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Comparison of Thermal Comfort Condition of Naturally Ventilated Courtyard, Semi-Outdoor and Indoor Air-Conditioned Spaces in Tropical Climate

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ABSTRACT

Universiti Tun Hussein Onn Malaysia (UTHM) elibrary is in the hot and humid tropical climate of Malaysia and has a distinctive feature of a circular courtyard and semi-outdoor spaces for practical public spaces and energy saving. This study was conducted on the ground level of the library which consists of an open terrace consisting of a cafeteria, a garden in the circular courtyard, and an air-conditioned seminar room. This study aimed to compare the thermal comfort condition of these spaces through physical and subjective measurements. Physical measurement was conducted for air temperature, relative humidity, air velocity and mean radiant temperature at the two selected sampling points on each investigated area positioned at 0.6 meters from the floor. Data were collected for three days in each area during two periods of time; 9 to 11 am and 2 to 4 pm. Subjective measurements were also collected through the distributed questionnaire to 150 respondents to determine the thermal sensation votes (TSV) of each investigated area. Calculations based on physical measurement showed the thermal comfort for both the cafeteria and garden were within 90% thermal comfort acceptability limit. PMV value for the air-conditioned seminar room was -0.45 with a PPD value of 9.03%. Both results complied with the ASHRAE 55 Standards for the acceptable condition for both naturally and air-conditioned spaces. The regression analysis showed that the comfort air temperature range based on the human response method for semi-outdoor spaces and indoor spaces were 24.8 ^{0}C to 29.0 ^{0}C and 20 ^{0}C to 23.5 ^{0}C respectively. The PMV regression analysis showed that the comfort air temperature range for indoor space was 22.4 ^{0}C to 23.5 ^{0}C. Results of the study showed that respondents perceived a higher comfort temperature range in the courtyard and cafeteria compared to indoor air-conditioned spaces, but still within the recommended range of ASHRAE 55 standard. The results of the study concluded that semi-outdoor places can potentially be designed as practical public spaces for comfortable and sustainable spaces.

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1. Introduction

The design of spaces is important to enhance the quality of life, general health conditions, and social-economic especially due to population growth and global warming issues worldwide. Paying more attention to human satisfaction in outdoor and semi-outdoor spaces is a crucial duty for thermal engineers as well as urban planner experts. Thermal comfort is regarded as one of the most important contexts for sustainability which plays a great role in urban zones in addition to noise level, air contamination, aesthetics, and approachability [1]. Thermally satisfaction of human beings in outdoor and semi-open spaces is extremely influenced by local microclimate parameters. Subsequently, the usage of these locations can be varied by the level of human thermal comfort [2].

Semi-outdoor spaces can be defined as spaces that are partly open in the direction of the outdoor circumstance [3]. This has reawakened interest in natural ventilation for the provision of comfort, particularly in terms of regulations and standards worldwide [4,5]. Designers are beginning to explore how they may widen the range of opportunities for occupant comfort, both in new-build and retrofit contexts [6,7]. The building sector is witnessing a mechanization increase and rising energy consumption. In the hot and humid tropical countries such as Malaysia, the air-conditioning system becomes the primary consumption of occupants' thermal comfort. This problem is largely linked to the current approach to comfort that is based on the heat balance model. As a result of adopting this model, thermal comfort is specified within a narrow range, which is usually difficult to achieve without air-conditioning. Consequently, it promotes unsustainable extensive use of these systems. Because of that, the current thermal comfort approach is one of the most controversial subjects in the field of building science [8].

In certain places, such as museums, cultural centers, and university campuses, activities are not restricted to indoor spaces only, semi-outdoor and outdoor spaces are also being utilized. Nikolopoulou *et al.,* [9] found that the thermal environment conditions of semi-outdoor and outdoor environments significantly influenced their utilization rate. For multi-functional public places, it is important to ensure thermal comfort in both outdoor and indoor environments. However, to ensure outdoor thermal comfort in the hot and humid weather such as in Malaysia, which is positioned in a hot and humid climate (temperature range between 24˚C to 38˚C during daytime and 21˚C to 27˚C during the night time and relative humidity around 70% to 90% RH throughout the year) is a challenging task [10].

Today, creating a thermally comfortable environment is still one of the most significant parameters to be reflected when designing a building. Thermal environment evaluation is considered together with additional elements such as air quality, light, and noise level. If the everyday working environment is disappointing, the working performance will certainly decline. Thus, it will give an effect on work efficiency. Although some detailed thermal comfort prescriptions such as ASHRAE Standard 55 and ISO 7730 have been established for indoor environments, no prescriptions have yet been established regarding thermal comfort in semi-outdoor environments [5,11]. Furthermore, since people spend most of their time indoors, researchers concerned with thermal comfort have generally focused on indoor environments.

Thermal comfort is a condition of mind which expresses satisfaction with the thermal environment and therefore needs to be assessed subjectively. Thermal comfort involves physiological and non-physiological factors. For example, the thermal perception range may be wider in semi-outdoor and outdoor environments because of the difficulty of modulating thermal conditions in these environments to make them as comfortable as indoor environments are recognized. Instead of the rational heat balance model, an adaptation model of thermal comfort, developed by De Dear and Brager [12] which relates acceptable temperature ranges to meteorological parameters, is more appropriate for situations where non-physiological factors are important. Owing to the difficulty of quantifying non-physiological factors, a field survey is recognized as the most appropriate investigative method. Furthermore, semi-outdoor and outdoor environments, which have different characteristics that may cause different thermal requirements, are considered the same in most studies [13]. Therefore, this study was conducted to compare the thermal acceptability in the courtyard, semi-outdoor, and indoor air-conditioned spaces in Tunku Tun Aminah Library, University Tun Hussein Onn Malaysia (UTHM).

