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A Prospective Study of Thermal Comfort in Users in Technical Institution TVET: Workshop Facilities Space

Kajian Prospektif Kenyamanan Termal pada Pengguna di Institusi Teknikal TVET: Ruang Fasilitas Bengkel

Noorazimah Mat Alias[1], Umar Kassim[2]
[1]Department of Civil Engineering, Polytechnic of Sultan Abdul Halim Mu'adzam Shah
[2]Faculty of Civil Engineering Technology, Universiti Malaysia Perlis

[1]Bandar Darulaman, 06000 Jitra, Kedah Darul Aman, Malaysia; [2]Kompleks Pusat Pengajian Jejawi 3, 02600 Arau,Perlis, Malaysia.

[*]Corresponding author email: noorazimah1981@gmail.com

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Abstract
Thermal comfort is a part of indoor environmental quality that should be considered to ensure the occupants' well-being. Unconducive buildings not only bring occupants discomfort but also tend to affect health, disrupt the process of teaching and learning, and reduce work productivity. Thus, this study determines the thermal condition of existing workshop buildings used in Technical and Vocational Education and Training (TVET) implementation. Evaluations of comfort are based on occupant surveys and environmental measurements. A total of 257 people completed a questionnaire distributed at three technical institutions in Kedah, Malaysia. According to the findings, the average thermal sensation vote is 1.85, which leads to 66.5% of respondents feeling discomfort. Meanwhile, the adaptive model analysis showed that the workshop environmental conditions were out of the comfort zone and did not comply with the ASHRAE 55 standard. Hence, the thermal discomfort factors from the occupants' perspective were identified and widely discussed. As a result, the research findings will benefit parties involved in new building construction or existing building renovations to improve indoor air quality.

INTRODUCTION

Thermal comfort study is one of the fields that has often received attention from researchers due to its importance to building occupants. Based on previous studies, various issues related to the thermal discomfort of the building have been recorded, and it was had negative impacts on occupants. Uncomfortable thermal can affect work efficiency and lead to a decrease in workers' productivity (Idkhan & Baharuddin, 2019). The previous study shows symptoms of fatigue, headache, dry skin, dry eyes, eye strain, etc. also due to the poor ventilation system of the air conditioning in the building (N. D. M. Amin et al., 2015). Hence, the condition of a space that is too hot or too cold also impacts the building's occupants in terms of psychology and physiology.

Referring to the ASHRAE 55 (2017) standard, thermal comfort is "that condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation". Therefore, an assessment of thermal sensation was measured to identify occupants' satisfaction and comfort level with the indoor thermal environment in the building. Due to Malaysia's warm and humid climate, the achievement of thermal comfort among building occupants, particularly for natural ventilation, is seen as a big challenge. Meanwhile, few studies in Malaysia of thermal comfort are more focused on buildings with air-conditioned systems. Hussin et al. (2014) found 89% of occupants were satisfied with the thermal condition in the building (air conditioning mode). Leong Chong et al. (2019) found the majority of occupants in workshop buildings were not comfortable with the thermal conditions in the spaces. Gagge et al. (1969) stated that metabolic activities are affected by human sensation. Kumar et al. (2020) through experimental studies showed that occupants were uncomfortable even though the indoor temperature was low.

Rather, Amin et al. (2015) showed the unacceptable thermal conditions in three building of a laboratory that were facilitated with an air conditioning system. Kwong et al. (2020) through an experiment on CFD software found the air temperature in both the laboratory and workshop did not comply with the MS 1525 standard, though at a low metabolic rate of 1.0 met. Past findings presented the issues of thermal comfort in educational buildings, focusing on labs and workshop users that are exposed to the sick building syndrome (SBS) symptoms, which lead to psychological and physiological effects (N. D. Amin et al., 2012). In addition, the focus on thermal comfort in educational spaces should be given consideration due to its influence on human well-being and performance (Zuhari et al., 2019).

