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(IJIREV)**www.gaexcellence.com/ijirev**THERMAL COMFORT ASSESSMENT FOR CAD/CAM
LABORATORY BASED ON ASHRAE 55 STANDARD IN
MUKAH POLYTECHNIC BUILDING**Farihana A. Rahman^{1*}, Syarafadila Ezurida Shaari², Lydia Aling³¹Department of Mechanical Engineering, Politeknik Mukah, Malaysia farihana@pmu.edu.my <https://orcid.org/0009-0009-3119-6193>²Department of Mechanical Engineering, Politeknik Mukah, Malaysia [syarafadila@pmu.edu.my](mailto:syarfadila@pmu.edu.my) <https://orcid.org/0009-0002-6158-7215>³Department of Mechanical Engineering, Politeknik Mukah, Malaysia lydia@pmu.edu.my <https://orcid.org/0009-0002-0998-1565>

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Abstract:

Thermal comfort plays a critical role in occupants' well-being, health and work performance. While thermal comfort has been widely studied in office and educational buildings, limited evidence is available on laboratory environments that operate under both air-conditioning and natural ventilation. There are many studies investigate thermal comfort in buildings to make sure thermal condition is acceptable in building conditioned with air-conditioning and natural ventilated. This study evaluated thermal comfort in a CAD/CAM laboratory using both occupant's subjective perceptions and objective environmental measurements. It also compared thermal comfort under air-conditioned conditions and natural ventilations. The experimental methods involved physical and subjective measurement. Environmental parameters including relative humidity, air temperature and air velocity were measured, while occupants' thermal perceptions were collected using a point-in-time questionnaire. Thermal comfort was evaluated using the PMV-PPD model based on ASHRAE Standard 55. Under air-conditioned conditions, the predicted mean vote (PMV) was +0.49, indicating a slightly warm but acceptable thermal sensation. Under natural ventilation, approximately 90% of occupants found the environment thermally acceptable at an operative temperature of 25.9°C. Overall, both ventilation strategies satisfied the thermal comfort requirements of ASHRAE Standard 55, indicating that the CAD/CAM laboratory provides an acceptable indoor thermal environment for its occupants.

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PMV, PPD, ASHRAE 55, Thermal Comfort



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Introduction

The laboratory is one of the important elements in the teaching and learning process in polytechnic. Comfortable laboratories have a great impact on occupants. This includes student performance. The laboratory should be in a good ventilation and comfortable condition where the thermal equilibrium level reaches the standard. Thermal comfort of an area depends on several important factors, namely air temperature, air velocity, relative humidity, clothing level, mean radiant temperature and metabolism rate. Among the methods adopted by occupants to achieve the level of comfort is to use air conditioner and to apply adaptive thermal comfort such as opening windows, wearing comfortable clothes and others. Thermal comfort in indoor environment prescribed by many standards that have been established. The standards that frequently used are ASHRAE 55 and ISO7730. This study focused on the level of comfort required by the occupants for both air-conditioning and natural ventilated based on ASHRAE 55 Standard.

This study is important to determine the thermal comfort level in the CAD/CAM Laboratory of the Mechanical Engineering Department of Mukah Polytechnic. In addition, this study also identifies the level of occupant perception in CAD/CAM Laboratory. This study is also important as a start for CAD/CAM Laboratory improvements in the future. This is because no studies have been done to determine the level of thermal comfort at CAD/CAM Laboratory if they are used. This is to ensure that lecturers and students are in a comfortable state during the teaching and learning process so that student will be more focused and effectively. Furthermore, CAD/CAM courses require diligence and focus to carry out lab activities. Based on Zhidan Zhao et. al (2017), people tend to spend their time indoor so much, so thermal comfort environment is important for satisfaction, well-being and productivity. The CAD/CAM Laboratory need to fulfil the standard of ASHRAE 55 Standard to ensure the environment of learning and teaching process are in good health and safe.

The aim of this paper is to assess thermal comfort through subjective and physical measurement. Other than that, to determine the comfort acceptability for both naturally ventilated and air-conditioning in CAD/CAM Laboratory.

