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Thermal Comfort of Indoor Open Spaces at University Library in Malaysia

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ABSTRACT

The issues of improving thermal comfort inside the building have become a global point of research interest attributed to the realization that people spend more than 90% of their time in the indoor environment. This study investigated the thermal comfort temperature range for indoor open spaces in second level of the Universiti Tun Hussein Onn Malaysia (UTHM) library. The study conducted through subjective measurement (thermal sensation questionnaire) and physical measurement (air temperature, relative humidity, air velocity, mean radiant temperature measurement). A total of 120 occupants completed the thermal sensation questionnaire of indoor open spaces for morning and afternoon sessions for six days. Physical measurements data were also collected at eight measurement sampling point across the indoor open space for six days. The linear regression analysis for air temperature with thermal sensation vote (TSV) and predicted mean vote (PMV) for both morning session and afternoon session shows a good fit of the regression model on the observed data. It shows 70% of the variation in the output variable of TSV and PMV can be explained by the input variables of air temperature. The thermal comfort temperature ranges for TSV of -0.5 to +0.5 were within the range of 24.17 ºC to 25.01ºC for morning session and 23.63 ºC to 24.20 ºC for the afternoon air temperature. In addition, the thermal comfort temperature ranges for PMV of -0.5 to +0.5 were 24.03 ºC to 25.15 ºC for morning session and 23.70 ºC to 24.47 ºC for the afternoon. By using linear regression equation, the relation between air temperature, PMV and TSV were obtained.

1. Introduction

Library buildings are significant in their representation as center of knowledge. Hence, education plays an important role in human development and economic growth by providing people with the tools and knowledge they need to understand and participate in the modern world [1]. In addition to that, the educational system becomes the national agenda to produce a dynamic young generation in the international arena. This could be achieved through encouragement of success in education and to improve the quality of its human capital [2]. Therefore, to achieve the target, the government

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has to provide various infrastructures in public buildings such as the library. The number of public libraries has been increased in December 2019, there were up to 1.440 units in all over Malaysia. One of the libraries situated in Universiti Tun Hussein Onn Malaysia (UTHM) [3]. Thus, library represent a place where students can conduct lots of activities in different spaces of the library such as auditoriums, rooms, and indoor open spaces [4]. Library building also have spaces for administrative office [5]. In addition, library is often equipped with large open spaces. This study was conducted to get insight on the thermal comfort range for occupants in indoor open spaces in library building. In addition, currently individuals spend over 90% of their time in building. In Malaysia, the poor design of the building causes often overheated during the daytime, and too cold at the night [6]. Hence, people install HVAC system inside the building and set it at very low temperature to cool them. Once people are uncomfortable with their thermal environment, their thermal satisfaction, and their ability to perform will increase [7]. The significant engineering applications regarding the thermal comfort can be observed throughout the building design [8]. Thermal comfort in indoor air conditioning spaces is normally affected by the clothing insulation and the level of activities of the occupants [9]. The thermal discomfort of the indoor environment of library buildings can create unsatisfactory conditions for library users especially students, this can be distracting for the occupants, and is likely to reduce their productivity and performance [10]. The challenge is to come out with self-sustaining library buildings which will facilitate learning and overcome the state of discomfort with minimizing temperature level and energy utilization [11].

Moreover, research conducted revealed that the thermal condition in the library buildings in a tropical environment is acceptable even though the thermal sensation votes (TSV) exceed the recognized limit specified by the ASHRAE standard [12]. In addition, the non-thermally comfort condition caused by heat can reduce users learning capacity, therefore there is the need to conduct the research study on the suitable thermally comfort temperature range for tropical climate such as in the Malaysian libraries [13]. Although some research has been carried out in the field of thermal comfort on educational buildings in a tropical environment, there were very few studies that have been published on thermal comfort in the library here in Malaysia [14]. This study implemented two methods physical measurements and subjective measurements. Physical measurements used several measuring devices that were used in this study to measure air movement, air temperature, mean radiant temperature and relative humidity, these parameters can be measured by several types of equipment.

The second methods are subjective measurement. The subjective measurement was to distribute questionnaire to the occupant while they were sitting in UTHM library to predict thermal acceptability and their comfort level. Comfortable thermal environment makes people healthy, both physically and psychologically and this will positively influence occupant's productivity [15]. The findings of this study will help in understanding the thermal comfort level in open spaces such as library. Furthermore, thermal comfort is imperative in both psychological and physical aspect where it could affect the morale and productivity of the occupants [16]. Based on the degree of thermal comfort, occupants may complain (either feeling hot or cold) and productivity may suffer [17]. This study found that, thermal comfort temperature range was in the same agreement for both TSV and predicted mean vote (PMV) suggesting that PMV calculation able to predict the actual TSV from the occupant for the indoor open space area in tropical climate. Overall, a large majority of the library occupants perceived their condition to be comfortable. This study also demonstrated that higher relative humidity beyond the recommended value would affect the cooling condition.

1.1 Basic Concept on Conditions of Thermal Comfort

Thermal comfort is defined as the mental state expressed by thermal satisfaction within the surrounding environment. Dissatisfaction can be caused by a sensation of discomfort by heat or cold, and when there are differences between the heat produced by the body and the heat lost to the environment. The sense of comfort is a relative issue that varies from person to person and varies according to the times. The comfortable climatic situation for a person at a given time, may not necessarily be convenient to him/her at another time. There are many variables that affect the sense of comfort such as health, gender, clothing, physiological composition, adaptability and age of the person, social determinants, and intellectual backgrounds [18]. As a result of the many variables that affect the sense of comfort, a specific definition of comfort cannot be given but there are several definitions, including the following; thermal comfort is a state of mind in which a person expresses his satisfaction with the thermal environment [19]. The human body will be in a state of thermal equilibrium with its environment when it loses heat produced by metabolism at the same rate as it gains heat, metabolic rate is an important determinant of the comfort or the strain resulting from exposure to a thermal environment. In particular, in hot climates, the high levels of metabolic heat production associated with muscular work aggravate heat stress, as large amounts of heat need to be dissipated, mostly by sweat evaporation as stated by ISO,8996, this can be demonstrated in Figure 1 below [20]. Mathematically, the relationship between the body's heat production and all its other heat gains and losses are shown in Eq 1 and similarly, Eq 2 expressed heat exchanges of the human body [21]. For heat exchange of the human body presented in Figure 2.