In Malaysia, laboratories and workshops are mostly operated under natural ventilation (NV mode) that is assisted by some mechanical parts such as wall fans and exhaust fans, without any mechanical cooling or heating system in operation. Occupants with a high metabolic rate will become more uncomfortable. These conditions tend to occur discomfort that can affect the effectiveness of the teaching and learning process. This can also affect the development of students' skills in various fields with varying activity levels. Hence, these issues prompt researchers to investigate the effects of the Malaysian climate on the thermal environment in workshop buildings (natural ventilation mode). Thus, the aims of this study are to identify the occupants' perceptions of the thermal environment and to determine the thermal condition of the workshop space.

MATERIAL AND METHODS

Location and Building Description

This study was conducted at three TVET educational institutions located in Jitra, Kedah, north of Peninsular Malaysia that are run by the government, namely the National Youth Skills Institute (IKBN) (6°18'15"N, 100°25'05"E) under the Ministry of Youth and Sports; the Industrial Training Institute (ILP) (6°15'20"N, 100°25'55"E) under the Ministry of Human Resources; and the Polytechnic of Sultan Abdul Halim Mu'adzam Shah under the Ministry of Higher Education. As case studies, five workshop facilities with varied programmes (carpentry, automotive, welding, and machinery) were selected. Figure 1 depicts the implementation operations in the workplace. The workshops are in NV mode (non-air conditioned). Evaluations of the thermal environment are based on subjective (surveying occupants) and objective (physical measurements) as referred to in ASHRAE 55 (2017). From the site observation, ventilation in three workshops (two welding and one machinery) was assisted by local exhaust, including capture devices, ducting, and fans to remove the fumes, gases, dust, and vapors. Whereas other workshops (carpentry and automotive) demonstrated the use of exhaust fans to support workplace ventilation.

Fig. 1 – Indoor Activities in Workshops.

Subjective Measurement

A questionnaire survey is used to evaluate the workspaces and collect information about the demographics and occupants' direct perceptions of the workshop environment. The survey is evaluated using the seven-point ASHRAE thermal sensation scale in order to estimate the proportion of voters who are "satisfied," "acceptable," or "comfortable." In order to rate their response to the experience, participants could choose from a scale of +3 (hot), +2 (warm), +1 (slightly warm), 0 (neutral), -1 (slightly cool), -2 (cool), or -3 (cold). The scale also depicts Predicted Mean Vote (PMV), which is connected to the Predicted Percentage of Dissatisfied (PPD) index. The survey also includes an investigation into thermal dissatisfaction with nature (causes) and the occupant's adaptive behavior. In addition, the thermal comfort assessment determined other two thermal comfort factors: clothing insulation, *Icl* (clo) and metabolic rate (met), which indicated the activity level of the occupants. The values of metabolic rate (met) and garment insulation (*Icl*) were referred to in the ASHRAE 55 standard.

Physical Measurement

Physical measurements were obtained through field studies in NV workshops, which involved measurements of four environmental factors, i.e., air temperature, radiant temperature, air velocity, and relative humidity. By using the instruments tool, thermal comfort parameters were obtained: globe temperature (Tg) and air temperature (Ta), to calculate mean radiant temperature (Tmrt) by using equation (1). Therefore, determination of operative temperature (Top) was obtained by using equation (2) according to past studies (Lau et al., 2019). The data was collected between 8.30 a.m. and 4.30 p.m. while occupants were doing activities. A measurement tool of the parameters for air temperature, black globe temperature, and relative humidity was taken by a wet bulb globe temperature metre with a 75 mm diameter globe, while a digital anemometer was measured for the air velocity parameter. Table 1 summarises the instruments' information: Web Bulb Globe Temperature and Anemometer. The position of physical measurements is at 1.1m from floor level in accordance to occupants (standing activities) at five observation points referring to the floor plan where most heat occurred, i.e., near entries and the centre of workshops. In applying the adaptive method, the prevailing mean outdoor air temperature (data from Malaysia Meteorology Department) was used to determine the comfort zone boundary.

