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

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ABSTRACT

Universiti Tun Hussein Onn Malaysia library is in the tropical climate of Malaysia and has a distinctive feature of the 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. Calculation based on physical measurement showed the thermal comfort for both cafeteria and garden were within 90% thermal comfort acceptability limit. PMV value for the air-conditioned seminar room was -0.45 with PPD value of 9.03%. Both results complied with the ASHRAE 55 Standards for the acceptable condition for both naturally and air-conditioned spaces. Meanwhile the averaged TSV values at the cafeteria, garden and seminar room were +0.40, +0.12 and -0.36 respectively. Results of the study concluded 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 showed that semi-outdoor places can potentially be designed as practical public spaces for comfortable and sustainable spaces.

Keywords:
Thermal comfort; courtyard; tropical climate; semi-outdoor

1. Introduction

Semi-outdoor spaces can be defined as spaces that are partly open in the direction of the outdoor circumstance [1]. Designers are beginning to explore how they may widen the range of opportunities for occupant comfort, both in new-build and retrofit contexts. This has reawakened interest in natural ventilation for the provision of comfort, particularly in terms of regulations and standards worldwide [2-5]. The building sector is witnessing a mechanization increase and rising energy consumption. In tropical countries such as Malaysia, the air-conditioning system becomes the

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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 [6]

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 [7-17].

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 [18-19] have been established for indoor environments, no prescriptions have yet been established regarding thermal comfort in semi-outdoor environments. Furthermore, since people spend most of their time indoors, researchers concerned with thermal comfort have generally focused on indoor environments.

2. Methodology

2.1 Study Location

The case study building presented in this study is the library building of Tunku Tun Aminah, UTHM. 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 total plan area of the building is 8091m^2 with 101.5 m of diameter. The courtyard area is 13 % of the total area which is 804 m^2 of an area with an inner diameter of 36 m. This study considered three areas; the UTHM library courtyard garden, UTHM library cafeteria and seminar room. Both the UTHM library courtyard garden and UTHM library cafeteria are naturally ventilated, while the seminar room is mechanically ventilated with centralized air condition systems. All these rooms are 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 spaces. Figure 3 shows the UTHM library cafeteria. The cafeteria has fan-assisted ventilation from the wall-mounted fan. Figure 4 shows the 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 enter the investigated spaces. This is to allow all occupants to equilibrate with their surroundings. The questionnaire that has been 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. A total of 150 respondents answered the questionnaire with 50 respondents in each investigated place.

Fig. 1. Aerial view of UTHM library

Fig. 2. UTHM library garden in courtyard spaces

Fig. 3. UTHM library cafeteria spaces

Fig. 4. UTHM library seminar room

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

3. Results

3.1 Subjective Measurement Results

Overall, 65% of the respondent was male and 85% was female out of 150 respondents 40% of the respondents age is between 26 to 30 years old while another 27% of the respondents' age is 21 to 25 years old. While another 16% of the respondents age is 31 to 35 years old. While another

10% of the respondents age is 36 to 40 years old. while another 7% of the respondents age is more than 40 years old.

Based on the subjective measurement conducted, the average Clo value for respondents in the cafeteria and garden was 0.46, and 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 lecture 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. The TSV value for the cafeteria, courtyard garden, and seminar room were +0.4, +0.12 and -0.36 respectively. The naturally conditioned 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.

3.2 Physical Measurement Results

Table 1 shows the average physical measurement data collected for three days in the three investigated spaces. The air-conditioned seminar room has lower operative, air temperature and mean radiant temperature. On the other hand, the courtyard garden has 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 [20-21].

Table 1
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

Both cafeteria and courtyard garden spaces were within the 90% acceptability limit of thermal comfort with only slightly different operative temperature and prevailing mean outdoor temperature values. Both spaces complied with ASHRAE 55 standards. The thermal comfort condition of the air-conditioned seminar room also complied with ASHRAE 55 standards.

3.3 Comparison of Thermal Condition

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 conditioned 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 comfort 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.

4. Conclusions

The TSV value based on the physical measurement method for UTHM Library ground floor for semi-outdoor spaces complied with the ASHRAE-55 standard for naturally ventilated spaces with a 90% acceptability limit. The PMV value based on physical measurement for UTHM Library ground floor for air-conditioned indoor spaces is - 0.45 which is within the comfort range (-0.5 <PMV< 0.5) based on ASHRAE 55 Standard for air condition spaces.

The TSV value based on the human response for the semi-outdoor spaces is +0.26 which is within the comfort range (-0.5 <TSV< 0.5) based on ASHRAE 55 Standard. Meanwhile, the PMV value based on the human response for air condition indoor spaces is - 0.36 which is within the comfort range (-0.5 <PMV< 0.5) based on ASHRAE 55 Standard.

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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