Over the years, many field studies on thermal comfort have been conducted in different outdoor and semi-outdoor spaces and under different climatic conditions, which provided valuable information on understanding the effects of semi-outdoor spaces and climatic conditions on people's thermal sensations as well as the use of semi-outdoor spaces [14,15]. However, outdoor, and semi-outdoor spaces thermal comfort in urban spaces is a complex issue and has become an increasingly prominent and hotly debated topic as reflected in the literature [16]. Empirical data from field surveys on the subjective human perception in the semi-outdoor context is still needed, as this would provide a broader perspective of thermal comfort.

Most of the semi-outdoor thermal comfort studies were conducted in temperate and cold climates and some of the studies were conducted in subtropical humid climates such as China and Taiwan, but relatively little research has been conducted in the context of Malaysia. Thus, it is worth carrying out a field study to evaluate the semi-outdoor thermal environment conditions and human thermal comfort perceptions in Malaysia. Thus, this study on the comparison of thermal comfort conditions for a courtyard, semi-outdoor, and indoor air-conditioned spaces on the ground floor of the UTHM library is needed to look at the possibility to utilize semi-outdoor spaces to reduce the energy consumption of the building.

In hot climate regions such as Malaysia, active cooling is always necessary to create comfortable indoor environments, while consuming a lot of energy. In this area, most office buildings need cooling for almost 10 months per year, which has become a heavy burden for energy saving. Having the common concern about thermal comfort issues in hot climate regions, researchers have conducted field studies in different countries as shown in Table 1.

Table 1
Previous research on air-conditioned and naturally ventilated thermal comfort in the tropical climate

Reference	City	Building type	Neutral temperature (°C)	Temperature range for acceptance or satisfaction(°C)
de Dear *et al.,* [18]	Singapore	NV, residence AC, office	28.5 (t_{op}) 24.2 (t_{op})	- -
Feriadi *et al.,* [19]	Singapore	NV, residence	29.3 (*ET**) or 28.6 (t_{op})	25.1–28(*ET**) (80% satisfaction)
Cao *et al.,* [20]	China	NV, office AC, office	29.6 (t_{op}) 26.8 (t_{op})	- -
Busch [21]	Bangkok	AC, office NV, office	24.7 (*ET**) 27.4(*ET**)	22–28(*ET**) (80% acceptability) up to 31(*ET**) (80% acceptability)
Kwok [22]	Hawaii	AC, classroom NV, classroom	26.8 (t_{op}) 27.4 (t_{op})	- -
Hwang *et al.,* [23]	Taiwan	NV+AC, classroom	26.3 (*ET**)	21.1–29.8 (*ET**) (80% acceptability)
Karyono [24]	Jakarta	NV+AC, office	26.7 (t_{op})	23.5–29.9 (t_{op}) (80% acceptability)
Feriadi and Wong [25]	Jakarta	NV, residence	29.2 (t_{op}) or 29.9 (*ET**)	-

Indraganti and Rao [26]	Hyderabad	NV, residence	29.2 (t_g)	26.0–32.5 (t_g) (80% acceptability)
Song *et al.,* [27]	Guangzhou	NV, classroom+ residence	-	Up to 29.5 (t_{ad}) or 31.0 (*ET*)* (80% acceptability)
Cândido *et al.,* [28]	Maceio	NV, studio+ classroom	Up to 32 (t_{op}) (related to outdoor temperature)	Related to outdoor temperature

2. Methodology

2.1 Study Location

The case study building presented in this study was the library building of Tunku Tun Aminah, UTHM. The library is located at 1°51’23.61N and 103°4’57.57” E which is about 20 kilometers from the Batu Pahat city, in Johor state. The building has a circular geometrical shape and has a courtyard area and semi-outdoor space at its core of building design. It is a multi-story building that contains 5 levels of story. The ground level consists of multipurpose rooms including tutorial rooms, seminar rooms, computer rooms, lecture halls, a book shop, a multimedia laboratory, a stationery shop, and semi-outdoor space including a cafeteria, and garden, and a fishpond in the courtyard spaces. Level one to four is the library spaces and on the top level is the administration office. The total plan area of the building was 8091m^2 with 101.5 m of diameter. The courtyard area was 13 % of the total area which was 804 m^2 of an area with an inner diameter of 36 m. The UTHM library location was isolated from the other buildings. The immediate surroundings of the building have not been affected by any other buildings. This study considered three areas, the UTHM library garden, the UTHM library cafeteria, and the seminar room. Both the UTHM library garden and UTHM library cafeteria were naturally ventilated, while the seminar room was mechanically ventilated with centralized air condition systems. All these rooms were located on the ground floor facing the courtyard. Figure 1 shows the aerial view of the UTHM library building. Figure 2 shows the UTHM library garden and a fishpond in the courtyard space.

Fig. 1. Aerial view of UTHM library

Fig. 2. UTHM library garden located in the courtyard space

Figure 3 shows the UTHM library cafeteria located at ground level facing the courtyard and has a ceiling height of 6 m. The side walls of the cafeteria were built with 110 mm thick brick walls, while the rest of the surrounding wall is built from 125 mm thick autoclaved aerated precast concrete. The finishing for both walls are coating and plaster. The floor area is around 450 m^2. The cafeteria has fan-assisted ventilation from the wall-mounted fan. Figure 4 shows the seminar room with a ceiling height of 3.2 m. The front wall of the room was built with a 110 mm thick brick wall, while the rest of the surrounding wall is built from 125 mm thick autoclaved aerated precast concrete. The finishing for both walls are coating and plaster. The floor area is 400 m^2. The openings available are from windows and doors in the room. The total opening size is 10.55 m^2. Mechanical ventilation used in the seminar room is a centralized air conditioning system.