$$S=M-W-E(R+C) \quad (1)$$

where the rate of heat storage in the human body which is proportional to the rate of change in mean body temp, S, metabolic rate which is heats released from human body per unit skin area depends on muscular activities, environment, body size, M, mechanical work done by human body through transformation of energy in the body, W, rate of total evaporation loss of latent heat energy through body fluid, E and dry heat exchange through radiation and Convection, R+C.

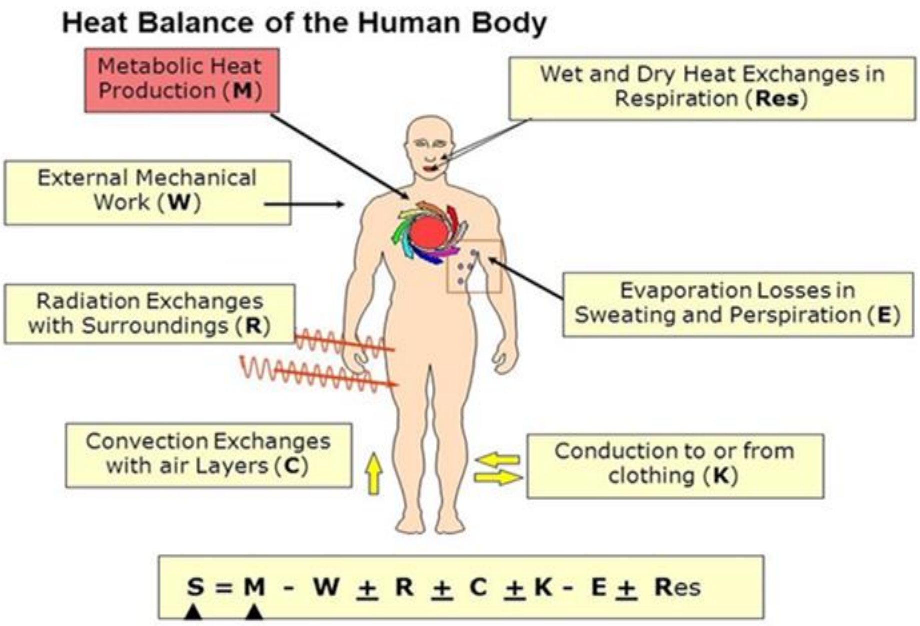

Fig. 1. Heat balance of the human body, interacting with its environment [20]

In which,

$$M \pm Rd \pm C v \pm C d \pm E v = \Delta S \quad (2)$$

where the metabolic heat production, M, net radiation exchange, Rd, convection (including respiration), Cv, conduction, Cd, evaporation (including respiration), Ev, and changed in stored heat. (have to be zero as a precondition of thermal comfort), ΔS. ΔS. A condition of equilibrium is that the sum (ΔS) is zero and such equilibrium is a precondition of thermal comfort at the 50% RH and less than 0.15m/s airflow speed.

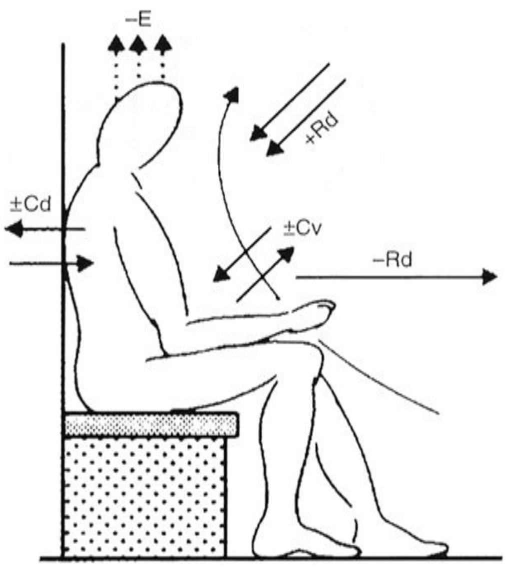

Fig. 2. Heat exchanges of the human body [21]

1.1.1 Thermal comfort assessment

There are essentially two techniques usually adopted in ascertaining people's thermal comfort which includes the thermal sensation scale and the thermal comfort scale techniques as shown in Table 1 often conducted by the use of questionnaires, and simultaneous measurement of environmental conditions, mostly in the spaces occupied by the respondents [22].The thermal comfort scales employed in the assessment of thermal environment can either have five-point or seven-point levels of evaluation includes those developed by ASHRAE, (2013) and ISO 7730, alongside with thermal comfort scale [23].