$$T_{mrt} = \left[\left(T_g + 273\right)^4 + \frac{1.1 \times 10^8 {V_a}^{0.6}}{\varepsilon D^{0.4}} \times \left(T_g - T_a\right)\right]^{\frac{1}{4}} - 273 \quad (1)$$

$$T_{op} = AT_a + (1 - A)T_{mrt} \quad (2)$$

Table 1. Specifications of Instruments

Instrument	Parameter	Range	Accuracy
Heat Index WBGT Meter 87786	Air Temperature	0 ~ 50°C	± 0.6°C
	Globe Temperature	0 ~ 80°C	± 1.0°C
	Relative Humidity	0 ~ 100%RH	± 3%RH
MS6252A Digital Anemometer	Air Velocity	0 ~ 30.00 m/s	± (2.0% reading + 50 characters)

RESULTS AND DISCUSSION

Field Observation Analysis

The evaluation of physical measurements was implemented through an adaptive method for NV spaces. Table 2 presents the overview of indoor environmental parameters, such as air temperature, globe temperature, air velocity, and relative humidity, that were collected during a field investigation in five workshop buildings with varying activity. The results showed the environment indoors data in BKLP for operative temperature is 33.0°C, air velocity is 0.2 m/s, and relative humidity is 55.7%. In BALP, the operating temperature was 31.6°C, the air velocity was 0.2 m/s, and the relative humidity was 54.9%.The next location, BKBN, showed an operative temperature of 31.1°C, an air velocity of 0.1 m/s, and a relative humidity of 60.8%. BPBN measured an operating temperature of 31.2°C, an air velocity of 0.1 m/s, and a relative humidity of 60.4%. Next, BKP showed an operative temperature of 30.4°C, an air velocity of 0.1 m/s, and a relative humidity of 65.1%.

Based on the results, the mean indoor air temperature, Ta, ranged from 30.2°C to 31.7°C while the mean indoor globe temperature, Tg, was in the range of 30.5°C to 33.3°C in March to April. During the workshop activities, the mean operative temperature, Top, was found to range from 30.4 °C to 33.0 °C with the main activities in the workspace being related to machinery operation, such as in welding work, carpentry work, automotive work, and machining work, with metabolic rates ranging from 1.0 met (sitting) to 2.0 met (machine work).

From the data recorded, the trend of temperature increases in the evening was also seen in the temperature readings. Based on the prevailing mean outdoor temperature from the nearest meteorological station (MetMalaysia), the data shows 28.5°C in March and 28.0°C in April, respectively, for the studied location. Meanwhile, the mean relative humidity recorded ranged from 55.7% to 65.1% and the mean air speed was recorded from 0.1 ms-1 to 0.2 ms-1. By considering the mean operative temperature, Top and the prevailing mean outdoor temperature, it was seen that all the workshop space was outside of the comfort zone. The finding also shows the high metabolic rate for workshop activity, while the comfort boundary in the existing standard is applicable to lower metabolic rates, which range from 1.0 met to 1.3 met. This finding is similar to past studies on high metabolic rates 1.89 met (Leong Chong et al., 2019).

Table 2. Measurements of Thermal Environment Factors

Parameter	**BKLP** (n=39)	**BALP** (n=66)	**BKBN** (n=64)	**BPBN** (n=61)	**BKP** (n=27)
Globe Temperature, T_g (°C)	33.3	31.6	31.1	31.2	30.5
Air Temperature, T_a (°C)	31.7	31.3	30.8	30.9	30.2
Operative Temperature, T_{op} (°C)	33.0	31.6	31.1	31.2	30.4
Air Velocity, V_a (ms^{-1})	0.2	0.2	0.1	0.1	0.1
Relative Humidity, RH (%)	55.7	54.9	60.8	60.4	65.1

Surveying Analysis

The questionnaire survey had 257 responses, with 235 (91.4%) males and 22 (8.6%) females participating. Based on the data collected, majority of respondents 97.7 % were students, while 2.3 % were instructors. In determining the thermal environment, responses to occupants' expectations are needed. Fig. 2 illustrates the data of thermal TSV based on the 7-point ASHRAE scale sensation. From a survey of 257 respondents, the votes from +1 to the +3 scale were obviously skewed to the right graph, which represents slightly cool (-1), neutral (0), slightly warm (+1), warm (+2) and hot (+3). The scale in (+2, +3) represents more of a 'hot feeling' than (-2, -3) more of a 'cold feeling'. Referring to ASHRAE 55, thermal satisfaction occurs when the votes range from -2 < satisfied < +2 for an acceptable thermal environment.

