The Effect of Environmental Factors on the Thermal Comfort of Occupants in Building Interior

Baharuddin Hamzah[*)], Ramli Rahim, Muh. Taufik Ishak, Samsuddin Amin

Department of Architecture, Faculty of Engineering, Hasanuddin University, Makassar 90245 Indonesia
[*)] Corresponding author, email address: baharsyah@yahoo.com

Abstract

This study aims to analyse the effect of the thermal environment on the thermal comfort of the occupants in building interior. This study analysed the results of several questionaire surveys of thermal comfort perception and thermal environment measurements in building interior. The measurements and questionaire surveys were carried out in Laboratory of Building Science and Technology, located in Department of Architecture Building, Faculty of Engineering, Hasanuddin University at Gowa Campus. For a room with natural ventilation, four kinds of treatment of air velocity with the aid of a fan have been carried out. The four treatments of air velocity were: 1) without the aid of a fan, 2) a fan with the lowest speed, 3) a fan with medium speed, and 4) a fan with the highest velocity have been carried out. For a room with air conditioning, four treatments with different thermostat settings have been conducted. The four treatments of thermostat settings were: 1) 18^{o}C, 2) 21^{o}C, 3) 24^{o}C, and 4) 27^{o}C. A total of 150 sets of data, which involved 29 respondents, students of the Architectural Study Program have been gathered from the surveys. Before the survey was carried out, a brief explanation to the students has been conducted to ensure that the respondents understand the purpose of this study and also how to fill out the questionnaire correctly. The results showed that environmental factors, particularly the air flow speed in the room with natural ventilation have significant effect on the thermal comfort of respondents. Although the temperature reached 32^{o}C, the existence of airflow, made 67% of respondent felt comfortable. For a room with air conditioning (AC), the study indicated a significant effect of air temperature on the thermal comfort of respondents. More than half (54%) of respondents felt cool (-2) and cold (-3) in the temperature ranges 25^{o}C to 28^{o}C.

Keywords: thermal comfort, air velocity, air temperature, relative humidity.

I. Introduction

Thermal comfort is defined by ISO 7730 standard as "That condition of mind which expresses satisfaction with the thermal environment" [1]. This means that the thermal comfort determined by the condition of person and his/her immediate environment. His/her condition related to the psychological and his/her physical condition (e.g. activities and clothing). To understand about the correlation between factors and human's thermal comfort becoming an interesting research topic. This topic has been studies since 1950s and has involved various different building functions including office, health care facilities, schools and classrooms.

A number of studies have been carried out in order to study this phenomenon in the classroom. The studies showed a positive correlation between the qualities of classroom, which is include the thermal environment, and the students' performance [2,3]. Researches on thermal comfort at classrooms have been carried out in many parts of the world [4-9] including research in tropic region [10-12]. Therefore, providing good qualities of classroom is an important aspect to be considered in the development of new campus of Faculty of Engineering, Hasanuddin University. This study aims to analyse the effect of the thermal environment on the thermal comfort of the occupants in building interior.

II. Literature Review

The study of thermal comfort in buildings has been carried out in humid tropical country of Indonesia at the first time between the years 1936-1940 by Mom and Wiesebron [13]. Some research on thermal comfort has been carried out in Jakarta [14,15]. The studies focused on office buildings. In addition, a study involving objective measurements and surveys of thermal comfort in a wider scale of residential buildings with natural ventilation has been conducted in Yogyakarta [16].

According to Lippsmeier [17] the effective temperature of 26°C human began to feel the sweat, the temperature of the human body 27,1-30°C ET sweat and work ability began to decline. When the temperature is 30-33,5°C ET the environmental conditions is difficult to adjust body condition, and at the temperature 33.5-36°C ET, the perceived environmental conditions are difficult to be felt.

By using effective temperature (ET), Webb in Soegijanto [13], proposed thermal comfort zone for Indonesia as follows:

1) Cool 20,5°C - 22,8°C (ET).
2) Thermal comfort - optimum 22,8°C-26°C (ET).
3) Optimum comfort 26,2°C (ET).
4) Warm 26°C -27,1°C (ET).

