of the MRT passengers while they are sitting on the platform is low (1 met) (Stanton et al., 2004). Predicted mean vote can be measured using Equation 1, *PMV* scores of the four sitting positions were 3.65, 3.66, 3.64 and 3.65 (extremely hot) with the *PPD* of 100% (everyone felt discomfort). Predicted mean vote of the arrival of one or two trains does not have significant influence towards the overall *PMV*; change occurred only when the wind hit the passengers.

Figure 4 shows the impact of wind speed due to train arrival. When there are no trains coming or leaving the station, the wind speed only comes from outside the station (Fig. 4a). The wind speed that arises and hits the seated passenger is around 0.258 $\text{m}\cdot\text{s}^{-1}$ and will produce *PMV* equal 3.67. When the MRT train enters the station at low speed, the train carries a gust of wind that hits passengers sitting in the platform waiting room (Fig. 4b). Gusts of wind from the coming train have changed the distribution of wind speed. The results of the simulation show that the average velocity of the wind (v) around the seat is 0.271 $\text{m}\cdot\text{s}^{-1}$ and produces *PMV* of 3.63, slightly lower than without a train. The third condition (Fig. 4c) is the arrival of trains and trains leaving the MRT station, which also changes the contour of the airspace that hits passengers sitting in the waiting room. From the CFD simulation, v of 0.271 $\text{m}\cdot\text{s}^{-1}$ and *PMV* of 3.62 are produced. Changes in wind speed due to trains do not significantly reduce *PMV* values.

Based on the simulation as described on Figure 4, arrival and departure of the train at the elevated MRT station did not have significant influence towards wind velocity that hit the passengers. Furthermore, change of wind velocity was unable to maintain passengers' thermal comfort by decreasing *PMV* and *PPD* at extremely hot category. Using the first and second formulation, sensitivity factor that develops *PMV* and *PPD*, which can reduce heat stress level rapidly, was to decrease temperature. To improve thermal comfort, the relationship between temperature, *PMV* and *PPD* must be known. This relationship was tested in the temperature range of 25–36°C, as shown in Figure 5. From these graphs it can be explained that at temperatures less than 27°C will give a negative *PMV* value (increasingly felt cold) and vice versa at temperatures greater than 27°C will give