Table 1
Categories of vote for thermal sensation and thermal comfort

Thermal sensation scale			Thermal comfort scale		
+3	=	hot	+3	=	Very Comfortable
+2	=	warm	+2	=	Moderately Comfortable
+1	=	slightly warm	+1	=	Slight Slightly Comfortable
0	=	neutral	0	=	Neutral
-1	=	slightly cool	-1	=	Slightly Uncomfortable
-2	=	cool	-2	=	Moderately Uncomfortable
-3	=	cold	-3	=	Very Uncomfortable

1.1.2 Various thermal comfort studies in hot climates

Over the past decade, the investigation of thermal comfort and thermal performance becomes a most interesting topic in a cooling system. Despite the limited number of thermal comfort studies in the mid-1990s been carried out in the tropical climate region. In hot climate regions as in Malaysia, active cooling is always necessary to create comfortable indoor environments and consuming a lot of energy [24]. In this area, most public buildings need cooling for almost 10 months per year, which has become a heavy burden for energy saving [25]. Having the common concern about thermal, researchers have conducted field studies in different countries as shown in Table 2 below

Table 2
Thermal comfort research in air-conditioned related buildings in tropical climate

Year	Research	Location	Type	Research Findings
1991	De Dear, R., Foo and Leow, K.G	Singapore	NV AC	TC survey (residential, office). The discrepancy between PMV and survey thermal perception vote in NV and AC buildings. For NV: thermal neutrality (comfort) at 28.5^{0}C (OT)
1992	Busch, J.F.	Thailand (Bangkok)	NV, AC	TC survey (office)For NV: the neutral temperature was found at 27.4^0 C (ET) but the upper bound of an acceptable level, defined by ASHRAE 55-81, was 31^{0}C (ET).
1998	Allison Kwok	Hawaii	NV AC	TC survey (school). Investigating thermal neutrality, preference, acceptability. Examining TC criteria of ASHRAE 55 for tropical classrooms
1996	Nicol, F.,Roaf, S.	Pakistan	AC	The role of adaptive behavior for TC in the office.
2000	Karyono, T.H	Indonesia (Jakarta)	NV AC	TC survey, neutral temperature. The impacts of proper cooling on energy conservation
2001	Ben Hussein *et al.,*	Malaysia	AC	TC survey (classroom), Estimate the comfort zone for temperature: Range of 23-24.5°C was establish for relative humidity: Range of 74%-83determined slightly out of range recommended by ASHRAE standard.
2003	Cheong *et al.,*	Singapore	AC	TC survey (classroom). It found that the measured air temperatures, air velocities, and relative humidity were within the limits of thermal comfort standards. The overall comfort vote, PMV, and PPD indices found the occupants to be slightly uncomfortable and dissatisfied.
2003	Ahmad and Ibrahim	Shah Alam, Malaysia	NV AC	TC survey (classroom), relate indoor comfort and outdoor climate. Assess the thermal comfort conditions in the classrooms, compare the results with ASHRAE standard
2009	Ben Hussein *et al.,*	Malaysia	NV AC	TC survey (school). A comparison study to investigate the differences between the occupants' thermal comfort sensations in air-conditioned and on-air-conditioned buildings
2010	Qahtan *et al.,*	Malaysia	AC	TC survey (office). The result shows that the thermal comfort parameters lie within the recommended comfort zone of Malaysian Standards. The result suggested workers' preferable condition 22°C to 23.75°C.
2012	Shaharon, M, N., and Jalaludin, J	Malaysia	AC	TC survey (office), Thermal comfort assessment-A Study toward workers' satisfaction. This study shows that the thermal comfort zone was identified to be within the temperature range of 21.6-23.6°C and relative humidity of 42-54%.

2. Materials and Methods

Due to Covid-19 outbreak, the university shifted to online learning, which causes a substantial reduce in number of the library visitors by almost 80%, since only 20% of students had obtained the permission to enter the university. Furthermore, the study was conducted on one of the levels only, which is the level two of the library building. Therefore, 120 respondents for six days' data collection were satisfactory and acceptable. All respondents took the questionnaire two times per day for the six days' duration, once in the morning session and once in the afternoon session, in order to investigate thermal comfort temperature, range for indoor open spaces of the Universiti Tun Hussein Onn Malaysia (UTHM) library. To achieve the objectives of this research, a field study had been carried out by using a subjective and physical measurements. The subjective measurement which was a questionnaire designed simply to aid respondents' assessment of thermal comfort condition in the library. The questionnaire was administered simultaneously with the physical measurements (measurement of indoor parameters) in the indoor open space of the library.

2.1 Subjective Measurement (Questionnaire)

This study used the ASHRAE (2013) thermal environment questionnaire with some modifications according to local conditions. The questionnaire was designed to reflect the respondent's subjective assessment of the indoor thermal environment. The main contents of the questionnaire include, respondents background, such as gender and age. Respondents clothing and activity rate. The respondents were usually involved in sitting and conducting their work when answering the questionnaire, after a thirty-minute exposure to the indoor open spaces environment. Respondents subjective thermal sensation. The ASHRAE seven-point thermal sensation scale was used in the survey questioner to help respondents express their thermal sensation. Respondents subjective thermal comfort, a 7-point scale was adopted to qualify respondents thermal comfort vote. Reactions to thermal sensation. This question is used mainly to evaluate the respondent's efforts to improve the thermal comfort of the spaces through an 8- point options provided.

2.2 Physical Measurement

The main focus of this study was to investigate the thermal comfort temperature range for indoor open spaces of the Universiti Tun Hussein Onn Malaysia (UTHM) library. Four environmental parameters had measured simultaneously with the questioner time, which includes air temperature, relative humidity, mean radiant temperature, and air velocity. For the indoor open spaces thermal comfort measurement, the equipment's were positioned at different points in the indoor open spaces at level of height 1 m. The instruments used in the physical measurements were KIMO instruments model AMI 310 with Black Globe, TSI Veloci Calc Plus Air Velocity Meter. The average data used for analysis represent the actual spaces thermal conditions as observed. The results of the environmental data recorded were analysed using the ASHRAE thermal comfort tool and descriptive statistics, compared against the ASHRAE (2010) and Malaysia Standard (MS 1525:2014).

3. Location

The location of the study is the Universiti Tun Hussein Onn Malaysia (UTHM) library building. This library building is considered among the most extensive library building in almost the entire South-East Asia region. The first library in UTHM began operating on 11 Jun 2013. Geographically, the building located in 151'23.61 N and 103°5'68. 68" E is nearly 25 kilometres apart from Batu Pahat district. The building contains five stories, with a circular geometrical shape. And has a total floor area of 16000 square meters, with 101.5m in diameter. The first level of the building is designed for a variety of activities. It is so big that it could accommodate around 3000 users. The library located in separated location from any other building, as shown in Figure 3.