Literature Review

Thermal Comfort

A study by Tongling, Bin and Yingxin (2018) was conducted in two office rooms at Guangzhou on thermal comfort and air conditioning energy use in an office building using WSZY-1A Self-recording thermometer & hygrometers. The equipment is to record indoor air temperature and humidity. The HWZY-1 Self-recording globe thermometers was used for globe temperature recording. The questionnaires involving the office workers. They were asked to fill in the questionnaires once a week. Total of 656 questionnaires were valid where 105 collected in autumn, 460 were collected in summer season and 91 in winter. Cooling capacity was using to evaluate the energy consumption of cooling for each room during summer study period.

The indoor air temperature was lower than 18°C in winter due to the relatively warm winter climate in Guangzhou even though there was not heating supply. The indoor temperature in summer usually higher than 26°C which is the setting temperature for air conditioning in many other cases in summer. The indoor temperatures distributed with the highest frequency occurred between 28°C and 29°C. The result for relative humidity, the dominated ranges in winter and autumn were 40 to 50% and 50 to 60% respectively.

According to the linear regression equation when TSV regression equals to 0, the neutral temperature in summer was 26.8°C and when TSV regression is within the range between -1 and 1 the upper limit of the acceptable temperature range was 30.4°C. In autumn when TSV regression equals to 0 the neutral temperature was 25.8°C and when TSV regression is within the range between -1 and 1 the acceptable temperature ranges were 22.1-29.6°C. The neutral temperature in winter is 23.3°C and the lower limit of the acceptable temperature range is 18.3°C.

Thermal Comfort In Natural And Air-Conditioned Building

A study by Guoqiang Zhang et. al (2007) investigates thermal comfort of naturally ventilated classrooms at Chinese subtropics performed in Hunan University in China. This study involving 1273 students who responded to the questionnaire and two teaching buildings with total of 25 classrooms. There are five points to carry out physical measurement in each classroom. Each sampling points the parameter was measured over 30 minutes period meanwhile metabolic rate and clothing insulation estimated accordance to ASHRAE Standard 55-1992.

Table 1 shows the summary of indoor climate. The results show the relative humidity is within the range of 40.2% to 90.6% and the value of mean air and radiant temperatures within 20.9°C and 22.5°C respectively. Mean air velocities ranged 0.01-0.60 m/s during the measurement and averaged 0.11 m/s. The clothing insulation value obtained for this study was between 0.65 and 1.93 clo. The coefficient of determination indicates that the increasing indoor air temperature will results in decreasing insulation through clothing by subjects.

Table 1: Summary Of Indoor Climate

	T_a (°C)	T_g (°C)	T_r (°C)	T_o (°C)	RH(%)	V (m/s)
Mean.	20.9	21.8	22.5	21.7	71.2	0.11
Max.	29.4	29.8	30.9	29.9	90.6	0.60
Min.	16.0	17.0	17.3	16.9	40.2	0.01
S.D.	3.09	3.24	3.58	3.24	0.11	0.13

Respondents gave feedback that for thermal responses, 78% perceive thermal sensation as neutral. The respondents' portion of accepting the thermal conditions was larger than the portion of corresponding of other natural ventilation study in Asia More than 96% respondents satisfied with the indoor humidity even ASHRAE Standard 55-1992 has described that it exceeded than the upper limit. Based on the results, the occupants may be not too sensitive to humidity variation. They perceived their condition to be comfortable and much more to independent of the humidity level.

This study found that when the indoor air temperature reached 28°C, students turned on the ceiling fans. Both subjective and field investigation showed that the indoor air velocity caused big problem in natural ventilation buildings. Table 2 shows the cross-tabulation of the thermal sensation and the preference responses. Seems most of the respondents were voting sensation -1, 0 and 1. Usually the results suggest that neutral thermal sensations are not always the preferred thermal state. The important thing is that all the results of thermal neutral temperatures are very close to the indoor temperatures and majority of students found their thermal environment acceptable.