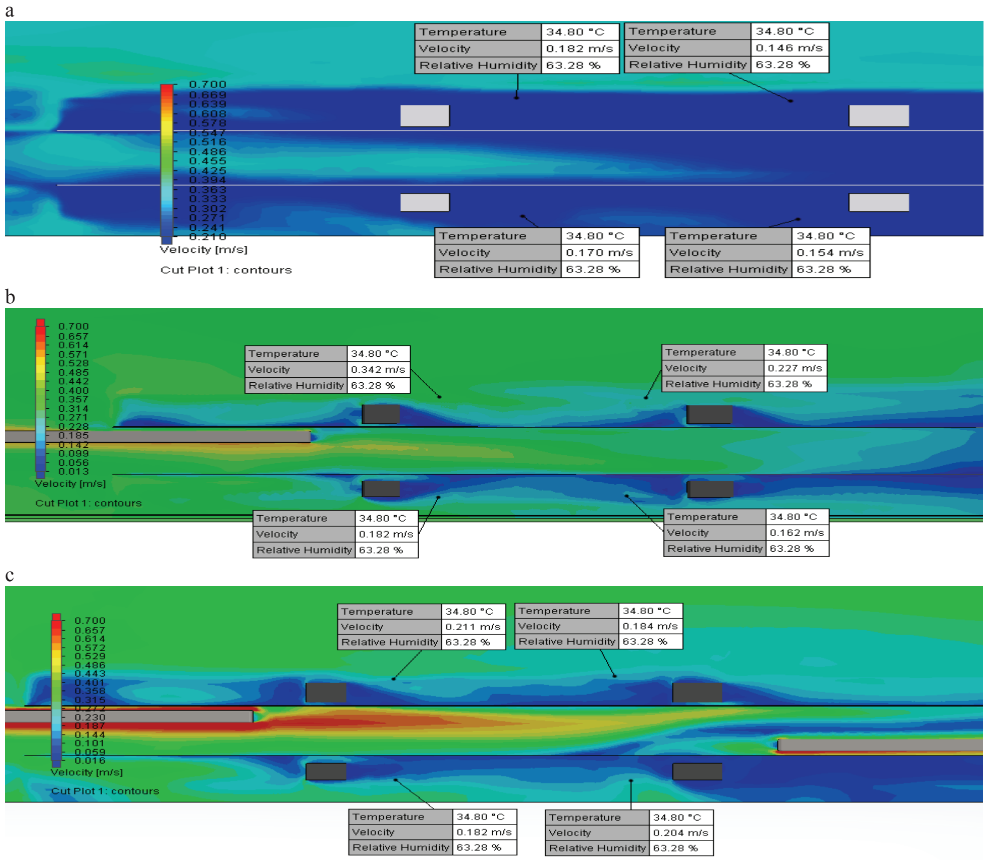

FIGURE 4. Impact of wind hitting chest of a sitting person (1 m above the floor level) on the passenger platform due to train arrival, when: a – there is no train; b – a train is arriving; c – different train is arriving and departing at the same time

a positive *PMV* value (the more heat is felt). This situation is used as a basis for determining the target temperature balance that occurs in the passenger lounge for elevated MRT stations. Simulations will be conducted at two temperature values: at 26°C which produces *PMV* of –0.74 with *PPD* of 16.7% and at 29°C which produces *PMV* of 0.71 with *PPD* of 15.8%. Standard ASHRAE 55-1992R which states that the maximum allowable *PPD* value of 10% will be used as a reference to find the right temperature value in the passenger's waiting room.

There are several alternatives to reduce the temperature around the waiting room of the elevated MRT station of which height is higher than 25 m from the ground surface. The alternatives are to install air conditioning, add certain types of plant in the waiting room, and reduce heat exposure by modifying the material used for the station roof. Previous studies (Sugiono et al., 2017) have investi-

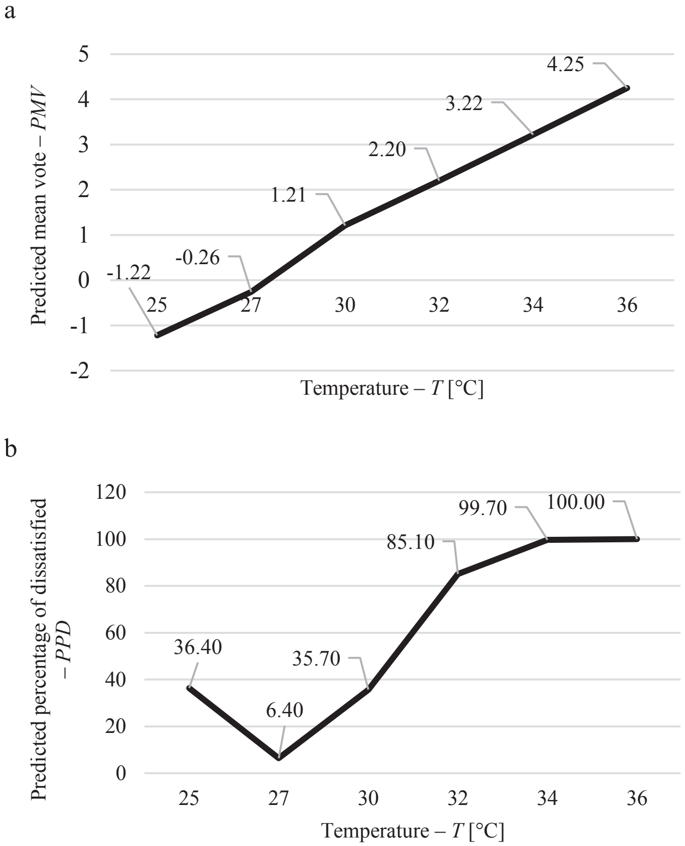

FIGURE 5. Sensitivity of the change of *PPD* and *PMV* scores towards the change of temperature at range of 25–36°C: a – relationship between value changes of *T* and *PMV*; relationship between value changes of *T* and *PPD*