Fig. 3. UTHM library building

3.1 Description of the UTHM Library Building

Building analysis provides requisite information about the floor level area, cooling system, energy consumption and operation hours of the UTHM library. Table 3 below shows detailed information of the UTHM library building survey. The information describes the general features, construction, energy requirement and interior features of the UTHM library building. This information's contained a more details of the library. Building analysis provides requisite information about the building information in general, such as area, cooling system, energy consumption and operation hours of the UTHM library

Table 3
General features and Information of UTHM library building

General Features and Information	
Location	UTHM Library (Parit Raja Campus)
Building type	The five-stores library, built with green building concept
Number of floors	5 floors
Total floor area of building	16000 square meters
Sitting capacity	Over 3,000 library users. and it could contain 300,000 reading materials
Diameter	101.5m
Construction	
Construction material	In-situ concrete block, and glass facade
Internal wall finishing	Rendered smooth and painted
External wall finishing	Fine-coarse and painted
Shading device	Perforated bricks on façades
Energy requirement	
Power utilization zoning	85% occupied area, 15% service areas
Power required	1500 to 2000kW
Power supply source	100% supply from public grid
Cooling system	100% air-conditioning
Building operation hour	8 am – 4 pm during peak period

3.1.1 Space selection criteria

The ASHRAE (2013), outlined the basic building criteria to fulfil the requirement for PMV/PPD determination in the study of thermal comfort in an air condition indoor space, which are Spaces must have fixed or inoperable windows. Spaces must have a mechanical cooling system (air-conditioning) without any complementary mechanical ventilation system. Opening and closing of the door as primary means of access to the spaces should always be close. Space area should be defined as indoor space. The occupants had to be engaged in near sedentary activity within a designated indoor open space. The mentioned criteria were observed in the subsequent selection of survey spaces, [26].

4. Subjective Measurement (Questionnaire)

Subjective thermal comfort data were recorded using a questionnaire adapted from ASHRAE (2013), with some modifications to suit the goal of this research. The questionnaire was distributed to the occupants on April 4 to April 9, 2020. The data collection duration was six days. There were 120 respondents in the indoor open spaces, throughout the six days of data collection. The analysis of respondent's thermal sensation perceptions votes, and thermal comfort of physical measurements was carried out for morning and afternoon sessions. The questionnaires were distributed and filled by occupants after 30 minutes of entering the indoor open spaces. This duration allowed all occupants to equilibrate with their surrounding environment. The collected data from subjective measurements were designed to measure the thermal sensation votes (TSV) value based on ASHRAE seven- points scales. The thermal sensation scale assumed that people voting +2, +3, or -2, -3 were dissatisfied (state of unacceptable thermal conditions), while those voting within the range of -1 to +1 were thermally satisfied (acceptable thermal conditions). Furthermore, the questionnaire was administrated at the same time with the physical measurements. Therefore, occupants were instructed to answer the questionnaire during their occupancy in the library's indoor open spaces and verify their thermal sensation vote. The questionnaire form was divided into three sections. Section one collected demographic information of the respondent. Section two, information on respondent's attire or dresses worn by occupants. In section three, occupant was required to vote their thermal sensation based on ASHRAE seven- points scales. During the questionnaire conducted, it was observed that some participants found difficulties in filling in the thermal sensation and preference sections, and they asked for clarification directly. TSV value was calculated based on Eq (3) for each sampling point.

$$TSV = \frac{Number\ of\ Respondent\ Vote \times PMV\ Scale}{Total\ Respondent} \tag{3}$$

4.1 Occupant Background

Occupant answered the questionnaire form twice; morning and afternoon within the six days of data collection. The sample included a total of 75% females and 25% males. While 40 % of the respondent age between 20 to 25 years old and another 60% aged between 26 to 30 years old as shown in Figure 4 and Figure 5.