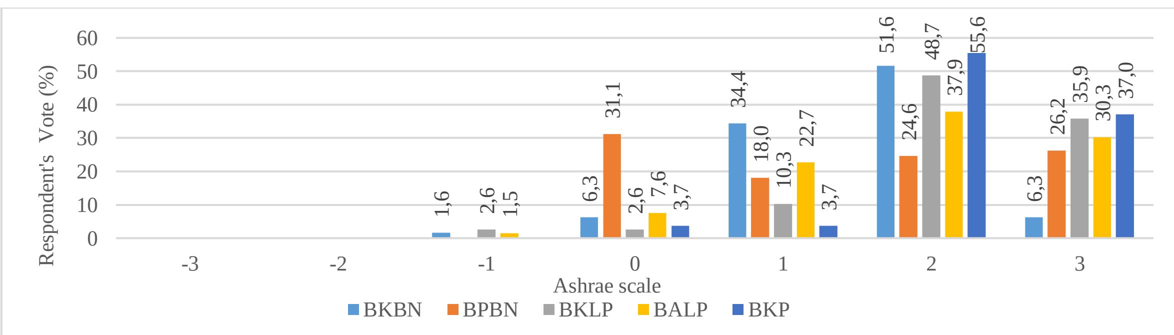

Fig. 2 - Percentage of Respondent's Votes.

Table 3. Thermal Sensation Votes of Workshop's Occupants

Workshop	Mean TSV	ASHRAE Sensation Scale							Total
		-3	-2	**-1**	**0**	**1**	2	3	
BKBN	1.55	0	0	**1**	**4**	**22**	33	4	64
BPBN	1.46	0	0	**0**	**19**	**11**	15	16	61
BKLP	2.13	0	0	**1**	**1**	**4**	19	14	39
BALP	1.88	0	0	**1**	**5**	**15**	25	20	66
BKP	2.26	0	0	**0**	**1**	**1**	15	10	27
Total	1.85	0	0	**3**	**30**	**53**	107	64	257

Table 3 shows the TSV mean in BKBN (1.55), BPBN (1.46), BKLP (2.13), BALP (2.13), and BKP (2.26), with an overall mean TSV of 1.85. Based on the responses, unsatisfactory levels of comfort were observed in BKBN 57.8% (37 individuals), BPBN 50.8% (31 people), BKLP 84.6% (33 people), BALP 68.2% (45 people), and BKP 92.6% (25 people). Overall, it is obvious that only 33.5% of the occupants feel comfortable in the environment, while majority of occupants,66.5% are unhappy or uncomfortable with the thermal conditions while practical work is performed. Thermal discomfort data showed a peak time of around 2.00 pm to 5.00 pm in the evening session of class. In conclusion, the results show that the workshop thermal conditions are inconducive for building occupants. Thus, the study continues with the identification factor of dissatisfied workshop occupants to the indoor environment.