Fig. 3. UTHM library cafeteria spaces

Fig. 4. UTHM library seminar room

2.2 Subjective Measurements

The subjective measurement was conducted by distributing questionnaires to the respondents in each of the investigated spaces to get their thermal sensation votes. The questionnaires were distributed and filled by the respondent after a minimum of 15 minutes they entered the investigated spaces. This was to allow all occupants to equilibrate with their surroundings. The questionnaire used was adapted from the ASHRAE 55 point-in-time survey [11]. The questionnaire asked about the respondent's gender, age, thermal sensation votes, clothing that they are wearing, current health condition, and their activity. 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). Comfort was evaluated using thermal sensation votes (TSV) between (-1) and (+3), inclusive, divided by total votes The subjective measurement was used to classify the thermal comfort inside a UTHM library according to the criteria indicated in the ASHRAE 55 Standard. A total of 150 respondents answered the questionnaire with 50 respondents in each investigated place.

2.3 Physical Measurements

Four parameters; air temperature, relative humidity, air velocity and mean radiant temperature were measured using KIMO AMI 310 and TSI VelociCalc equipment Model 8386. The measurement periods of the physical measurements in this study were three days with four-hour data collection from 9 am to 11 am and 2 pm to 4 pm. The measurement periods were directly determined to be the critical hours of anticipated occupancy. Measurement intervals for air temperature, mean radiant temperature, and humidity shall be five minutes or less, and for air velocity, shall be three minutes or less. The equipment was positioned 0.6 m from the floor.

The collected measurement data consists of three main locations which were the semi-outdoor environment that was located inside the building perimeter (cafeteria), the courtyard area (garden and a fishpond), and the selected indoor room (seminar room). The data taken were air temperature, relative humidity, air velocity, and mean radiant temperature. Data were collected at two points for every location and as shown in Figure 5. The prevailing mean outdoor temperature was measured based on the mean outdoor dry-bulb temperature for three days positioned outdoors near the investigated location under the roof and not directly under the sun.

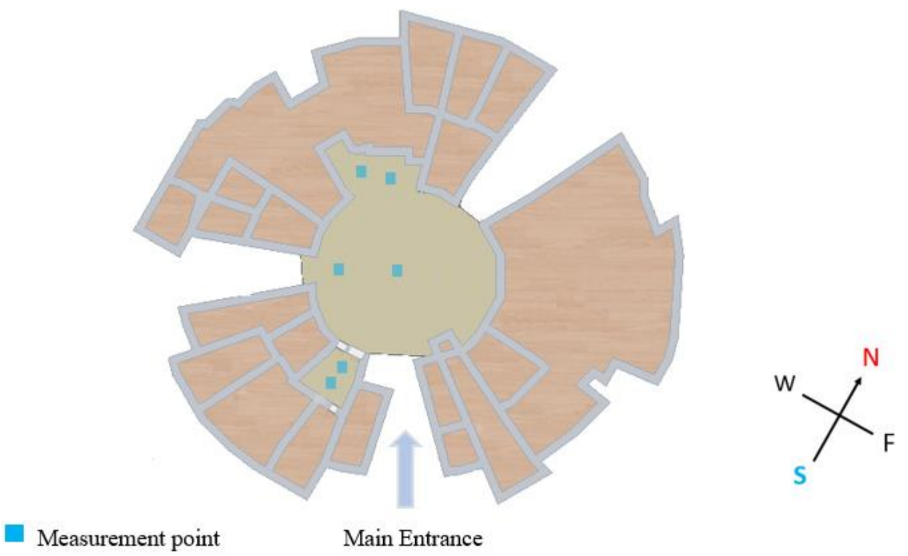


Fig. 5. The locations of measurement points on the UTHM Library ground floor

The operative temperatures were calculated based on Eq. (1)

$$t_o = At_a + (1 - A)t_r \tag{1}$$

where, t_0 = operative temperature, t_a = average air temperature, t_r = mean radiant temperature and A = values as a function of average air velocity.

2.4 PMV, PPD and Acceptability Limit

Assessments of thermal comfort conditions were divided into air-conditioned spaces and naturally ventilated spaces. The analysis of this study was conducted via CBE thermal comfort tool which is the online calculator for thermal comfort conditions [17]. Figure 6 shows the predicted percentage dissatisfaction (PPD) as a function of the predicted mean vote (PMV) for air-conditioned spaces. Based on the assumption of the people who voted +2, +3, -2, or -3 on the thermal sensation scale classified as dissatisfied, then the PPD value was determined and is symmetric around a neutral PMV. The acceptable thermal environment for PMV is -0.5 < PMV < +0.5. Figure 6 shows (PPD) as a function of (PMV).