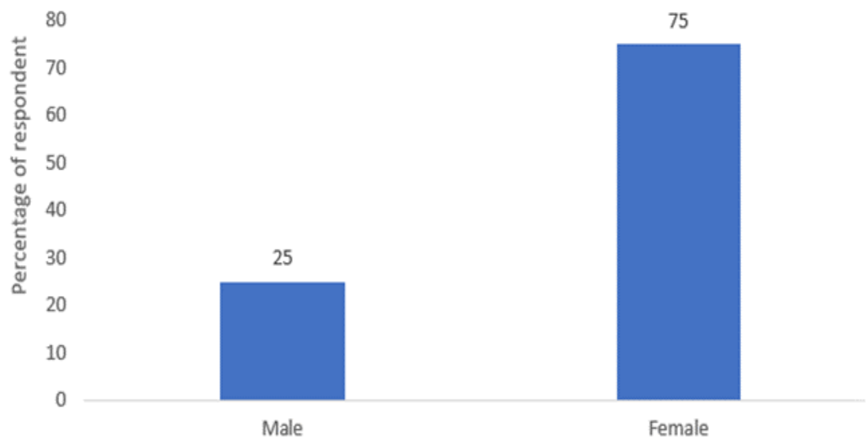

Fig. 4. Respondent’s gender

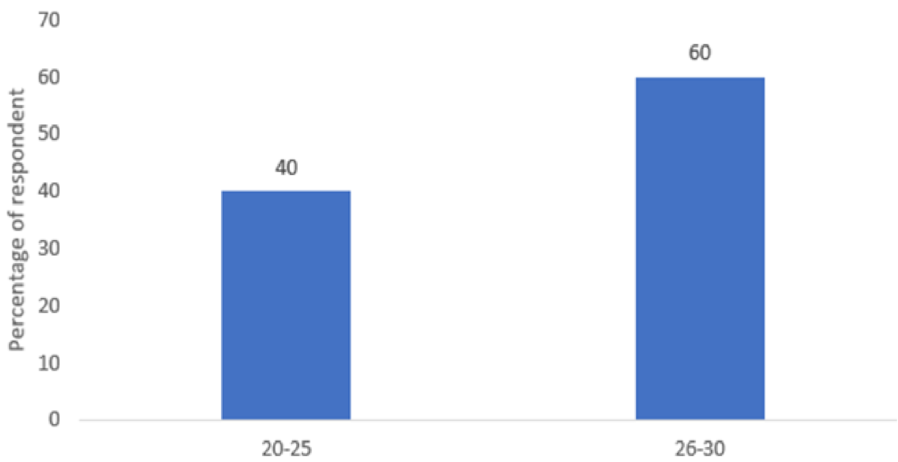

Fig. 5. Respondent’s age

4.2 Clothing and Metabolic Rate

The impact of metabolic rate on thermal comfort is critical. Human bodies continuously generate heat through metabolism, which is defined by the ASHRAE Standard 55 (2013) as “the rate of transformation of chemical energy into heat and mechanical work by metabolic activities within an organism, usually expressed in terms of unit area of the total body surface.” [27]. Furthermore, the metabolic rate for typical library activities is as tabulated in Table 4. In addition, Figure 6 shows the graphical illustration of different activities and metabolic rate level for instance, when subjects relax is 0.8 Met, light work, 1.0 Met, hard work is 1.4 Met. If subjects walk 3 km/h, the metabolic rate can reach up to 2.0 Met. Fast walking at 5 km/h, the metabolic rate is 3.0 Met. If the subjects run at 10 km/h, the metabolic rate can be up to 6.0 Met. Therefore, the metabolic rate of the occupants fixed at 1 Met (55 W/m^2) for seated occupants for reading or writing activities. Moreover, clothing is an important mechanism that can be used to control the influence of thermal conditions when freely chosen. The values for the clothing worn by the occupants were calculated by using clo unit, an estimation of the insulating properties of clothing using the tables provided by ASHRAE Standard 55-(2013). Therefore, clothing resistance is numerically represented by the unit “clo” which 1 clo equal to 0,155 kWh\m^2. In Table 5, the average clothing value of respondent divided into two; male type and female type. Male type group (A, B) description which include corporate attire, a corporate garment with a blazer with clothing values of 0.75 clo and 0.98 clo respectively. For male type group (C, D, E) which include casual attire and sport attire with the average clothing values of 0.74 clo, 0.60

clo, 0.73 clo respectively. In addition to the female clothing ensemble description group (A, B) description formal attire corporate apparel with a blazer with clothing values of 0.61 clo and 0.91 clo and for group (C, D, E) description casual attire, casual attire and sport attire with clothing values of 0.50 clo, 0.57 clo and 0.53 clo respectively. In addition, Table 6 indicated the clothing values of different clothing ensembles for all six investigated days for all 120 respondents.

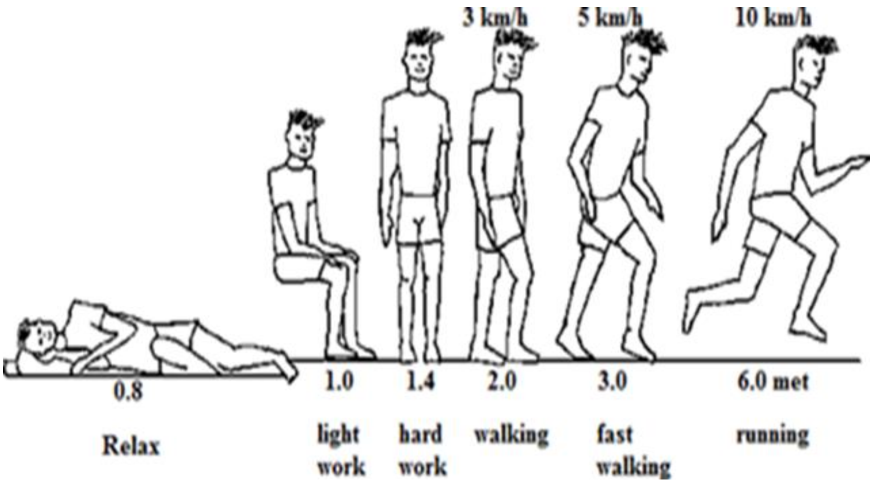

Fig. 6. Graphical representation of different activities [27]

Table 4
Average metabolic rate for typical library activities

Activity	MET	W/M^2
Sleeping	0.7	40
Reclining	0.8	45
Seated, quiet	1.0	60
Standing, relaxed	1.2	70
Reading, seated	1.0	55
Writing	1.0	60
Typing	1.1	65
Sedentary activity (office, dwelling, school, laboratory)	1.2	70
Filling, standing	1.4	80
Walking about	1.7	100
Lifting/packing	2.1	120

Table 5
Average clothing value of respondent

Clothing Ensembles					
Male	Description	Clo	Female	Description	Clo
Type A	Corporate attire	0.75	Type A	Formal attire	0.61
Type B	A corporate garment with a blazer	0.98	Type B	A Corporate apparel with a blazer	0.91
Type C	Casual attire	0.74	Type C	Casual attire	0.50
Type D	Casual attire	0.60	Type D	Casual attire	0.57
Type E	Sport Attire	0.73	Type E	Sport Attire	0.53