gated the effectiveness of plants (English Ivy, peace lily, Boston fern and *Rhoeo spathacea*) to improve thermal comfort. Plants are able to maintain slower heart rate compared to people in a room without any plants. Predicted percentage of dissatisfied for room without plants was 59.1% and white lily reduced *PPD* drastically to 11.1% and Boston fern reduced the index to 14.3%. In conclusion, plants can reduce heat stress among human and work like air conditioning. Heat transfer through conduction, convection, and radiation from a building mostly takes place through wall, windows and ceilings (Humphreys & Fergus Nicol, 2002). Roof with high solar reflective index (*SRI*) and high emission play pivotal role in cooling down a building and increasing thermal comfort (Latha, Darshana & Venugopal, 2015). The roof of Jakarta MRT station is made of zinc–aluminium, has low absorptivity (short wave) and emissivity (long wave) from sun radiation. Uemoto Sato and John (2010) explained that lime silica brick (0.45 absorptivity, 55% brightness) and pine wood (0.4 absorptivity, 50% brightness) are suitable material for roof.

Another alternative to reduce the temperature is changing the design of the elevated MRT station from semi-outdoor to indoor station and then, to add air conditioning (AC). Installation of six units of AC is adjusted to the velocity contour plot from the existing model that hit the train station, so that airflow from the AC decreases the temperature of the waiting room more effectively. Figure 6a shows the installation site for six air conditioners (2pk) located on the station wall. Several experiments with CFD simulations were carried out to get the right AC setting temperature, which is at 23°C for $AC_{1,2,3,4,5}$ and 24°C for AC_6. Based on the simulation, AC installation reduced *PMV* in a significant manner to the targeted thermal comfort. Referring to Figure 6b, the *PMV* for Seat 1 (T = 26.64°C, RH = 48.16%, v = 0.116 m·s^{-1}) is –0.03 with *PPD* of 5%, for Seat 2 (T = 25.85°C, RH = 44.68%, v = 0.147 m·s^{-1}) is –0.04 with *PPD* of 8.3%, for Seat 3 (T = 26.70°C, RH = 48.42%, v = 0.118 m·s^{-1}) is –0.03 with *PPD* of 5%), and for Seat 4 (T = = 25.73°C, RH = 44.22%, v = 0.181 m·s^{-1}) is –0.58 with *PPD* of 12.1%. In conclusion, installation of six units of AC can effectively change the passengers' perception of a room from discomfort/ extremely hot (*PMV* = ±3.6) to neutral/ comfortable (*PMV* = ±0.04).