Table 2: Cross-Tabulation Of Thermal Sensation And Preference Responses

Thermal sensation scales	Thermal preference scales		
	Want cooler	No change	Want warmer
-3, -2	0	0	13 (100%)
-1, 0, 1	280 (22.67%)	628 (50.85%)	327 (26.48%)
2, 3	18 (72%)	7 (28%)	0

According to Wei & Guoqiang (2008), they also run a thermal comfort study for air-conditioned building in China. The study was involving 229 occupants from 111 buildings. The operative temperature calculated as the average of mean radiant temperature and air temperature. All measurements represent the height of the occupant at seated level at a height of 1.1 m above the floor. Based on the study, people tended to feel more comfortable and comfort in air-conditioned buildings. The air-conditioned occupants were voting with higher acceptability which is 89% than the naturally ventilated occupants which is 58%. Table 3 shows the summary of indoor climate for both naturally ventilated and air-conditioned building. Air velocity and relative humidity were similar in both building types but the difference between the temperatures was obvious with air-conditioned buildings having much cooler conditions.

Table 3: Summary Of Indoor Climate

	Naturally ventilated				Air-conditioned			
	65 buildings visited, 129 respondents				46 buildings visited, 100 respondents			
	Mean	SD	Minimum	Maximum	Mean	SD	Minimum	Maximum
Air temperature(°C)	33.0	2.4	27.8	38.1	28.5	2.5	21.3	33.3
Mean radiant temperature(°C)	33.6	2.6	28.0	39.4	28.9	2.6	21.9	33.4
Relative humidity(%)	74.0	11.6	51.0	93.2	72.4	11.8	51.4	95.8
Air velocity(m/s)	0.17	0.19	0.01	1.10	0.13	0.07	0.03	0.34
Operative temperature(°C)	33.3	2.4	27.9	38.8	28.7	2.5	21.6	33.2

PMV Application And Occupant's Satisfaction Level

A study by Zhidan, Mahdi and AbdIMonem (2017) had evaluated the application of PMV model in Qatar with dry and subtropical desert climate. They also examined the occupants' adaptive behaviour. The study conducted in the office building with a central VAV air conditioning system. The central VAV air conditioning system is to reveal the occupant perception of indoor thermal comfort. In each office it is occupied by 1 university instructor and 14 occupants. The sensors were used to monitor the indoor thermal comfort conditions such as relative humidity, indoor air velocity and temperature. The data were recorded with data acquisition system in 15 minutes intervals. In this study, the air temperature was equal as mean radiant temperature because considering big thermal mass of building and shading at the outside of the north external wall for sunblock function. The Preference Monitoring Application (PMA) was using to evaluate occupant perception of the indoor thermal comfort. A 3-to-5-minute web-based survey contains 10 questions that collects time-stamped occupant responses. The survey was designed based on the ASHRAE 55 Standard on a seven-point scale from cold -3 to hot +3 and occupants' personal values such as their activity levels and cloth levels and their adaptive actions. The experimental zone temperature is pushed to 18°C as the low limit and 26°C as the high limit regularly. The data collected from the study were involving 613 effective occupant feedback from March 2016 until March 2017.

There is big difference for Actual Thermal Sensation (ATS) and calculated PMV when the occupant has evaluated thermal comfort as neutral and above. The error in the hot region always bigger compared than cold region because tolerances of occupants are different for hot and cold. Hence, the average PMV values are linearly correlated with the operative temperatures. The predicted neutral temperature is 24.6°C. The predicted neutral temperature always higher than the actual neutral temperature. For air-conditioned building, PMV model could not provide good estimation for actual thermal comfort sensation of occupant in the hot arid climate. This may be because mean radiant temperature estimated using air temperature instead real measurement.

