The effect of indoor environmental quality on occupants’ perception in a laboratory environment

Hong Leong Chong¹, Md Eirfan Safwan Md Jasman¹, Boon Tuan Tee¹,²*

¹Fakulti Kejuruteraan Mekanikal, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia.
²Centre for Advanced Research on Energy, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia

*Corresponding e-mail: tee@utem.edu.my

Abstract. Indoor environment conditions of a building are one of the concerned issues as most people usually spend their time inside the buildings. Poor indoor environmental conditions can influence human health in terms of physiological, perceptual and emotional as well. The main objective of this study is to investigate the effect of indoor environmental quality (IEQ) towards occupants’ perception in engineering laboratories/workshops at Mechanical Engineering Laboratories Complex. Thermal comfort and indoor air quality analysis were conducted to evaluate the indoor environment quality of the laboratory/workshop. The analysis consists of physical measurement and subjective measurement. Physical measurements were conducted with occupancy and no occupancy condition while subjective measurement was carried out through the questionnaire. Results show that air-conditioned machine workshop has temperature of 20.8°C which is not within the ASHRAE Standard-55 but still acceptable for occupants. Meanwhile, the thermal condition of non-air-conditioned welding workshop has not complied with the standard in terms of air temperature. In addition, result from occupant’s air odour perception indicates that air odour problem occurred in both case study areas. Based on the findings, indoor environment quality improvement measures are proposed to enhance the indoor environment quality (IEQ) level of the laboratory.

1. Introduction
The laboratory is an enclosed area where activities involving tests and experiments are being conducted. Safety, comfort and energy efficiency are considered as the most important criteria in maintaining laboratory condition. In this case study building, there are different types of workshops and laboratories that are used by the students to undergo engineering practices. Thus, the ideal indoor environmental quality in every workshop and laboratory are different due to the thermal environment, machines and equipment, and activities. Based on previous observations, it is indicated that some of the students who have practical sessions in laboratories complained about the lab environment, either too hot or too cold. Some of them are also feeling dizziness and tiredness when conducting workshop practices due to uncomfortable indoor conditions. These problems should be further investigated in order to find a suitable solution for improving the current indoor conditions.

In this research, the focuses are on thermal comfort condition and indoor air quality. The analysis is conducted in the welding workshop and machine workshop located in UTeM’s mechanical engineering
laboratories. The thermal comfort parameters such as air temperature, air velocity, and relative humidity are measured by using thermal comfort meter. Meanwhile, indoor air quality parameters such as carbon dioxide concentration and dust concentration are measured by using indoor air quality meter. Subjective measurements are conducted through questionnaire survey to obtain occupant perception towards the current indoor condition.

Throughout this research, the quality of the indoor thermal environment and indoor air in mechanical engineering laboratories can be evaluated and determine whether it meets with the current standard. The data from this study can be a good input for the lab management team to propose necessary improvement measures. The research activities will also help in spreading awareness of the importance of maintaining good indoor environmental condition for engineering laboratories. The respective data for thermal comfort and indoor air quality parameters can also be used as a benchmark for future research on indoor environmental conditions among university buildings.

2. Methodology

Based on the scope of this study, thermal comfort and indoor air quality analysis are conducted in order to investigate the indoor environmental quality of mechanical engineering laboratories in the complex. In this study, a non-air-conditioned welding workshop and an air-conditioned machine workshop shown in Figure 1 are selected as the case study for physical measurement and survey.

![Figure 1. (a) Welding workshop (non-air-conditioned), (b) Machine workshop (air-conditioned)](image)

Physical measurements (indoor air temperature, air velocity, relative humidity) involve two sets of conditions which are with occupants and without an occupant. In this study, the instrument used to measure the thermal comfort parameters is Delta Ohm Thermal Microclimate HD 32.1. The operative temperature range and relative humidity range for this instrument are -5°C to 50°C and 0% to 90% respectively. This instrument consists of 8 inputs for probes with SICRAM module. The probes are all fitted with an electronic circuit and can be set for calibration [1].