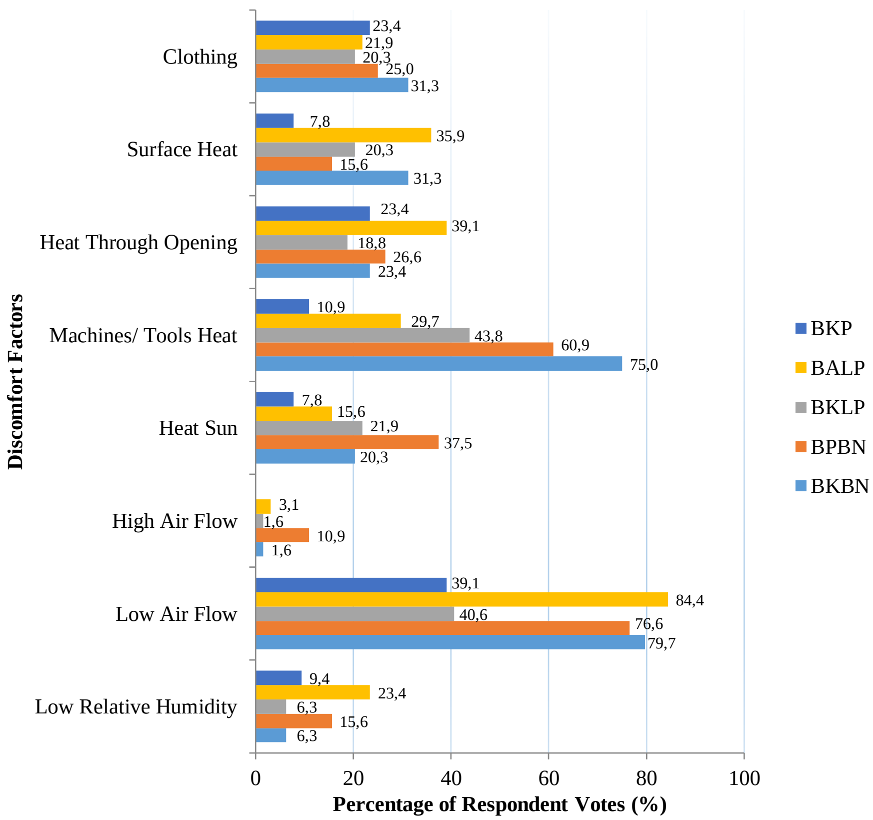

Fig 3. Vote's Percentage on Discomfort Factors

According to the findings in Fig.3, based on more than 50% of respondents' votes, two primary sources of thermal discomfort were identified: low airflow, which ranged from 39.1% to 84.4%, and heat from machine operation, which ranged from 10.9 % to 75.0 %. This conclusion can be attributed to the observed airflow rate of 0.14 ms^{-1}, which impacted the occupants' activities with a high metabolic rate of between 1.0 met and 2.0 met when doing welding, automotive, and machining activity.

Nevertheless, votes on clothing insulation showed 20.3% to 31.3%, hot surrounding surface 7.8% to 35.9%, heat from opening 18.8% to 39.1%, incoming sun 7.8% to 37.5%, high air speed 1.6% to 10.9%, and low humidity 6.3% to 23.4%. The vote percentage below 50% tends to be influenced by occupants' wear in dress code (combination of t-shirt, trousers, jacket/overall, and shoes/boots), where *Icl* showed 0.98 clo, which complies with ASHRAE 55, less than 1 clo. Meanwhile, based on observations of the building envelope, i.e., a roof with an aluminium layer was used as thermal insulation, while the walls were made of brick with plaster on both sides. Moreover, the factor of the opening through doors and windows also affected the occupant's sensation. From the building's orientation side, it showed all the buildings were ideal for the direction of the sun. However, two other factors, i.e., high airflow and low humidity, were found to have no effect on internal heat gain in buildings.

Adaptive Behavior

This paper also examined occupants' thermal adaptation to the workshop environment through various actions, such as moving out of the area, taking a break, drinking water, adjusting clothes, turning on the fan, and opening windows, as shown in Fig.4. From the survey, occupants preferred to move out of their workspaces as an action to release the indoor heat by taking in fresh air, with a vote ranging from 54.5% to 81.5%. Moreover, occupants also chose to take a break, for example, sitting for a while before continuing work, with votes ranging from 63.6% to 87.2%. These actions have been an option to rest the body's fatigue. Action to drink water to quench their thirst during the practical activities recorded 59.3% to 86.9% votes. It is caused by individuals who are exposed to heat and have a high metabolic rate, which tends to dehydrate.

The percentage of clothing adjustment showed 28.8% to 79.5% of the votes by opening their jackets to adapt to the workshop thermal conditions. The behaviour shows that users were in an uncomfortable condition. Even during the COVID-19 pandemic recently, occupants also needed to wear masks in the workspace. Hence, it is also seen as a hindrance to achieving comfort.

Meanwhile, actions such as turning on the wall fan or adjusting fan speed received a low percentage of votes, ranging from 10.3% to 68.8%, due to the suitability of fans used while doing practical, which were perceived as limited to specific activities such as welding, which are exposed to dust, fumes, vapours, or gases related to safety issues. Low percentage votes also shown to the window opening by 17.9% to 44.3%, possibly for the same reason as the wall fan operation. In conclusion, occupants' acts to do some adapt the environment workplace in workshops occupants preferred to take personal actions to adapt to the workshop environment.