Mom and Wiesebromn in Soegijanto [13], also proposed thermal comfort zone for Indonesia, which are vary according to the effective temperature (ET) as follows:

1) Comfortably cool 20,5°C-22,8°C (ET),
2) Comfortable-optimum 22,8°C-25,8°C (ET),
3) Comfortably warm 25,8°C-27,1°C (ET).

The most dominant influence on human physical comfort in the buildings is thermal comfort, which is including air temperature, air humidity and air velocity. In addition to those proposal above, Satwiko [18] also proposed thermal comfort zone in humid tropics. According to Satwiko [17] thermal comfort can be achieved with the limits of 24 ° C <T <26 ° C, 40% <RH <60%, 0.6 <V <1.5 m/s, with leisure activities, light clothing and a coat.

Thermal comfort standards such as ASHRAE Standard 55 [19] and ISO 7730 [1] have been widely used as thermal comfort standards in various countries. ASHRAE Standard 55 [16] using a 7-point scale to measure the thermal sensation votes (TSV). According to the 7-point ASHRAE scale is rated +3 (hot), +2 (warm), +1 (slightly warm), 0 (neutral), -1 (slightly cool), -2 (cool), and -3 (cold). The results of the study Feriadi & Wong [15] showed that the prediction of thermal comfort using the PMV of Fanger [20], resulted a value that is different from the TSV chosen by respondents.

If the air temperature around the human body is higher than normal body temperature (37°C), blood flow in the body will increase the temperature of the skin so that the heat release in the body of radiation into the air will occur and the body will sweat. If the temperature is lower than normal body temperature, blood circulation to the surface of the body is reduced, thus reducing the release of body heat to the surrounding air. At lower temperatures, the hands and feet become pale and cold, the muscles will contract and the body will shiver. This is the last attempt to obtain additional body heat through increased metabolic processes. In more extreme conditions, either too hot or too cold, people may not be able to survive longer.

II.1. Air temperature

The hottest area in the globe to receive the highest solar radiation, i.e. the equator, areas of land is heated two times faster than the water field of the same size. Water filed lost heat energy due to evaporation, because the air temperature is largely determined by the reflection of the air to the ground, then there is a higher air temperature with low humidity and moderate temperatures with high humidity.

Maximum daily air temperature is reached some time after the maximum light intensity of approximately two hours after the beam of sunlight falls perpendicular to the middle of the day because it was the highest heat gain in a building located on the west facade so as a general rule can be considered that the highest temperature for about two hours after the highest position of the sun, and the lowest temperature before sunrise the temperature has begun to rise again when the sun began to rise because of the spread of radiation in the sky.

Heat received by building on the tropical climate regions that will penetrate into the room through the roof and walls. The building heating can occur due to direct solar radiation, diffuse radiation, and reflected radiation. Then the building may receive and emit long-wave radiation from the surface of the surrounding buildings. In addition to solar radiation, the building receives heat from the room as heat lamps, electrical equipment, working machines, the kitchen is being used to cook, and heat the occupant's body evaporate.

II.2. The relative humidity (RH)

According to BMG [21], a relative humidity (RH) is the ratio between the water vapour pressures measured by the pressure of water vapour in saturated conditions at a temperature of dry bulb. Saturated air means that air can no longer absorb water if in a certain temperature has been reached maximum water vapour e.g. air temperature 37°C can absorb water vapour ten times more than the air temperature of 0°C. So the saturation point will increase with increasing temperature. In the tropical climate conditions, humans began to feel unpleasant on the vapour pressure of water above 2 kPa (kilo Pascal), the evaporation of the skin resulting in the body is hard to be cooled and the air can no longer absorb enough moisture. For ensuring that the body should be in the area of air humidity was 30% -70%, the optimal humidity not exceeding 60% and not lower than 20%, and changes not exceeding 20% per hour.

II.3. Air velocity

According to Bayong [22], the wind speed is basically determined by the difference in air pressure between the point of origin and destination and the wind resistance impassable terrain. Air velocity is an important climatic factor in building planning and design. Thermal comfort in the room will raise the temperature and humidity, without air flow, making the room quickly saturated and become unhealthy due to high concentrations of CO_2, the oxygen is becoming low (the RH close to 100%). In these conditions, it can be ensured that thermal comfort cannot be achieved. People in the room will be sweating, while sweat cannot evaporate in the saturated air without airflow.