Table 6
Average clothing value of respondent

No. of Respondents	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
1	0.75	0.57	0.57	0.57	0.57	0.75
2	0.57	0.60	0.98	0.60	0.60	0.69
3	0.61	0.50	0.69	0.63	0.55	0.75
4	0.60	0.75	0.57	0.68	0.59	0.91
5	0.60	0.57	0.96	0.76	0.63	0.50
6	0.60	0.74	0.60	0.63	0.54	0.69
7	0.57	0.57	0.57	0.57	0.60	0.73
8	0.60	0.57	0.57	0.60	0.57	0.60
9	0.57	0.74	0.61	0.59	0.60	0.57
10	0.98	0.91	0.75	0.75	0.75	0.60
11	0.57	0.60	0.57	0.59	0.60	0.74
12	0.57	0.73	0.50	0.57	0.50	0.91
13	0.57	0.58	0.50	0.58	0.59	0.58
14	0.57	0.57	0.61	0.57	0.60	0.69
15	0.60	0.75	0.61	0.61	0.75	0.74
16	0.60	0.57	0.60	0.60	0.57	0.60
17	0.73	0.69	0.50	0.70	0.60	0.74
18	0.60	0.57	0.50	0.50	0.57	0.60
19	0.60	0.60	0.60	0.60	0.60	0.57
20	0.57	0.75	0.60	0.75	0.75	0.60
Average	0.62	0.65	0.60	0.60	0.60	0.60

5. Physical Measurements Approach

The following parameters were measured in the indoor open spaces of the UTHM library: air temperature, air velocity, relative humidity and mean radiant temperature. Measurements were made at eight locations inside the indoor open spaces. The collected measurement data consists of eight sampling point located in indoor open spaces locations as shown in Figure 7. The data was collected for six days, starting from April 4 to April 9, 2020. The measurement was conducted from 9 am to 12pm in the morning session and afternoon session from 2 to 4 pm. The acceptable range for specific physical parameters for building was based on the Malaysia Department of Safety and Health (DOSH) Industry Code of Practice on Indoor Air Quality (2010) and ASHRAE Standard 55 (2010), for air temperature in DOSH 2010 standard is between 23 – 26 ˚C and Standard range (ASHRAE 55) (2010) between 22.5˚C - 26˚C. Meanwhile, the acceptable percentage of relative humidity in DOSH,2010 standard is 40 %– 70%, and between 30% - 60% in ASHRAE 55 Standard range. The acceptable range of air velocity in Standard range DOSH is between 0.15 – 0.50 m/s, and for ASHRAE must be < 0.25 m/s as shown in Table 7 [28,29]. This recommended range is as reference for acceptable indoor environment of building. The PMV predicts the mean value of the thermal votes of a large group of people exposed to the same environment. However, individual votes are scattered around the mean value, and it is significant to be able to predict the number of people likely to feel uncomfortable warm or cool. Thus, the PPD model is an index determined from PMV that establishes a quantitative prediction of the percentage of thermally dissatisfied people who feel too cool or too warm. Moreover, in Table 8, the minimum number of sampling point must be identified to make sure that the data obtained were in an acceptable range as recommended by the Malaysian Department of Safety and Health (DOSH) (2010). For the total floor area of < 3,000 the minimum Number of sampling points need to be 1 per 500m2. Hence, for a total floor area between 3,000 - < 5,000, the minimum Number of sampling points must to be 8 minimum number of sampling points, and from 5,000 - < 10,000, shall be 12 minimum sampling. In addition, for a total floor area between10,000 - < 15,000, the minimum number of sampling point is 18. And for the total area of 20,000 - < 25,000, the minimum number of sampling points required to be 21sampling points. Thus, if total floor area is ≥ 30,000, the minimum number of sampling point shall be

1 per 1,200 sampling points as described in in Table 8 [30]. In addition, the recommended instrument measurement range and accuracy stated by ASHRAE-55, 2013 are given in Table 9, for air temperature, the measurement range need to be between 10°C to 40°C (50°F to 104°F) with the accuracy of ±0.2°C (0.4°F). And for Mean radiant temperature the measurement ranges between 10°C to 40°C (50°F to 104°F) with the accuracy of ±1°C (2°F). The relative humidity percentage shall between 25% to 95% rh with the accuracy of ±5% rh [31]. Air velocity ranged from 0.05 to 2 m/s (10 to 400 fpm) with accuracy of ±0.05 m/s. Black globe temperature the measurement ranges between -40°C-125°C with the accuracy of ±0.4°C.