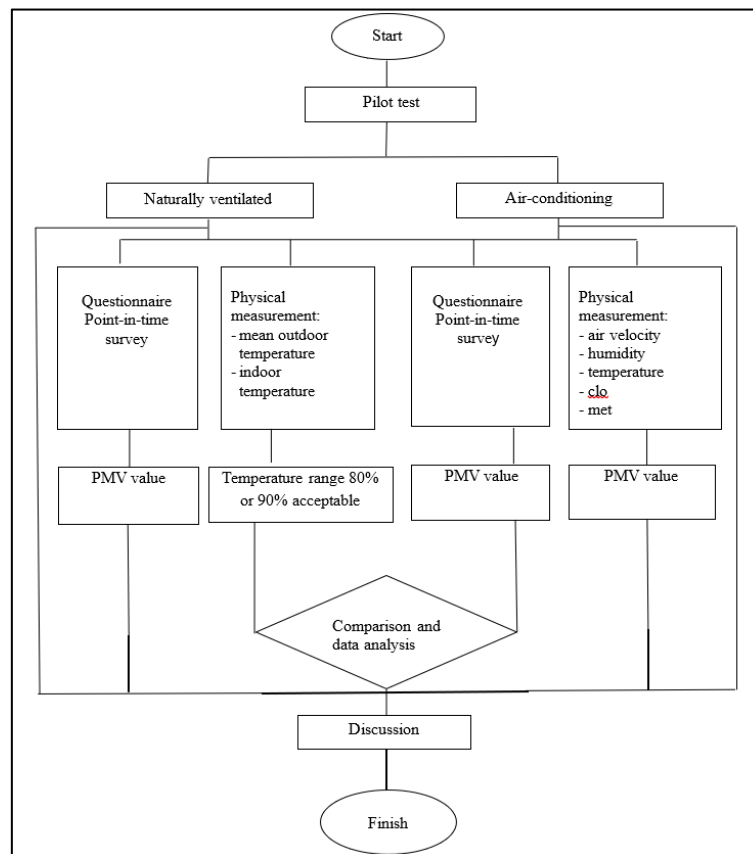
From 613 scenarios, about 43% occupants were evaluated as satisfied with thermal comfort and only 27% rated as neutral for thermal comfort sensation. There is 47% from occupants will adjust the thermostat, 35% will adjusting the cloth to improve the comfort level and 12% will open internal office indoor to introduce the warm or cold corridor air. Adjusting the thermostat directly impact the building energy system and therefore impact the building energy consumption. The performance of the building energy system may affect if the internal door is opening indirectly. Adjusting the cloth also is normally of self-adaptive way for the occupant

of building to improve the thermal comfort. But it may impact the energy of the building in long run.

Methodology

The aim of the study is to investigate the thermal comfort perception and preference of CAD/CAM Laboratory occupants. Other than that, the study also to determine the comfort acceptability for both naturally ventilated and air-conditioning in CAD/CAM Laboratory. Two laboratory conditions are considered using air-conditioning and natural ventilated. The primary procedures in the study are focused on:

- i. Pilot test.
- ii. Distribute questionnaires to occupants (subjective measurement).
- iii. Air temperature, air velocity and relative humidity measurement (physical measurement).
- iv. Analysis of PMV value and comfort acceptability.
- v. Discussion and conclusion.



Assessment Method

The experiment was conducted at CAD/CAM Laboratory, Mechanical Engineering Department, Mukah Polytechnic with 81.7m² area. This laboratory has two split air-conditioning. For natural ventilated, thermal comfort was measured with ceiling fans using. Fans play a significant role in reducing the heat stress (Iftikhar A. Raja et. al, 2001). The experiment has been conducted with 136 totally occupants for both pilot test and field test. The

occupants as subjects during the experiment as to measure the comfort index based on the questionnaires. Thermal comfort parameters were measured at the same time as students answered a survey of their perception of indoor climate. Figure 1 and 2 shows CAD/CAM Laboratory with natural ventilated and air-conditioning respectively.



Figure 1: CAD/CAM Laboratory with Natural Ventilated



Figure 2: CAD/CAM Laboratory with Air-Conditioning

Pilot Test

Pilot test is to examine the feasibility of an approach that is intended to be used in a larger scale study. It is important to run a pilot test to make sure the procedure and methodology stated are correct to follow.

Field Test

After pilot test was run, the results were determined and the field test was proceeds for other data. The field test is divided to subjective measurement and physical measurement.

Subjective Measurement

The subjective measurement is to distribute questionnaire to occupant while they are doing their activity in CAD/CAM Laboratory to predicted thermal acceptability and to indicate their discomfort level. The questionnaires were distributed and filled by occupant 30 minutes after teaching and learning process started. This is to allow all occupants to equilibrate with their surroundings. The questionnaire that has been used was point-in-time survey. Thermal sensation questions shall include the ASHRAE seven-point thermal sensation scale subdivided as follows, cold (+3), cool (+2), slightly cool (+1), neutral (0), slightly warm (-1), warm (-2) and hot (-3).