In this study, IAQ-Calc Indoor Air Quality Meter 7545 is used to measure CO and CO₂ concentrations. The CO₂ concentrations probe is placed at 1.1 m from the floor level. Pilot measurement is conducted by setting a 10 seconds time interval for data collection in 10 minutes duration. The time interval can be adjusted if the data shows significant changes. After that, the real measurement is conducted by with similar time interval set for each zone. The measurement is conducted at the same time with the thermal parameter measurement during morning session (10 am to 12 pm) and afternoon session (2 pm to 5 pm) for both cases with occupants and without occupants.

Apart than physical measurement, the questionnaire forms are distributed to the occupants during the class session for the selected workshops in the morning (10 am to 12 pm) and afternoon (2 pm to 5 pm). The main purpose of this survey is to obtain their perception towards the indoor environment while having session in the workshops.
3. Results and Discussions

3.1. Physical Measurement

Overall, the average readings for each parameter for both conditions in the machine workshop and welding workshop are tabulated in Table 1.

| Condition/Parameter | Without occupants | With occupants |
|---------------------|-------------------|----------------|
|                     | Machine workshop  | Welding workshop | Machine workshop | Welding workshop |
| Indoor Air Temperature, $T_a$ ($°C$) | M: 19.5°C$^a$ | M: 28.11°C$^a$ | M: 20.9°C$^a$ | M: 31.37°C$^a$ |
|                     | A: 18.8°C$^a$ | A: 30.9°C$^b$ | A: 20.8°C$^a$ | A: 33.0°C$^a$ |
| Relative Humidity, RH (%) | M: 52.8%$^a$ | M: 78.4%$^a$ | M: 58.6%$^a$ | M: 62.26%$^a$ |
|                     | A: 57.4%$^b$ | A: 67.63%$^b$ | A: 56.7%$^b$ | A: 56.3%$^b$ |
| Air Velocity, $V_a$ (m/s) | M: 0.20 m/s$^a$ | M: 0.23m/s$^a$ | M: 0.10m/s$^a$ | M: 0.24m/s$^a$ |
|                     | A: 0.16 m/s$^b$ | A: 0.14m/s$^b$ | A: 0.12 m/s$^b$ | A: 0.13m/s$^b$ |
| Carbon Dioxide Level (ppm) | M: 404.7ppm$^a$ | M: 346.7ppm$^a$ | M: 533.8ppm$^a$ | M: 357.3ppm$^a$ |
|                     | A: 381.1ppm$^b$ | A: 362.5ppm$^b$ | A: 546.0ppm$^b$ | A: 390.7ppm$^b$ |

$^a$ Morning session
$^b$ Afternoon Session

Referring to Table 1, the indoor air temperature for both conditions in the machine workshop is lower than the minimum recommended air temperature and hence not comply with the Malaysia Standard (MS1525-2014). The indoor air temperature in morning and afternoon do not vary much due to the existence of air conditioners in the workshop. Air conditioners maintain the indoor temperature in cool condition by removing the heat to outdoor. However, the increment of air temperature when occupants are present is because of additional heat gains from occupants and machines. Referring to Table 1, the indoor air temperature for both conditions in welding workshop is slightly higher than the maximum recommended air temperature and hence not complying with the standard.

Table 1 also shows that the relative humidity in the machine workshop for both conditions is within the recommended range by Malaysia Standard. This implies that the humidity condition inside the machine workshop is at acceptable condition. Based on Table 1, the relative humidity in welding workshop for both conditions are within the recommended range by ASHRAE 55-2017 [2] except the morning session for no occupancy condition. 78.4% of relative humidity is higher than the maximum allowable relative humidity by standard. However, most of the natural ventilated buildings in tropics have relative humidity higher than 70% due to the hot and humid climates.