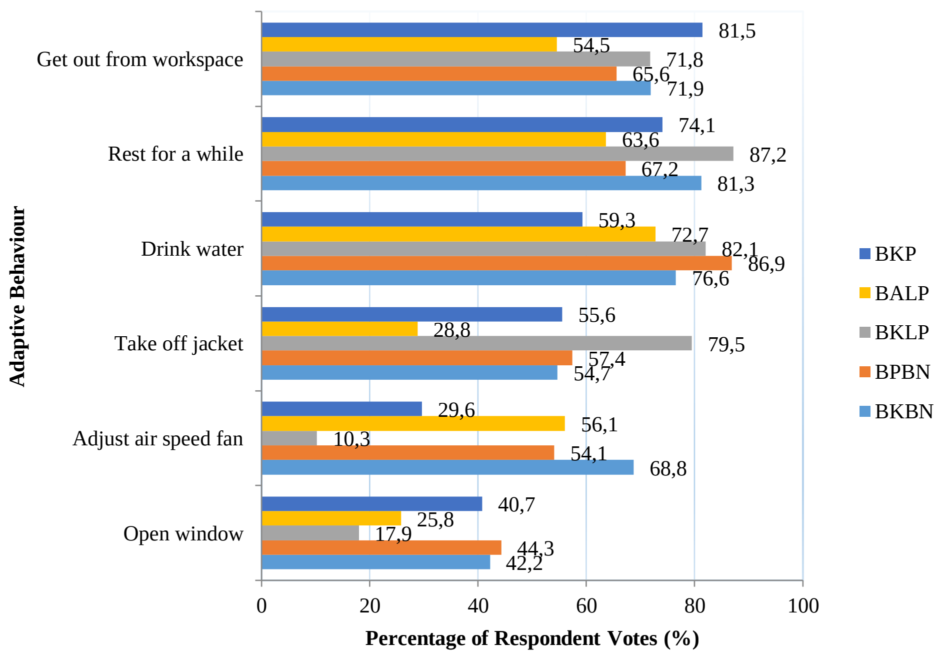

Fig 4. Vote's Percentage on Adaptive Behaviors

CONCLUSION

This study presents findings from an investigation into the environmental conditions of NV workshops in Malaysian TVET educational buildings. The main objectives of this research were obtained through two methods of subjective and objective assessment based on the ASHRAE-55 standard. The key conclusions of this study are as follow: (1) Environmental observations revealed that all workspaces in five workshops were out of the comfort zone, with the mean indoor air temperature, Ta, ranging from 30.2°C to 31.7°C and the mean indoor globe temperature, Tg, ranging from 30.5°C to 33.3°C. During the workshop activities, the mean operative temperature, Top, was found to range from 30.4°C to 33.0°C. Meanwhile, based on the 7-point ASHRAE scale, 66.5% of respondents did not accept the thermal conditions in the workspace, which led to more "hot feelings" and feelings of discomfort while implementing the teaching and learning session. (2) The main activities in the workspace area were related to machinery operation, such as in welding work, carpentry work, automotive work, and machining work with high metabolic rates ranging from 1.0 met to 2.0 met, which tends to produce heat gain from the activities in the NV building. (3) According to the findings, the mean air velocity, Av, ranged from 0.1 ms^{-1} to 0.2 ms^{-1} in all workshops. This low air speed had an impact on thermal discomfort with the percentage votes ranging from 39.1% to 84.4%. Nevertheless, in terms of air flow, most workshops were bound to the safety factors that were caused by dust, fumes, etc. (4) Relative humidity (RH) levels ranging from 55.7% to 65.1% were considered acceptable by the occupants, with votes ranging from 6.3% to 23.4% for low RH of discomfort factor. Furthermore, the RH value was acceptable as recommended by the DOSH Malaysia, i.e., in the range of 40%-70%, which does not impact occupants' heat stress. (5) The mean clothing insulation, *Icl*, was 0.98 clo, which was very close to the ASHRAE-55 recommended standard of 1.0 clo.

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