Airflow resulting in the release of heat from the skin surface by evaporation affects the reduction of temperature, in other word, cooling process in the skin. The greater the speed of the airflow the greater the heat loss, this happens when the outside air temperature is lower compared to the temperature of the body. If the room temperature is higher than the skin, the body is warming. Thermal conditions is still causing evaporation, but the cooling that occurs as a result of the airflow can no longer compensate for the heat received by the body. Vector Olygay in Lippsmeier [16] set a speed limit of indoor airflow as follows:

1) 0.1-0.25 m/s comfortably, without the perceived air movement.
2) 0.25-0.5 m/s comfortable, air movement has been felt on the skin.
3) 0.5-1.0 m/s, light air movement.
4) 1.0-1.5 m/s, mild airflow to unpleasant.
5) 1.5 m/s and above, airflow are not pleasant, air-conditioning required.

III. Research Method

The study has been carried out using experimental methods. The experiments were carried out in two rooms. One was naturally ventilated room and the other was air-conditioned room. For a room with natural ventilation, four kinds of treatment of air velocity with the aid of a fan have been carried out. The four treatments of air velocity were:

1) without the aid of a fan,
2) a fan with the lowest speed,
3) a fan with medium speed,
4) a fan with the highest velocity have been carried out.

For a room with air conditioning, four treatments with different thermostat settings have been conducted. The four treatments of thermostat settings were as follows:

1) 18^{o}C,
2) 21^{o}C,
3) 24^{o}C,
4) 27^{o}C.

A total of 150 sets of data, which involved 29 respondents, students of the Architectural Study Program have been gathered from the experimentations. The respondents represent eight regencies/cities in South Sulawesi Province, two regencies/cities from South East Sulawesi Province, and one city from Central Sulawesi Province. Before the experiments was carried out, a brief explanation to the students has been conducted to ensure that respondents understand the purpose of this study and also how to fill out the questionnaire correctly.

III.1. Measurements tools

The objective measurements including personal data i.e. clothing and activities and the environmental data, which included air temperature, air humidity, air velocity, and mean radiant temperature (MRT). The measurements tools used for this research namely, LSI Thermal Comfort Multi Logger (Figure 1a) and six HOBO data-loggers. There were two types of HOBO loggers: HOBO UX100 Temp/RH Logger (UX100-003) (Figure 1b) and HOBO U12 Temp/RH/Light/External Logger (U12-012) (Figure 1c).

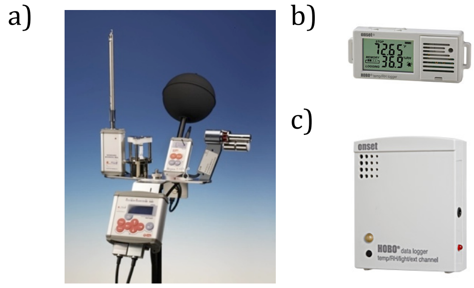

Figure 1. Measurement tools: a) LSI Thermal Comfort, b) Hobo temp/RH logger, and c) Hobo temp/RH/Light/External logger

III.2. Location of measurement tools

The experiments have been carried out using six HOBO loggers (logger A to F), and one LSI thermal comfort logger (G). HOBO loggers A and B measured the air temperature, air humidity, air velocity, and light intensity. While loggers C to F only measured air temperature and air humidity. Data-logger G measured air temperature, air humidity, air velocity, and MRT (mean radian temperature). The loggers were located according to the position Figure 1 at about one meter above the floor level. In order to increase the air velocity a fan with three speed levels has been used.