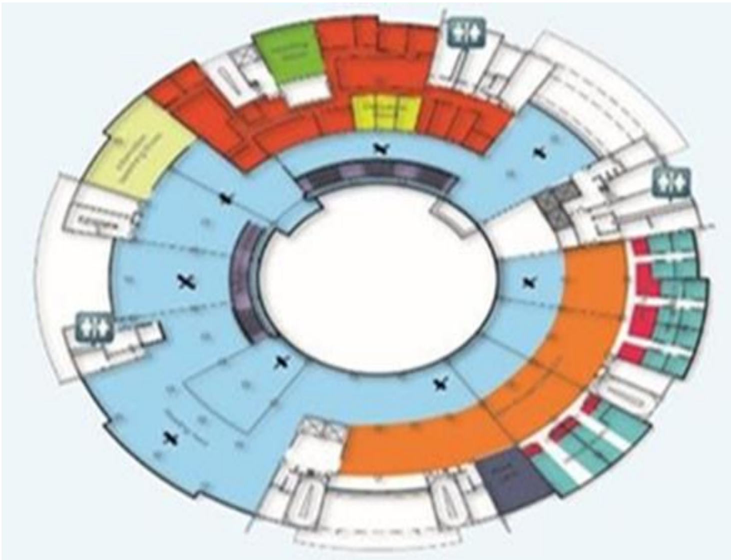

Fig. 7. The locations of measurement points in UTHM Library

Figure 8 shows Indoor open spaces of level two of UTHM library. Moreover, Figure 9 indicated the instrument set-up during data collection of physical measurement. The selected area to set up the physical measurement devices were specified to be 1.0 m from the floor to get better reading of thermal comfort data based on the sitting position of the occupants [32]. Figure 10 shows KIMO instrument model AMI 310 with black globe sensor, is also known as multifunctional instrument because it can measure 6 simultaneous parameters according to the applications which are pressure, temperature, humidity, air quality (CO/CO_2), air velocity and airflow, AMI 310 can record up to 500 data of 20000 points a day on an SD card and can restore on a PC via USB. Figure 11 presented the TSI velocityCalc Plus Velocity Meter (Model 8386) device. The TSI Model 8386 VelociCalc Plus Air Velocity Meter can measure air velocity, air temperature, relative humidity and differential pressure. It will also calculate and display volumetric flow rates. Measurements are achieved using-constant temperature anemometryin. The TSI VelociCalc is a multipurpose instrument. It can be used for many applications including indoor air quality study, HVAC measurements, energy efficiency studies, clean room studies, and fume hood/bio-safety cabinet certification. The operating temperature for this instrument is from 5˚C to 45˚C and data storage capabilities up to 1394 samples as shown in Figure 11 respectively. Hence, for simple regression analyses of PMV against air temperature for morning and afternoon sessions can be calculated based on the linear polynomial Eq. (4).

$$y = ax + d \tag{4}$$

where the predicted value of the dependent variables, Y, independent variables and it is plotted along the x- axis, x, the slope of the line, d and the intercept, a

Fig. 8. Indoor open spaces of level two of UTHM library

Fig. 9. Instrument set-up during data collection

Fig. 10. KIMO instruments model AMI 310 with black globe

Fig. 11. TSI VelociCalc Plus Air Velocity Meter (Model 8386)

Table 7
Acceptable Range of Specific Physical Parameters [28,29]

Parameters	Standard range (DOSH)	Standard range (ASHRAE 55)
Air Temperature (˚C)	23 - 26	22.5 - 26
Relative Humidity (%)	40 – 70	30 - 60
Air Velocity (m/s)	0.15 – 0.50	< 0.25

Table 8
Minimum number of sampling points [30]

Total floor area (m2)	Minimum number of sampling points
< 3,000	1 per 500m2
3,000 - < 5,000	8
5,000 - < 10,000	12
10,000 - < 15,000	15
15,000 - < 20,000	18
20,000 - < 25,000	21
≥ 30,000	1 per 1,200 m^2

Table 9
Instrument measurement range and accuracy [31]

Quantity	Measurement Range	Accuracy
Air temperature	10°C to 40°C (50°F to 104°F)	±0.2°C (0.4°F)
Mean radiant temperature	10°C to 40°C (50°F to 104°F)	±1°C (2°F)
Plane radiant temperature	0°C to 50°C (32°F to 122°F)	±0.5°C (1°F)
Surface temperature	0°C to 50°C (32°F to 122°F)	±1°C (2°F)
Humidity, relative	25% to 95% rh	±5% rh
Air speed	0.05 to 2 m/s (10 to 400 fpm)	±0.05 m/s
Black globe temperature	-40°C-125°C	±0.4°C
Directional radiation	–35 W/m^2 to +35 W/m^2 (–11 Btu/h·ft^2 to +11 Btu/h·ft^2)	±5 W/m^2 (±1.6B/ h·ft^2)

5.1 Physical Measurement Duration and Measuring Points

The measurement periods of the physical measurements in this study were six days divided into two sessions; morning session and afternoon session. The measurements were periods 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 [32]. The collected measurement data consists of the indoor open space at second floor. The data taken are air temperature, relative humidity, air velocity, and mean radiant temperature.

5.2 Physical Measurement Positions

Thermal environment measurements shall be made in the building at a location where the occupants are spending their time. Measurements shall also be taken in locations where the most extreme values of the thermal parameters are observed or estimated to occur. If occupancy distribution cannot be observed or estimated, then the measurement locations shall include both of the following: The centre of the room or space distance 1 m from wall. the measurement location shall be 1.0 m (3.3 ft) inward from the largest window. For height above floor air temperature and average airspeed (Va) shall be measured at the 0.1, 0.6, and 1.1 m (4, 24, and 43 in.) levels for seated occupants. Measurements for standing occupants shall be made at the 0.1, 1.1, and 1.7 m (4, 43, and 67 in.) level [33].

6. Results and Discussion
6.1 Thermal Sensation Votes (TSV)

From the data obtained and shown in Figure 12 and Figure 13 the cumulative percentage of TSV for six days morning session, 47.64% of the occupants voted neutral (0), 25.50% voted slightly cool (-1),10.66% voted cool (-2), 15.58% voted slightly warm (+1) and 0.62% voted warm (+2). In Figure 12 the cumulative percentage of TSV for six days' afternoon session were 20.77% of the occupants voted neutral (0), 54,91% voted slightly cool (-1), 12.55% voted cold (-2), 0.62% voted cold (-3), 10.60% voted slightly warm (+1),0.30%voted warm (+2) and 0.25% voted hot (+3). The result of TSV shows that most of the occupant voted neutral (0) in the morning session and slightly cool (-1) in the afternoon session. This may due to the effect of the relative humidity level inside the library. The minimum relative humidity value was 68.46% and maximum value was 83.78% for the morning session. While for the afternoon session, the minimum and maximum value were 67.06 % and 85.80% respectively. The recommended range of relative humidity recommended by the ASHRAE Standard

55. 2004 and for Malaysian IAQ Code of Practice is between 30% to 70%. [34]. In the Figure 12, during the morning session. Most of the respondents vote distribution on their thermal sensation perception are centred around the -2 to +1 for thermal sensation respectively. In the Figure 13 during the afternoon session the thermal sensation vote concentrated around -2 to +1 categories.