For point-in-time surveys, comfort was being evaluated using votes on the acceptability and thermal sensation scales. For both natural ventilated and air-conditioning, on each scale, votes between -1 and +3, inclusive, has been divided by total votes to obtain the probability of comfort acceptability observed during the survey period. The subjective measurement is used to classify the thermal comfort inside a CAD/CAM Laboratory according to the criteria indicated in the ASHRAE 55 Standard.

Physical Measurement

Figure 3 and 4 shows the equipment that have been using to get physical measurements. The equipment was to determine air temperature, air velocity and relative humidity. The measurement interval for air temperature and humidity was five minutes and for air velocity was in three minutes. For each point, the data was collected about two hours. The CAD/CAM Laboratory was divided into three points which are front (Point 1), middle (Point 2) and back (Point 3). These points were based on the ASHRAE 55 Standard, the floor plan of the measurement location included both of the following are the centre of the laboratory and 1.0m inward from the centre of each of the laboratory's walls. While the height above floor is 0.6m level for seated occupants to collect the data.



Figure 3: Air Velocity Meter



Figure 4: Thermohygrometer

CBE Thermal Comfort Tool

The physical measurement obtained from the field survey then evaluated using CBE Thermal Comfort Tool to get PMV-PPD value for air-conditioned. CBE Thermal Comfort Tool is a web-based graphical user interface for thermal comfort prediction according to ASHRAE 55 Standard. It includes models for conventional building systems (predicted mean vote) and for comfort using the adaptive comfort model and with increased air speeds. For example, when using fans for cooling. Provide ongoing upgrades and new features, such as visualization of comfort boundaries within the psychrometric and temperature-humidity charts and automatic generation of LEED documentation for thermal comfort credits.

PMV And PPD Relationship

This method is limited to representative occupants with metabolic rates between 1.0 and 1.3 met and clothing insulation between 0.5 and 1.0 clo in spaces with air speeds less than 0.2 m/s (ASHRAE, 2013). Figure 5 shows predicted percentage dissatisfied (PPD) as a function of predicted mean vote (PMV). Based on the assumption of the people which voting +2, +3, -2, or -3 on the thermal sensation scale classified as dissatisfied, then the PPD value was determine and is symmetric around a neutral PMV. The acceptable thermal environment for PMV is $-0.5 < PMV < +0.5$.

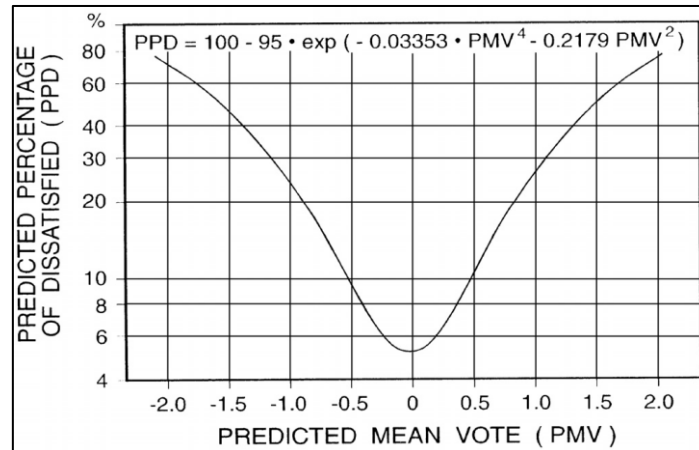


Figure 5: Predicted Percentage Dissatisfied (PPD) As A Function Of Predicted Mean Vote (PMV).

Acceptable Thermal Comfort For Naturally Ventilated Space

Based on the point-in-time survey analysis, then the acceptable operative temperature was determined. This method defines acceptable thermal environments only for occupant-controlled naturally conditioned spaces that meet all the following criteria (ASHRAE, 2003):

- i. There is no mechanical cooling system (e.g., refrigerated air conditioning, radiant cooling, or desiccant cooling) installed. No heating system is in operation.
- ii. Representative occupants have metabolic rates ranging from 1.0 to 1.3 met.
- iii. Representative occupants are free to adapt their clothing to the indoor and/or outdoor thermal conditions within a range at least as wide as 0.5 to 1.0 clo.
- iv. The prevailing mean outdoor temperature is greater than 10°C (50°F) and less than 33.5°C (92.3°F).