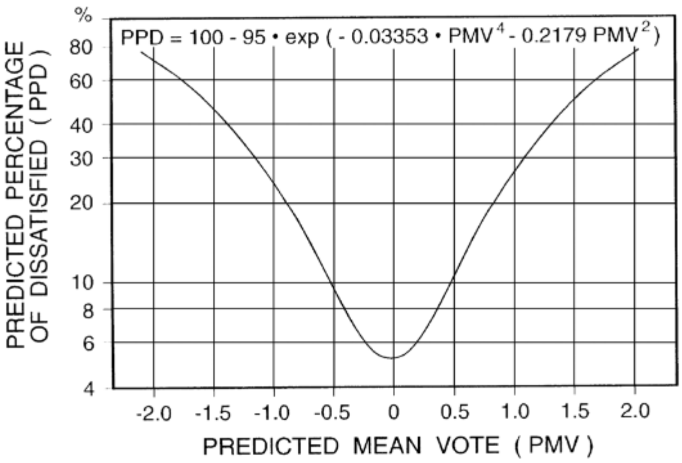
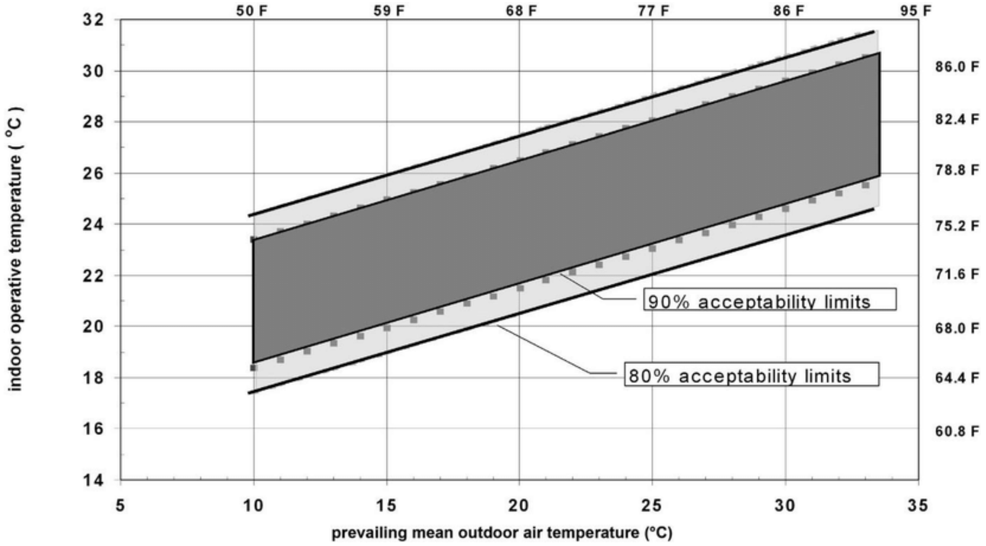


Fig. 6. Predicted percentage dissatisfaction (PPD) as a function of the predicted mean vote (PMV) [11]

Figure 7 shows the acceptable thermal conditions in occupant-controlled naturally ventilated spaces. Two parameters need to be plotted: indoor operative temperature and the prevailing mean outdoor temperature. The acceptability limit was divided into 90% and 80% acceptability limit as shown in Figure 7.



80% acceptability limits: operative temperature 23.9 to 32.7 °C
90% acceptability limits: operative temperature 24.9 to 31.7 °C

Fig. 7. Acceptable operative temperature (t_0) for naturally ventilated spaces [11]

3. Results

3.1 Subjective Measurement Results

Overall, 43% of the respondent were male and 57% were female out of 150 respondents. Figure 8 shows the age of the respondents. 40% of the respondents age was between 26 to 30 years old, 27% of the respondents age was 21 to 25 years old, 16% of the respondents age was 31 to 35 years old, 10% of the respondents age was 36 to 40 years old and 7% of the respondents age was more than 40 years old.

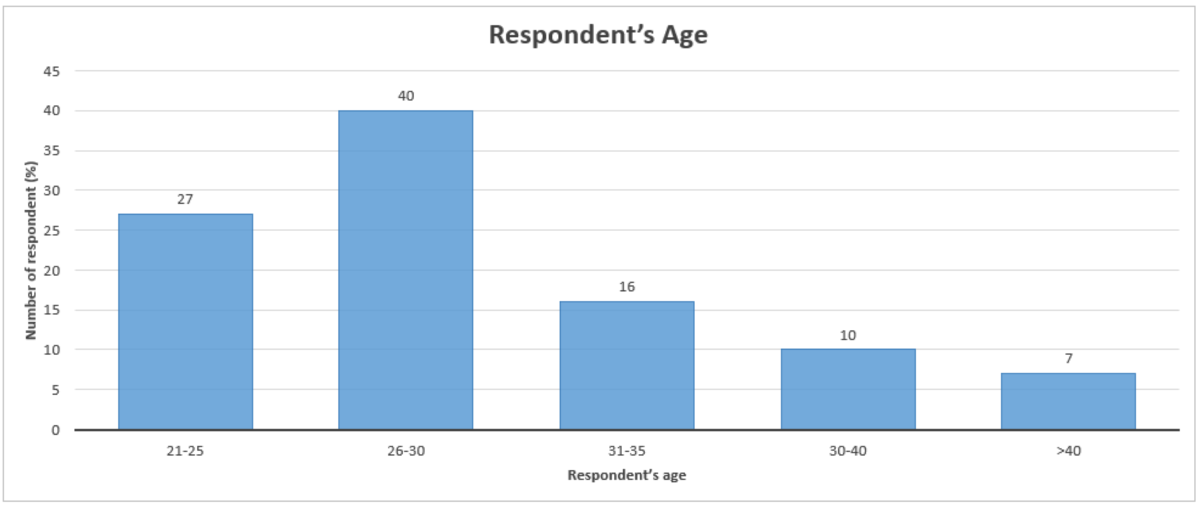


Fig. 8. Respondent's age distribution

Based on the subjective measurement conducted, the average Clo value for respondents in the cafeteria and garden was 0.46, and higher Clo value of 1.05 for the seminar room. There is a significant difference in terms of Clo value affected by the personal clothing adaptation by the respondent. The respondent having lectured in the seminar room mostly wore additional jackets compared to respondents in semi-outdoor and courtyard garden areas. The metabolic rate value was determined as a constant of 1 Met based on their activity; sitting with light works. Table 2 shows the mean TSV value collected from the questionnaire. The TSV value for the cafeteria, courtyard garden, and seminar room were +0.4, +0.12 and -0.36 respectively. The naturally ventilated spaces show a higher TSV value compared to the air-conditioned spaces. However, both TSV values were well within the recommended range of PMV by ASHRAE 55 standard (-0.5 < PMV < +0.5.). This result shows on average all respondents were within the thermally comfortable condition.