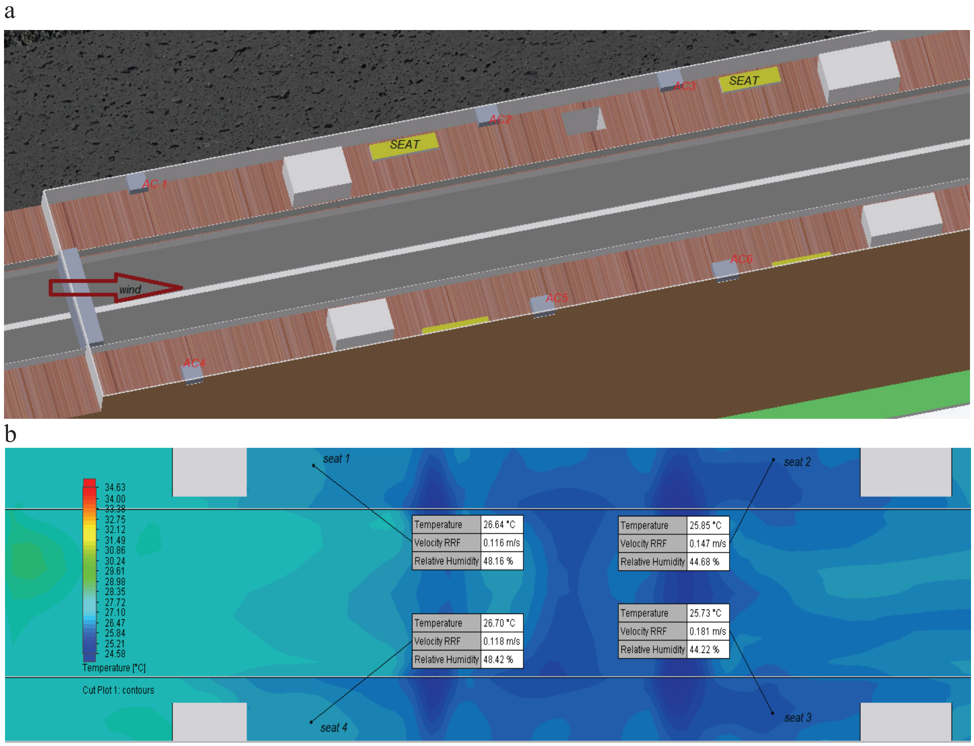

FIGURE 6. Semi-outdoor elevated MRT station with additional AC installations: a – axonometric overview; b – contour plot, result of the CFD simulation

Conclusions

The paper shows how to employee thermal comfort knowledge to optimise the design of elevated MRT stations at Jakarta. The investigation worked to find the best set up of air conditioning which will consume less energy. Thermal comfort method of predicted mean vote (*PMV*) and predicted percentage of dissatisfied (*PPD*) involved six main parameters: air temperature, mean radian temperature, wind velocity, relative humidity, cloth insolation and metabolic rate. Based on the analysis, the thermal comfort of existing station model produced *PMV* of 3.6 and *PPD* of 100% (all passengers in the waiting room feel discomfort due to heat).

Based on the CFD simulation, variety of *PMV* parameters for relative humidity, wind speed, metabolism, and clothing insolation did not reduce *PMV* value significantly as the higher of air temperature. As consequence, to increase the human thermal comfort needed to control (reduce) air temperature by using air conditioning (AC) in indoor elevated MRT station. Installing six units of AC (2pk, 23°C for $AC_{1,2,3,4,5}$, 24°C for AC_6) successfully reduced *PMV* scale into –0.04 (comfort zone) with *PPD* less than 10%. Putting some trees/flowers can also improve air quality and air fresh (more oxygen) that indirectly maintain thermal comfort.

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Summary

Impact of elevated outdoor MRT station towards passenger thermal comfort: A case study in Jakarta MRT. Comfort of the train passengers is the main priority of modern mass rapid transit (MRT) management. Objective of this paper is to investigate the thermal comfort of the elevated MRT station in tropical climate. The first step of this study was to conduct literature review on human thermal comfort, environment ergonomics, computational fluid dynamic (CFD), computational aeroacoustics (CAA), and predicted mean vote (*PMV*). Air quality in elevated MRT station was measured based on several parameters: relative humidity, wind speed, temperature, and wind direction. A 3D model of MRT designed was used to describe existing condition prior to simulations with CFD and CAA softwares. Predicted mean vote is arranged based on the value of metabolism, wind speed, ambient temperature, mean radiant temperature, amount of insulation from clothing, and relative humidity. Whereas predicted percentage of dissatisfied (*PPD*) can be derived from *PMV* calculations. The analysis shows that the average *PMV* of existing condition for elevated outdoor MRT station is 3.6 (extremely hot) with *PPD* is 100% (all passengers felt discomfort). Some recommendations to reduce heat stress were addressed such as: adding plant, changing materials of the MRT station, and change the design of the elevated MRT station. Modifying open elevated MRT station into indoor elevated MRT station with installing six units of AC (2pk, ±23°C) can improve air quality and maintain the thermal comfort scale of *PMV* to be –0.04 (comfort) with *PPD* of < 8%. Based on the analysis, it can be concluded that the most suitable design for elevated MRT station in tropical climate (hot and humid) is indoor MRT station with pay attention to both direct and indirect heat exposure that hit the station.

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