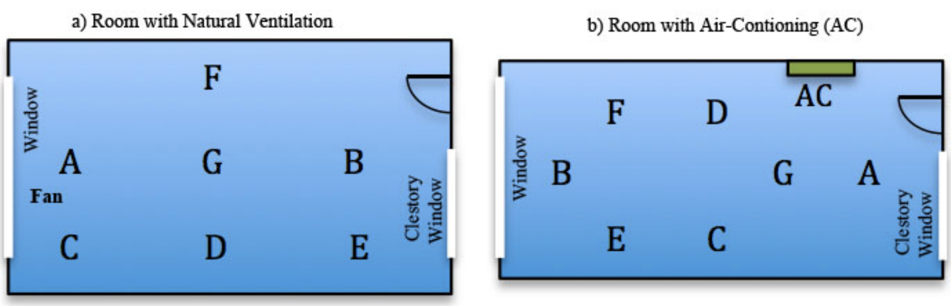

Figure 2. The position/location of measurement loggers at Thermal Workshop Room (left) and Monitoring Room (right)

IV. Result and Discussion

IV.1. Thermal environment conditions

The thermal environment conditions during the surveys and measurements were divided into two, namely external conditions and internal condition. The external condition was measured and collected by Vaisala weather station. The station is located at the rooftop of Architecture Building. The station data is monitored and stored by Net-Logger software. One LSI-Thermal comfort logger and six HOBO loggers were used to measure the internal thermal conditions.

IV.1.1. External thermal conditions

The external thermal conditions during the measurement time are displayed in the Figure 3. As presented in Figure 3, the measurements have been conducted in four days for collecting the temperature, humidity, solar radiation, and wind speed. The temperature at the four days measurements shows a similar trend and almost same minimum and maximum values. The temperature ranges from 25°C in the early morning to around 32°C at noon. Most of the external temperature readings were outside the thermal comfort zone according to the SNI standard as well as ASHRAE standard. For the air humidity, the four days measurement showed high humidity in the morning, which was more than 80%. The humidity decreased and fluctuated at the ranges 50 to 60% from 9 am to 4 pm. This humidity conditions are mostly located in the comfort zone.

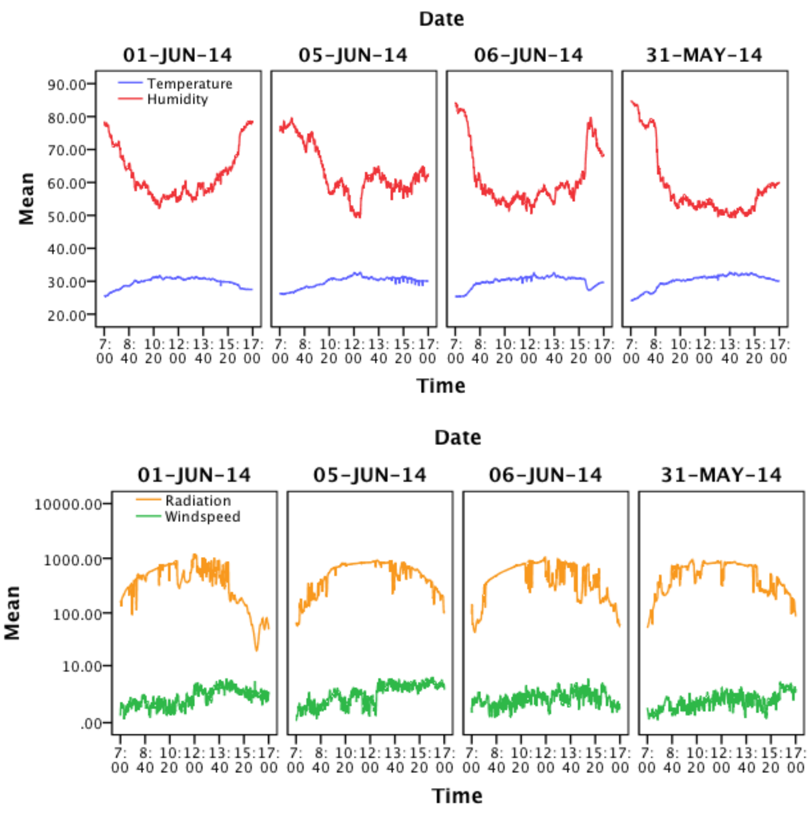

Figure 3. External thermal conditions: temperature and humidity (above), and radiation and wind speed (below) measured by Vaisala weather station
Source: Data Measurement