Table 2
Mean TSV value

ASHRAE 7-point		Cafeteria	Garden	Seminar Room
Hot	+3	0	0	0
Warm	+2	0	0	0
Slightly warm	+1	20	10	1
Neutral	0	30	36	30
Slightly cool	-1	0	4	19
Cool	-2	0	0	0
Cold	-3	0	0	0
Average TSV		+0.4	+0.12	-0.36

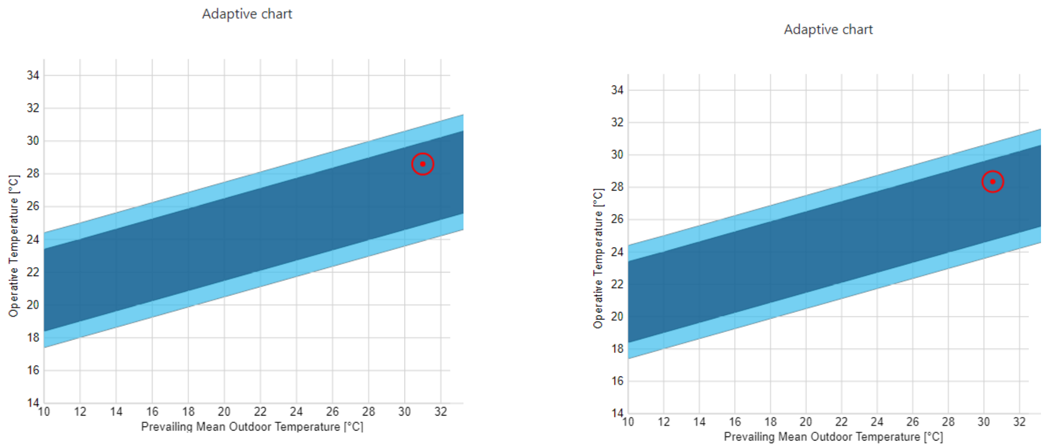
3.2 Physical Measurement Results

Table 3 shows the average physical measurement data collected for three days in the three investigated spaces. The air-conditioned seminar room had lower operative temperature, air temperature, and mean radiant temperature. On the other hand, the courtyard garden had the highest air velocity and relative humidity. The results were in line with the finding of natural features such as vegetation; trees, flowers, shrubs, grass, and water ponds have been revealed as very effective in courtyard thermal performance. The fact that humid regions like a water pool are rather recommended in a hot dry climatic region as a water pond can improve courtyard humidity level and thereby influencing positively the hot-dry atmospheric conditions [29,30].

Table 3
Physical measurement data

Parameter measurement	Cafeteria	Garden	Seminar Room
Operative temperature (˚C)	28.8	28.5	23.7
Air Temperature (˚C)	29.0	28.7	24.0
Air velocity (m/s)	0.2	1.2	0.2
Relative humidity (%)	78.5	82.1	78.4
Mean Radiant temperature (˚C)	28.2	28.0	23.5
Prevailing mean outdoor temperature (˚C)	31.0	30.5	31.0

Figure 9(a) and Figure 9(b) show the naturally ventilated spaces of the cafeteria and courtyard garden respectively. Both spaces were within the 90% acceptability limit of thermal comfort with only slightly different operative temperatures and prevailing mean outdoor temperature values. Both spaces complied with ASHRAE 55 standards.



(a) (b)

Fig. 9. Thermal comfort condition for (a) Cafeteria and (b) Courtyard Garden

Figure 10 shows the thermal comfort condition of the air-conditioned seminar room. The seminar room was thermally comfortable and complied with ASHRAE 55 standards.

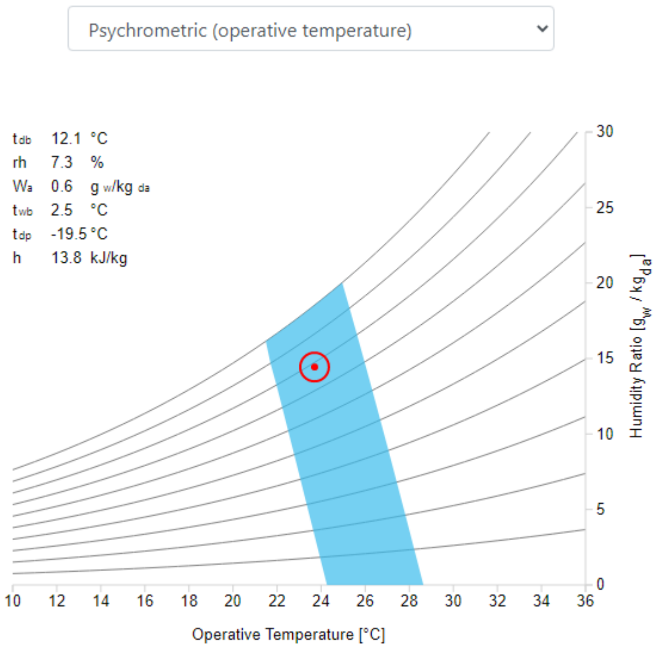


Fig. 10. Thermal comfort condition for seminar room

3.3 Comparison of Thermal Condition

Table 4 summarized and compared the thermal condition of the investigated semi-outdoor cafeteria, courtyard garden, and air-conditioned seminar room. Referring to the physical measurement, all three spaces complied with the ASHRAE 55 standard with less than 10% of PPD and within 90% of the acceptability limit. For the naturally ventilated semi-outdoor cafeteria and courtyard garden, the courtyard garden was voted by the respondent as more comfortable (nearer to the neutral scale of 0) with a TSV value of +0.12.

The air-conditioned seminar room's TSV value was -0.36 and was on the colder side of the ASHRAE 7 -points scale. The value of PMV was much lower to -0.45. This shows the respondent on average were thermally comfortable with slightly different TSV and PMV results. However, the Clo value for the respondent in the seminar room was also high (1.05 Clo) suggesting that the room could be set to a higher temperature and occupants can reduce their Clo value (i.e., removing their jacket) and still within the thermally comfort range.