Figure 6 shows acceptable operative temperature ranges for naturally conditioned spaces. Based on the measurement, the thermal acceptability was determined.

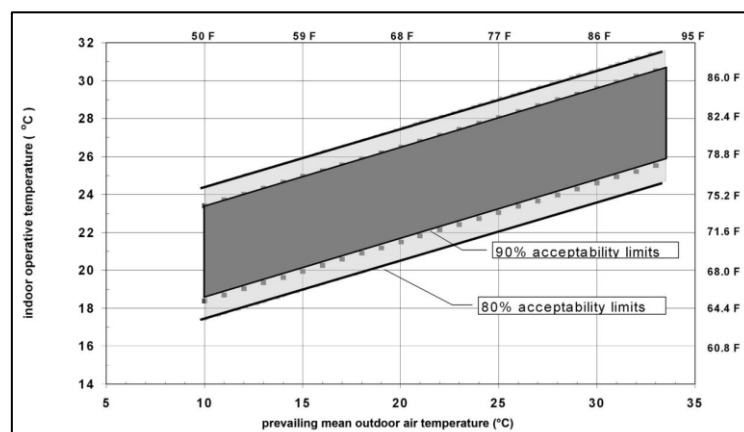


Figure 6: Acceptable Operative Temperature (To) Ranges For Naturally Conditioned

Discussion

Based on the data and the results obtained, the PMV value for air-conditioning using physical measurement is +0.49 and occupant survey is -0.03. Meanwhile PMV for natural ventilated using physical measurement is 90% acceptability and using occupant survey is +0.24. Based on the ASHRAE, the value for the acceptable thermal environment for general comfort is ± 0.5 . So that all the results obtained were fulfilled the ASHRAE 55 Standard. This result slightly different with a study conducted by R.J. de Dear et al. (1991) where they found that the thermal comfort in air-conditioned building in Singapore was just on the cool side which is -0.34. However, for natural ventilation, this study agrees with their study as the operative temperature range between 23.5°C and 28.5°C with 90% acceptability and they found that the operative temperature was 28.5°C with 90% acceptability. ASHRAE 55 specifies that the condition in which 80% or more will found the environments thermally acceptable. It is considered that subjects who vote within the comfort scale of the ASHRAE are satisfied with their thermal environment.

Conclusion

A field study of thermal comfort in CAD/CAM Laboratory carried out successfully. The findings from this study are:

- i. The PMV value based on physical measurement for air-conditioning in CAD/CAM Laboratory is +0.49. It is within the comfort range ($-0.5 < \text{PMV} < +0.5$) based on ASHRAE 55 Standard.
- ii. The PMV value based on occupant survey for air-conditioning in CAD/CAM Laboratory is -0.03. It is within the comfort range ($-0.5 < \text{PMV} < +0.5$) based on ASHRAE 55 Standard.
- iii. The PMV value based on physical measurement for natural ventilation in CAD/CAM Laboratory is 90% acceptability, within the comfort range based on ASHRAE 55 Standard.
- iv. The PMV value based on occupant survey for natural ventilation in CAD/CAM Laboratory is +0.24. It is within the comfort range ($-0.5 < \text{PMV} < +0.5$) based on ASHRAE 55 Standard.
- v. The operative temperature range for natural ventilated in CAD/CAM Laboratory is between 23.5°C and 28.5°C based on 90% acceptability.
- vi. The results show the value obtained are within the ASHRAE 55 Standard, so that the methodology can be used for further investigation for other buildings with some of guidelines need to be followed.
- vii. Overall, a large majority of the occupants found their thermal environment is acceptable. Among of the occupants, percent voted within the ASHRAE thermal sensation scale which indicated they were satisfied with the level of thermal comfort in CAD/CAM Laboratory.

- viii. The conclusion demonstrates that occupants perceived their condition to be comfortable.

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