IV.1.2. Internal conditions

The two common internal conditions, namely air temperature and air humidity were measured at all locations. While the air velocity only measured at location A, B, and G and the MRT (mean radiant temperature) was only measured at location G. The readings on 31 May 2014 are presented in Figure 4 and 5. Figure 4 shows the air temperature and air humidity. As seen in Figure 4, the air temperature fluctuated from just below 31°C to above 33°C. This air temperature is laid above the comfort zone level. On the other hand, the humidity at the time of survey is laid in the comfort zone, which ranged from 50 to 60%.

Figure 5 shows the wind speed (air velocity), MRT, and the light intensity (this parameter is not analysed in this paper). The wind speed in the location A was fluctuated from 0 to 2.2 m/s, while in the location B, no air velocity was recorded. The air velocity in the location G fluctuated from 0 to 0.22 m/s. These air velocity readings show that the location near the window received more air than the location far from the windows. The MRT readings fluctuated from just above 31ºC to almost 35ºC. This indicated that the building fabrics received a lot of solar radiation during the day.

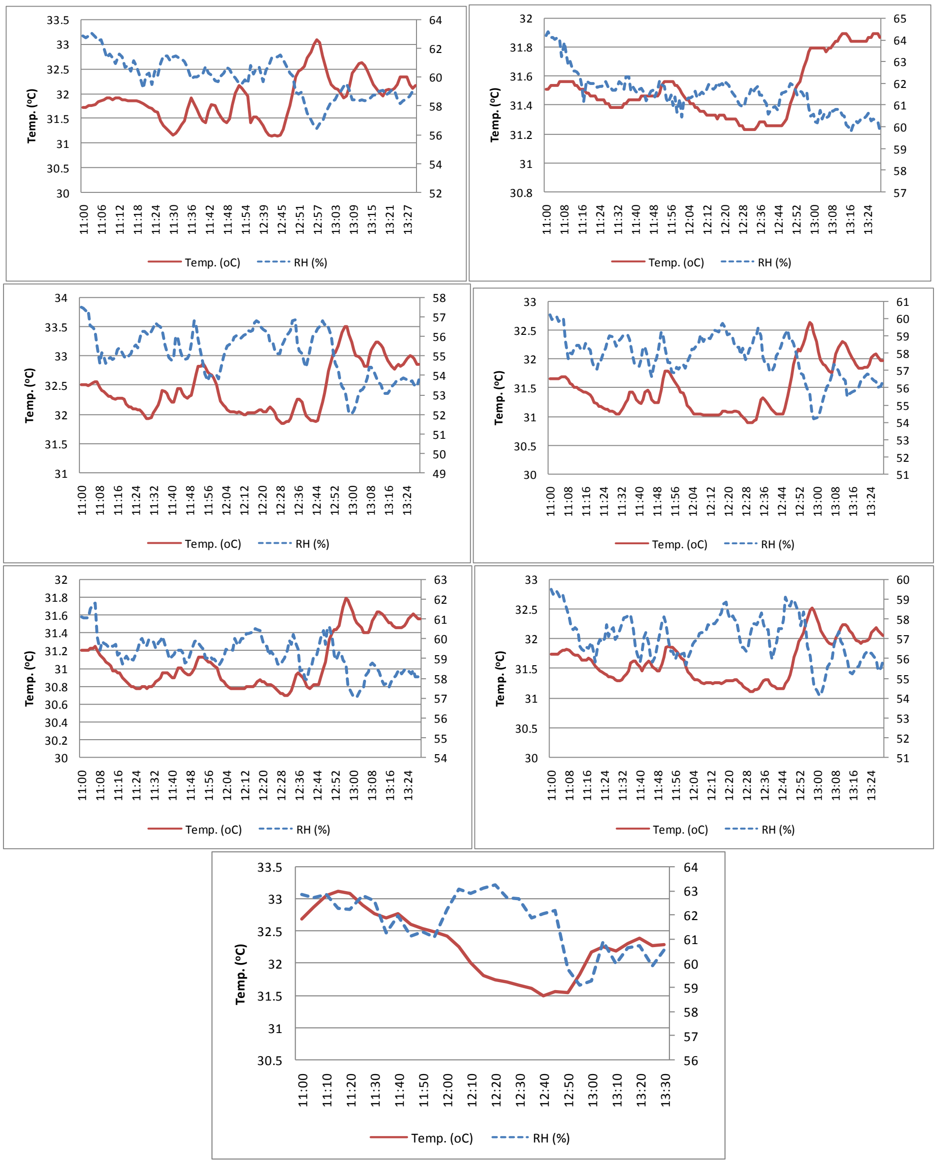

Figure 4. The internal temperature and humidity conditions at different location inside the room (location A to G)

Source: Data Measurement

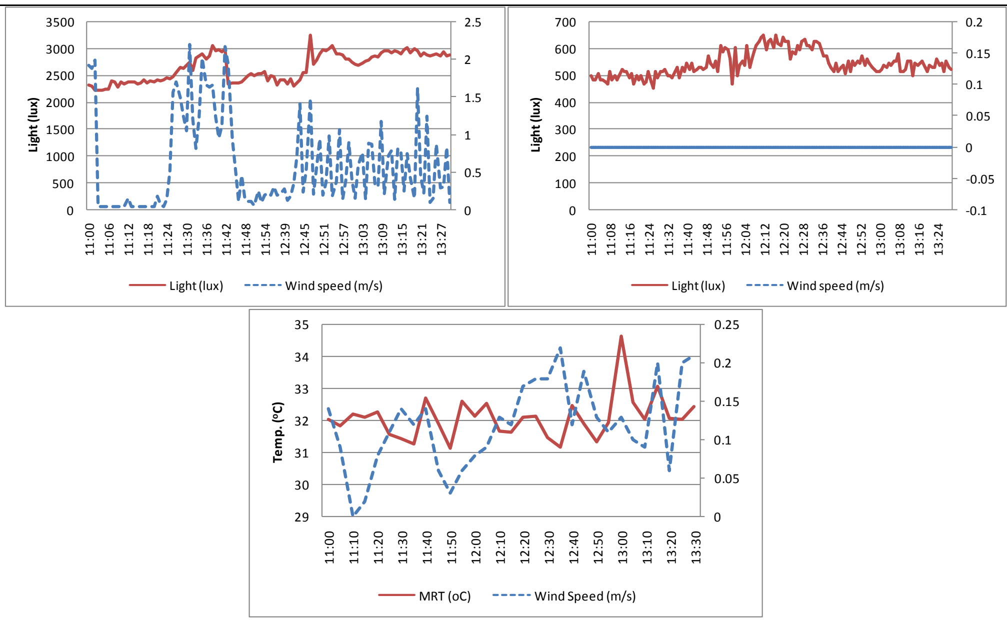

Figure 5. The internal air velocity, light intensity and MRT at different location inside the room (location A, B and G)
Source: Data Measurement

IV.2. The effect of airflow on the thermal comfort

With the internal temperature ranged from 31°C to 32°C, 67% respondents feel comfortable (-1 to +1). Interestingly, about 23% respondents felt cool (-2) and cold (-3), and only 10% felt warm. This result is quite interesting, however, it agrees with our previous research finding [12].

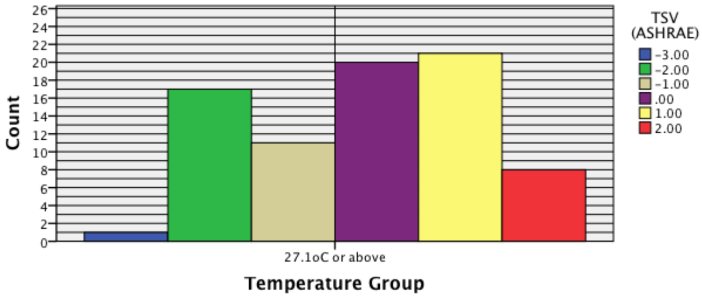

Figure 6. The thermal sensation votes (TSV) of respondents in the naturally ventilated room
Source: Data Analyses