Table 4
Comparison of thermal comfort conditions for the investigated semi-outdoor cafeteria, courtyard garden and air-conditioned seminar room

Spaces	Measurement		ASHRAE 55-2017 standard
	Subjective measurement	Physical measurement	Compliance
Cafeteria	+ 0.40	90% Acceptability limit	complied
Courtyard Garden	+ 0.12	90% Acceptability limit	complied
Seminar Room	-0.36	PMV: -0.45 PPD: 9.03%	complied

3.4 Comfort Temperatures

The PMV model remains among the most recognized thermal comfort models to evaluate the thermal environment. Thermal comfort condition based on ASHRAE-55 Standard recommend PMV value within the range of - 0.5 and + 0.5. Hence, the highest limit and the lowest limit of the PMV/TSV standard were used to define the air temperature of semi-outdoor and indoor spaces UTHM library ground floor. The comfort temperature of the physical measurement method was calculated based on the regression analysis of PMV obtained from data analysis of the physical measurement. While the comfort temperature of the human response method was estimated based on the TSV obtained from the questionnaire. Figure 11 and Figure 12 show the simple regression analysis results for TSV against air temperature of semi-outdoor and indoor spaces respectively. The comfort air temperature that was found based on the human response method for semi-outdoor spaces was 24.8 ^{0}C to 29 ^{0}C. Meanwhile, the comfortable air temperature for indoor spaces session was 20 ^{0}C to 23.5 ^{0}C. The comfort temperature range for semi outdoors was in line with other findings related to hot and humid climates [31].

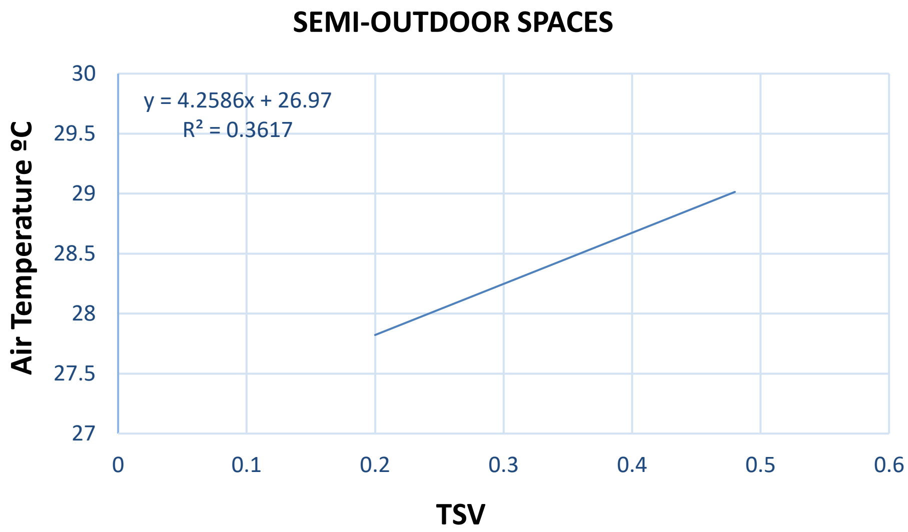


Fig. 11. Simple regression analysis of TSV against air temperature for semi-outdoor space

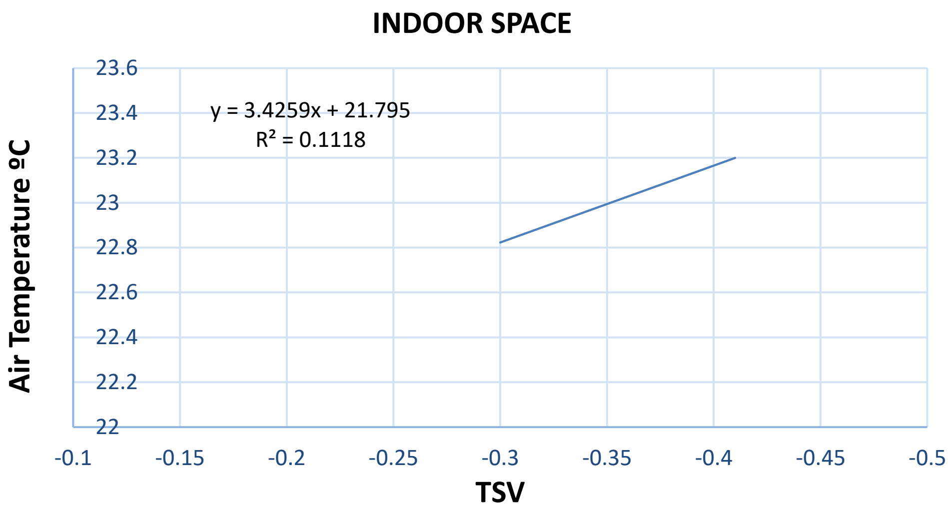


Fig. 12. Simple regression analysis of TSV against air temperature for indoor space

Figure 13 shows the simple regression analysis of PMV against air temperature for indoor space. Based on the regression equation, the comfort temperature for indoor space was 22.4 ^{0}C to 23.5 ^{0}C.