According to Table 1, the air velocity for no occupancy condition is within the recommended range by Malaysia Standard, MS1525-2014. Meanwhile, the air velocity when occupants are present in the machine workshop is not within the recommended range by Malaysia Standard. However, it can still consider acceptable as the ASHRAE Standard 55-2017 recommended range for air velocity is from 0.1 m/s to 1.2 m/s. Moreover, the study mentioned that 0.1 m/s to 1.5 m/s of air velocity is considered acceptable for residents in tropical countries [3]. From this analysis, it is shown that the indoor air velocity is lower when occupants are present. The research found that amount of heat dissipation from the occupant decreases as higher number of occupant present in a closed space with constant ventilation rate. This is because the number of occupants affects the changed in air-flow field and wind speed decreases [4]. Hence, this can explain why the air velocity is lower for occupancy condition in machine workshop. Referring to Table 1, the air velocity in welding workshop for both conditions is within the recommended range by ASHRAE 55-2017.

Most of the studies mentioned that carbon dioxide level commonly used as a parameter to determine the indoor air quality of a building. Carbon dioxide level can be used to evaluate the adequacy of the
room ventilation [5]. Based on Table 1, the carbon dioxide level for both conditions in the machine workshop is within the maximum allowable level recommended by ASHRAE 62.1 [6]. According to Table 1, the carbon dioxide level for both conditions in welding workshop is also within the recommended level by ASHRAE 62.1. The carbon dioxide level increases when occupants are present. Most of the studies showed that the carbon dioxide level increases with the increment number of occupants.

3.2. Subjective Assessment

Based on measurement results shown in Table 1, the air temperature in the machine workshop is around 20.8°C when occupants are present. From the subjective measurement results, the thermal condition in machine workshop is not acceptable as less than 80% of the respondents voted for slightly cool, neutral, and slightly warm. However, another result shows that 100% of the respondents satisfied with the temperature in machine workshop. Based on the overall comfort perception, 95% of the respondents agreed that the environment condition in machine workshop was comfortable. This situation shows that the occupants are still in comfort condition even though the indoor temperature is not within the recommended range by MS1525-2014. Previous research indicates that the thermal comfort for occupants in tropics usually not depend on theoretical neutrality. Occupants in tropical regions are more satisfied with slightly colder thermal environment. Moreover, thermal requirements depend on the occupants’ factors such as their age, gender, metabolic rates and clothing types [7]. In this study, the clo value and metabolic rate for both workshops are estimated based on Deltalog10 software. The total clo value is 0.87 and the metabolic rate as a milling machine operator is 1.89 met or 110 W/m2. The age of occupants in machine workshop is range from 20 to 22. Hence, this explains that the indoor temperature of 20.8°C in machine workshop is considered as comfort condition for the occupants that require lower temperature due to their personal factors.

Based on measurement results in Table 1, the indoor air temperature in the welding workshop during morning session and afternoon session is 31.37°C and 33.0°C respectively. After comparison, the indoor air temperature is considered high and not within the recommended range. According to survey analysis, less than 80% of the respondents voted for interval (-1, 0, +1). Besides that, 85% of the respondents are not satisfied with the air temperature in welding workshop. Moreover, the analysis also shows that most of the respondents are feeling discomfort with the environment in welding workshop. Hence, the hot thermal condition in welding workshop has to be improved to provide a more comfortable environment for occupants.

As indicated in Table 1, the relative humidity in the machine workshop for occupancy condition is within the recommended range by the standard. From subjective assessment, 75% of the respondents voted for neutral, slightly humid and slightly dry as their humidity perception in machine workshop. 100% of the respondents felt comfortable with the environment condition in machine workshop. This indicates that the occupants accept the current humidity condition in machine workshop.

Based on measurement results in Table 1, the relative humidity in welding workshop for occupancy condition is within recommended range by the standard. From subjective assessment, 60% of the respondents voted for neutral, slightly humid and slightly dry as their humidity perception in welding workshop. The survey indicated that the majority of the occupants felt that the humidity condition in welding workshop is acceptable.