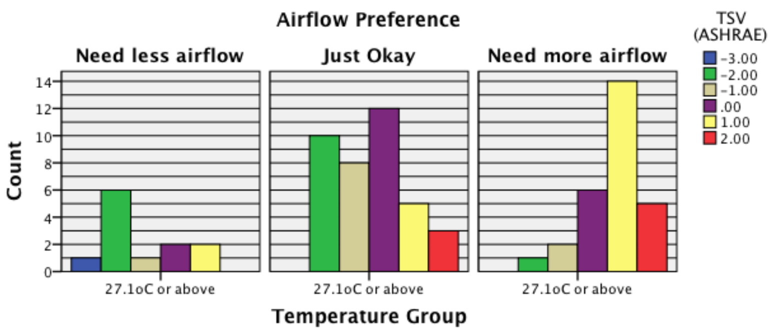

Figure 7. The TSV versus the air velocity vote in the naturally ventilated room
Source: Data Analyses

Figure 7 and 8 show the airflow preference of respondents in the naturally ventilated room. Figure 7 shows that about half of respondents (49%) prefer the actual air velocity, which mostly ranges from 0 to 0.25 m/s. Only 36% of respondents required more air velocity, while only about

15% felt the air velocity is too strong, so they preferred the reduction of air velocity. Among the 36% respondents required more wind velocity, most of them (86%) only felt 0-0.25 m/s (Figure 8).

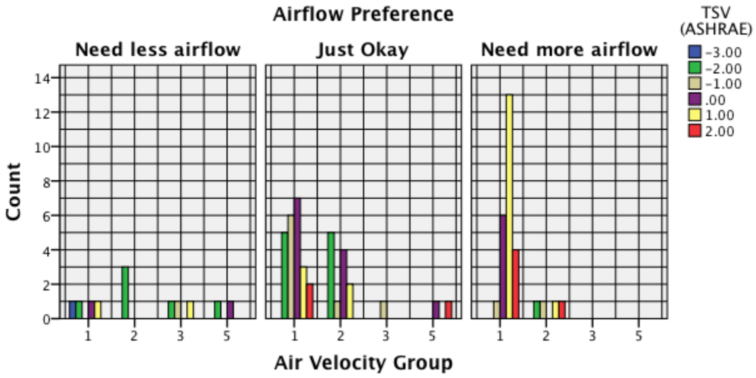

Figure 8. The TSV versus the air velocity group in the naturally ventilated room
Source: Data Analyses

IV.3. The effect of temperature on the thermal comfort

The following analyses are based on the data gathered in the air conditioning room. Figure 9 shows the TSV of respondents under three different temperature groups according to Mom and Wiesbromn [13]. With the internal temperature ranged from 25°C to 28°C, 43% feel comfortable (-1 to +1). Interestingly more than 54% respondents felt cool (-2) and cold (-3) and about 3% felt warm. This temperature ranges are higher than the comfort zone proposed by Satwiko [18] which is 24°C<T<26°C or by Webb, and Mom and Wiesbromn [13].

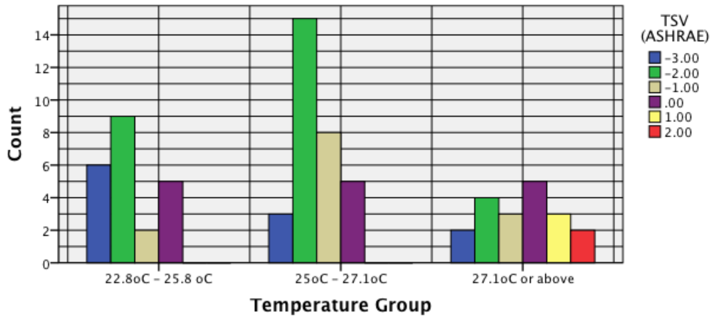

Figure 9. The impact of temperature on the TSV (ASHRAE)
Source: Data Analyses

The TSV of respondents under different seating locations and the city/regency of origins are illustrated in Figure 10 and 11, respectively. As seen in Figure 10, most of respondents seating in the location G and A, which are very closed to the AC diffuser, felt cool (-2) and cold (-3).