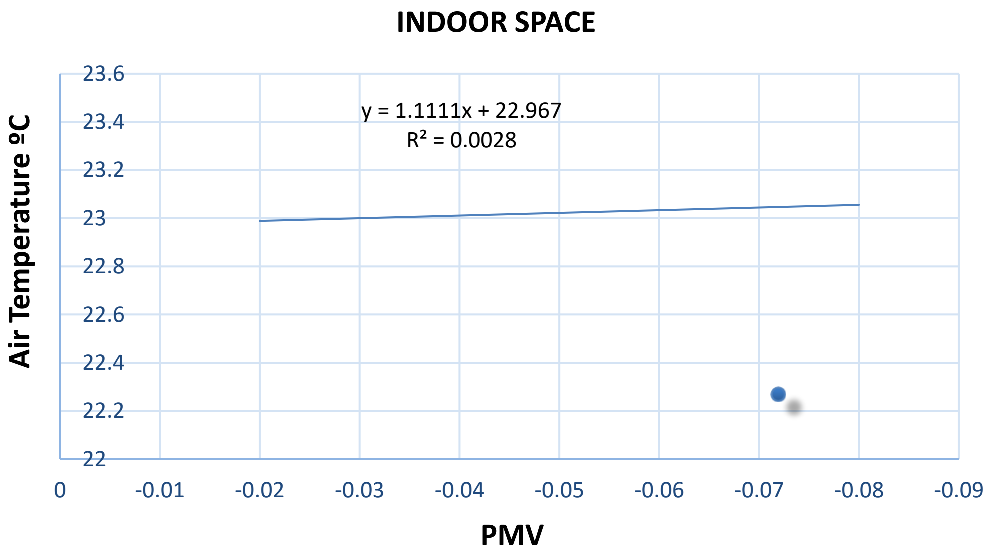


Fig. 13. Simple regression analysis of PMV against air temperature for indoor space

4. Conclusions

A field study of thermal comfort in the UTHM library ground floor in semi-outdoor and indoor spaces has been successfully carried out. The TSV value based on the human response for the semi-outdoor spaces was +0.40 and +0.12 for the cafeteria and courtyard garden respectively. Both TSV values were within the comfort range (-0.5 < TSV < 0.5) based on ASHRAE 55 Standard. Meanwhile, the TSV value based on the human response to air conditions indoor spaces was - 0.36 which was also within the comfort range based on ASHRAE 55 Standard.

The physical measurement data analysis for the semi-outdoor spaces complied with the ASHRAE-55 standard for naturally ventilated spaces and was within the 90% acceptability limit. Meanwhile, the PMV value based on physical measurement for air-conditioned indoor spaces was - 0.45 which was also within the comfort range (-0.5 < PMV < 0.5) based on ASHRAE 55 Standard for air condition spaces. The regression analysis showed that the comfort air temperature range based on the human response method for semi-outdoor spaces and indoor spaces were 24.8 ^{0}C to 29 ^{0}C and 20 ^{0}C to 23.5 ^{0}C respectively. Meanwhile, the regression analysis showed that the comfort air temperature range based on the PMV method for indoor space was 22.4 ^{0}C to 23.5 ^{0}C.

Results of the study concluded that humans perceived a higher comfort temperature range in semi-outdoor naturally ventilated spaces compared to indoor air-conditioned spaces. The results of the study showed that semi-outdoor places can potentially be designed as practical public spaces for comfortable, sustainable, and energy-efficient spaces.

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References

[1] Mayer, Helmut, Jutta Holst, Paul Dostal, Florian Imbery, and Dirk Schindler. "Human thermal comfort in summer within an urban street canyon in Central Europe." *Meteorologische Zeitschrift* 17, no. 3 (2008): 241-250. https://doi.org/10.1127/0941-2948/2008/0285

[2] Chen, Liang, and Edward Ng. "Outdoor thermal comfort and outdoor activities: A review of research in the past decade." *Cities* 29, no. 2 (2012): 118-125. https://doi.org/10.1016/j.cities.2011.08.006

[3] Nikolopoulou, Marialena, and Koen Steemers. "Thermal comfort and psychological adaptation as a guide for designing urban spaces." *Energy and Buildings* 35, no. 1 (2003): 95-101. https://doi.org/10.1016/S0378-7788(02)00084-1

[4] Refrigerating, and Illuminating Engineering Society of North America. *Energy standard for buildings except low-rise residential buildings. Vol. 90*. American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2004.

[5] ISO, En. "7730: Ergonomics of the Thermal Environment. Analytical Determination and Interpretation of Thermal Comfort Using Calculation of the PMV and PPD Indices and Local Thermal Comfort Criteria." *CEN (European Committee for Standardization)*. Geneva (2005).

[6] Van der Linden, A. C., Atze C. Boerstra, Arjen K. Raue, Stanley R. Kurvers, and R. J. De Dear. "Adaptive temperature limits: A new guideline in The Netherlands: A new approach for the assessment of building performance with respect to thermal indoor climate." *Energy and Buildings* 38, no. 1 (2006): 8-17. https://doi.org/10.1016/j.enbuild.2005.02.008

[7] Nicol, Fergus, and Lorenzo Pagliano. "Allowing for thermal comfort in free-running buildings in the new European Standard EN15251." In *Proceedings of 2nd PALENC Conference and 28th AIVC Conference on Building Low Energy Cooling and Advanced Ventilation Technologies in the 21st Century*, pp. 708-11. 2007.

[8] Chappells, Heather, and Elizabeth Shove. "Debating the future of comfort: environmental sustainability, energy consumption and the indoor environment." *Building Research & Information* 33, no. 1 (2005): 32-40. https://doi.org/10.1080/0961321042000322762

[9] Nikolopoulou, Marialena, Nick Baker, and Koen Steemers. "Thermal comfort in outdoor urban spaces: understanding the human parameter." *Solar Energy* 70, no. 3 (2001): 227-235. https://doi.org/10.1016/S0038-092X(00)00093-1

[10] Makaremi, Nastaran, Elias Salleh, Mohammad Zaky Jaafar, and AmirHosein GhaffarianHoseini. "Thermal comfort conditions of shaded outdoor spaces in hot and humid climate of Malaysia." *Building and Environment* 48 (2012): 7-14. https://doi.org/10.1016/j.buildenv.2011.07.024

[11] Standard, ASHRAE. "Standard 55-2017 Thermal environmental conditions for human occupancy." *Ashrae: Atlanta, GA, USA* (2017).