According to the measurement results in Table 1, the air velocity in the machine workshop is around 0.1 m/s. The air velocity is considered acceptable when compared with ASHRAE 55-2017. From the subjective assessment, all of the respondents voted for neutral, slightly still and slightly draughty. This indicates that the air velocity in machine workshop is within acceptable condition. On the other hand, measurement results in Table 1 show that the air velocity in welding workshop complies with ASHRAE 55. From the subjective assessment, majority 65% of the respondents voted for neutral, slightly still and slightly draughty. This implies that the overall air velocity condition is considered acceptable.

Based on measurement results in Table 1, the indoor air quality parameter, which is the carbon dioxide level in machine workshop is far below the maximum allowable level by ASHRAE 62.1. From
subjective assessment, 95% of the respondents voted for moderate odor in machine workshop while only 5% of the respondents voted for weak odor. Since the indoor air quality parameters are satisfied with the standard, occupants in machine workshop felt moderate odor is due to the indoor air circulated around the workshop. Previous research found that most of the rooms with split air-conditioner do not have outdoor air exchange and only depend on infiltration process. Insufficient ventilation requirement caused the bad dispose of the current air in a room [8]. In this study, 6 splits air-conditioners are used in machine workshop and the outside air exchange occurs only through process of infiltration. This explains why the air change rate in machine workshop is not acceptable and hence the odor produced from existing machines and workshop activities keep on circulating in the workshop.

As shown in Table 1, the carbon dioxide level in the welding workshop is also far below the maximum allowable level by ASHRAE 62.1. From subjective assessment, majority 65% of the respondents voted for moderate odor. Since the indoor air quality parameters are satisfied with the standard, occupants in machine workshop felt moderate odor is due to the insufficient air change rate and hence the odor produced from existing machines and workshop activities trapped inside the workshop.

4. Conclusions
Results obtained from thermal comfort analysis showed that the indoor air temperature in the machine workshop is not within the comfort zone range recommended by Malaysia Standard 1525:2014. Meanwhile, the thermal condition of welding workshop has not complied with ASHRAE Standard 55-2017 in terms of air temperature. Moreover, results obtained from indoor air quality analysis showed that the concentration of CO2 level in both workshops are far below the maximum concentration allowed by ASHRAE Standard 62.1.

Subjective assessment through questionnaire shows that both workshops were not in acceptable thermal conditions. Majority of the occupants are satisfied with the relative humidity and air velocity condition in both workshops. However, most of them felt that the air has a moderate odor in both workshops. Based on the current condition for both workshops, the measures should further focus on ventilation rate as good ventilation system can enhance air movement and remove air odor.

Acknowledgement
The authors gratefully acknowledge the use of the services and facilities of the Fakulti Kejuruteraan Mekanikal, Universiti Teknikal Malaysia Melaka (UTeM).

References
[1] Delta Ohm SRL. (2009). Thermal Microclimate HD32.1. from http://www.deltaohm.com/ver2012/download/HD32.1_M_uk.pdf
[2] ASHRAE. (2017). ASHRAE Standard-55: Thermal Environmental Conditions for Human Occupancy.
[3] Kwong, Q. J., Adam, N. M., & Sahari, B. (2014). Thermal comfort assessment and potential for energy efficiency enhancement in modern tropical buildings: A review. Energy and buildings, 68, 547-557.
[4] Fang, Z., Liu, H., Li, B., Baldwin, A., Wang, J., & Xia, K. (2015). Experimental investigation of personal air supply nozzle use in aircraft cabins. Applied ergonomics, 47, 193-202.
[5] Telejko, M. (2017). Attempt to Improve Indoor Air Quality in Computer Laboratories. Procedia Engineering, 172, 1154-1160.
[6] ASHRAE (2016). ASHRAE Standard-62.1: Ventilation for Acceptable Indoor Air Quality.
[7] Sattayakorn, S., Ichinose, M., & Sasaki, R. (2017). Clarifying thermal comfort of healthcare occupants in tropical region: A case of indoor environment in Thai hospitals. Energy and buildings, 149, 45-57.
[8] Putra, K., Djunaedy, E., Bimaridi, A., & Kirom, M. (2017). Assessment of Outside Air Supply for Split AC System Part B: Experiment. *Procedia Engineering*, 170, 255-260.