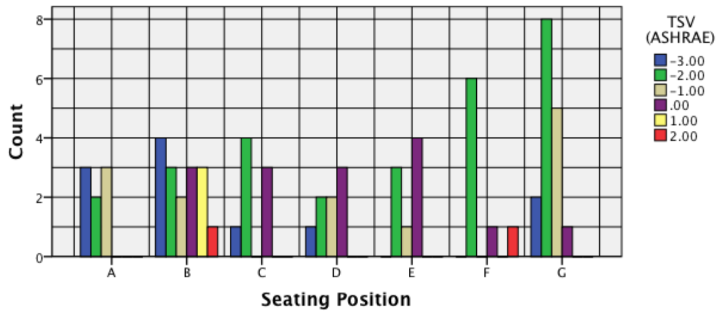

Figure 10. The TSV (ASHRAE) of respondents based on their different seating locations
Source: Data Analyses

Figure 11 shows that most of respondents were originally come from Makassar and followed by Regency of Gowa. Most of respondents (67%) from Makassar felt slightly cool (-1) to cold (-3) and only 10% felt slightly warm (+1) and warm (+2). Respondents come from outside

Makassar as Gowa, Bone, Bulukumba, Buton, and Palopo were mostly feeling cool (-2). While some of respondents originated from Palu, Pare-pare, Selayar and Sinjai were feeling neutral (0).

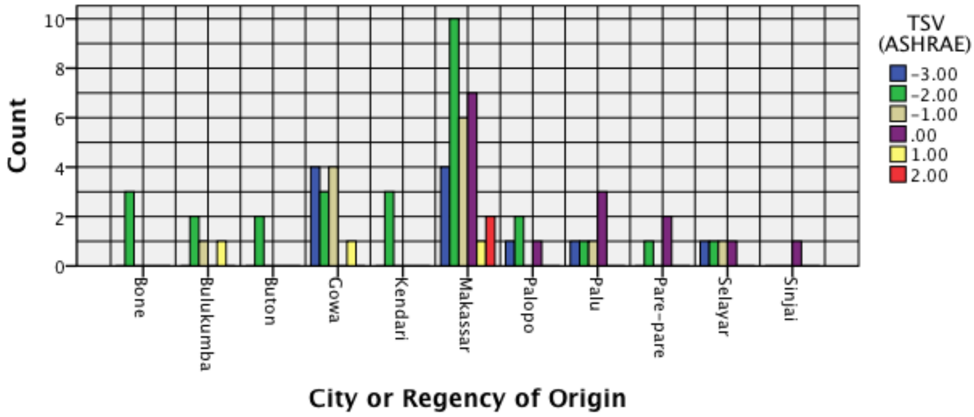

Figure 11. The TSV (ASHRAE) of respondents based on their city or regency of origins
Source: Data Analyses

V. CONCLUSION

The results showed that the air temperature in the room that uses natural ventilation when the study was conducted is as high as the average 32^{o}C, with maximum and minimum reaching 33,4^{o}C and 30.9^{o}C, respectively. These conditions, of course, was outside the comfort zone of ASHRAE standard of thermal comfort and the Indonesian thermal comfort standard SNI T-14-1993-03. However, most respondents were still tolerant with these conditions. More than 67% of respondents were comfortable (-1 to +1) and only 10% of them felt warm (+2). Interestingly, there are about 23% who felt cool (-2) and cold (-3). Air humidity was generally located in the comfort zone (59.5%). Air velocity averaged 0.27 m/s. However, the air velocity was not evenly distributed throughout the room. The area located farthest from the window did not get enough airflow.

In the room with air conditioning (AC), most respondents have felt comfortable, but some also felt cold. Originally the sitting location was not significantly affect respondents' choice of comfort. With an average room temperature of 27^{o}C (temperature ranges 25^{o}C to 28^{o}C), more than 43% of respondents felt comfortable (-1 to +1), 39% of respondents felt cool (-2) and 15% felt very cold (-3), the rest was just 7% felt warm (+2).

It is recommended to conduct further research to find the best strategy for the airflow to be more evenly distributed throughout the room.

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