[12] De Dear, Richard J., and Gail S. Brager. "Thermal comfort in naturally ventilated buildings: revisions to ASHRAE Standard 55." *Energy and Buildings* 34, no. 6 (2002): 549-561. https://doi.org/10.1016/S0378-7788(02)00005-1

[13] De Dear, Richard, and Gail Schiller Brager. "The adaptive model of thermal comfort and energy conservation in the built environment." *International Journal of Biometeorology* 45, no. 2 (2001): 100-108. https://doi.org/10.1007/s004840100093
[14] Nikolopoulou, Marialena, and Spyros Lykoudis. "Thermal comfort in outdoor urban spaces: analysis across different European countries." *Building and Environment* 41, no. 11 (2006): 1455-1470. https://doi.org/10.1016/j.buildenv.2005.05.031
[15] Cao, Bin, Maohui Luo, Min Li, and Yingxin Zhu. "Thermal comfort in semi-outdoor spaces within an office building in Shenzhen: A case study in a hot climate region of China." *Indoor and Built Environment* 27, no. 10 (2018): 1431-1444. https://doi.org/10.1177/1420326X17728152
[16] Vanos, Jennifer K., Jon S. Warland, Terry J. Gillespie, and Natasha A. Kenny. "Review of the physiology of human thermal comfort while exercising in urban landscapes and implications for bioclimatic design." *International Journal of Biometeorology* 54, no. 4 (2010): 319-334. https://doi.org/10.1007/s00484-010-0301-9
[17] Tartarini, Federico, Stefano Schiavon, Toby Cheung, and Tyler Hoyt. "CBE Thermal Comfort Tool: Online tool for thermal comfort calculations and visualizations." *SoftwareX* 12 (2020): 100563. https://doi.org/10.1016/j.softx.2020.100563
[18] de Dear, Richard J., K. G. Leow, and S. C. Foo. "Thermal comfort in the humid tropics: Field experiments in air conditioned and naturally ventilated buildings in Singapore." *International Journal of Biometeorology* 34, no. 4 (1991): 259-265. https://doi.org/10.1007/BF01041840
[19] Feriadi, Henry, Nyuk Hien Wong, Sekhar Chandra, and Kok Wai Cheong. "Adaptive behaviour and thermal comfort in Singapore's naturally ventilated housing." *Building Research & Information* 31, no. 1 (2003): 13-23. https://doi.org/10.1080/0961321021000013830
[20] Cao, Bin, Maohui Luo, Min Li, and Yingxin Zhu. "Thermal comfort in semi-outdoor spaces within an office building in Shenzhen: A case study in a hot climate region of China." *Indoor and Built Environment* 27, no. 10 (2018): 1431-1444. https://doi.org/10.1177/1420326X17728152
[21] Busch, John F. "A tale of two populations: thermal comfort in air-conditioned and naturally ventilated offices in Thailand." *Energy and Buildings* 18, no. 3-4 (1992): 235-249. https://doi.org/10.1016/0378-7788(92)90016-A
[22] Kwok, Alison G. "Thermal comfort in tropical classrooms." *Transactions-American Society of Heating Refrigerating and Air Conditioning Engineers* 104 (1998): 1031-1050.
[23] Hwang, Ruey-Lung, Tzu-Ping Lin, and Nai-Jung Kuo. "Field experiments on thermal comfort in campus classrooms in Taiwan." *Energy and Buildings* 38, no. 1 (2006): 53-62. https://doi.org/10.1016/j.enbuild.2005.05.001
[24] Karyono, Tri Harso. "Report on thermal comfort and building energy studies in Jakarta-Indonesia." *Building and Environment* 35, no. 1 (2000): 77-90. https://doi.org/10.1016/S0360-1323(98)00066-3
[25] Feriadi, Henry, and Nyuk Hien Wong. "Thermal comfort for naturally ventilated houses in Indonesia." *Energy and Buildings* 36, no. 7 (2004): 614-626. https://doi.org/10.1016/j.enbuild.2004.01.011
[26] Indraganti, Madhavi, and Kavita Daryani Rao. "Effect of age, gender, economic group and tenure on thermal comfort: A field study in residential buildings in hot and dry climate with seasonal variations." *Energy and Buildings* 42, no. 3 (2010): 273-281. https://doi.org/10.1016/j.enbuild.2009.09.003
[27] Song, Xiaoji, Liu Yang, Wuxing Zheng, Yimei Ren, and Yufan Lin. "Analysis on human adaptive levels in different kinds of indoor thermal environment." *Procedia Engineering* 121 (2015): 151-157. https://doi.org/10.1016/j.proeng.2015.08.1042
[28] Cândido, Christhina, Richard de Dear, and Roberto Lamberts. "Combined thermal acceptability and air movement assessments in a hot humid climate." *Building and Environment* 46, no. 2 (2011): 379-385. https://doi.org/10.1016/j.buildenv.2010.07.032
[29] Meir, Isaac. "Courtyard microclimate: A hot arid region case study." In *17th PLEA Int. Conf.*: Cambridge, UK, pp. 218-222. 2000.
[30] Bulus, Markus, Malsiah Hamid, and Yaik Wah Lim. "Courtyard as a Passive Cooling Strategy in Buildings." *International Journal of Built Environment and Sustainability* 4, no. 1 (2017). https://doi.org/10.11113/ijbes.v4.n1.159
[31] Fohimi, Nor Azirah Mohd, Muhammad Hanif Asror, Rosniza Rabilah, Mohd Mahadzir Mohammud, Mohd Fauzi Ismail, and Farid Nasir Ani. "CFD Simulation on Ventilation of an Indoor Atrium Space." *CFD Letters* 12, no. 5 (2020): 52-59. https://doi.org/10.37934/cfdl.12.5.5259