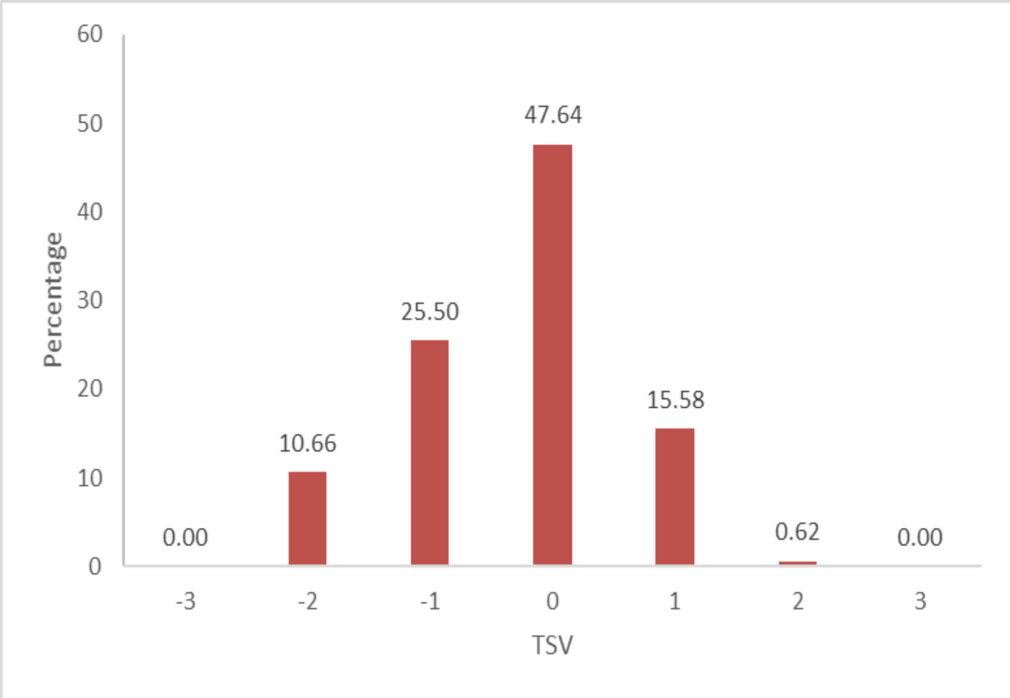

Fig. 12. Cumulative percentage of TSV for six days (morning session)

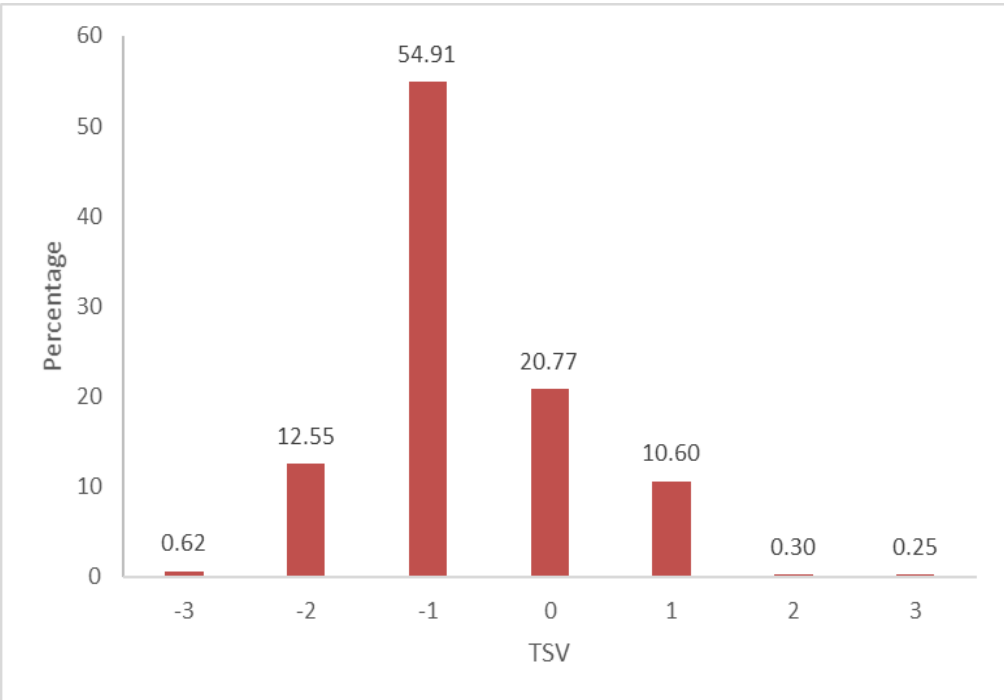

Fig. 13. Cumulative percentage of TSV for six days (afternoon session)

Figure 14 and 15 shows the linear regression analysis of air temperature and TSV for both morning session and afternoon session respectively. This result was based on physical measurement and subjective measurement after the data collection process has been conducted. This result was based on the PMV from thermal comfort tool and TSV for 120 samples under different temperature. Both analysis shows R^2 value of 0.7 which shows a good fit of the regression model on the observed data. It shows 70% of the variation in the output variable of TSV can be explained by the input variables of air temperature. To emphasize the linear regression between air temperature and TSV for morning session give strong connection (R^2=0.7524) was found with Eq. (4) y = 1.1946 x –29.374 in Figure 14, while the linear regression of air temperature and TSV for afternoon session shows strong regression (R^2 =0.7331) with Eq. (5) y=1.749 x –41.826 in Figure 15. The most suitable relation used was linear regression equation which the equation of the relation of air temperature and TSV. Also shows correlation and accuracy which is 75 % accurate when this relation had implemented during the real time analysis. The comfort air temperature and its range were within the recommended range for ASHRAE Standard 55 which is between 22.5 °C to 26°C and DOSH (2010) from 23 °C to 26°C.

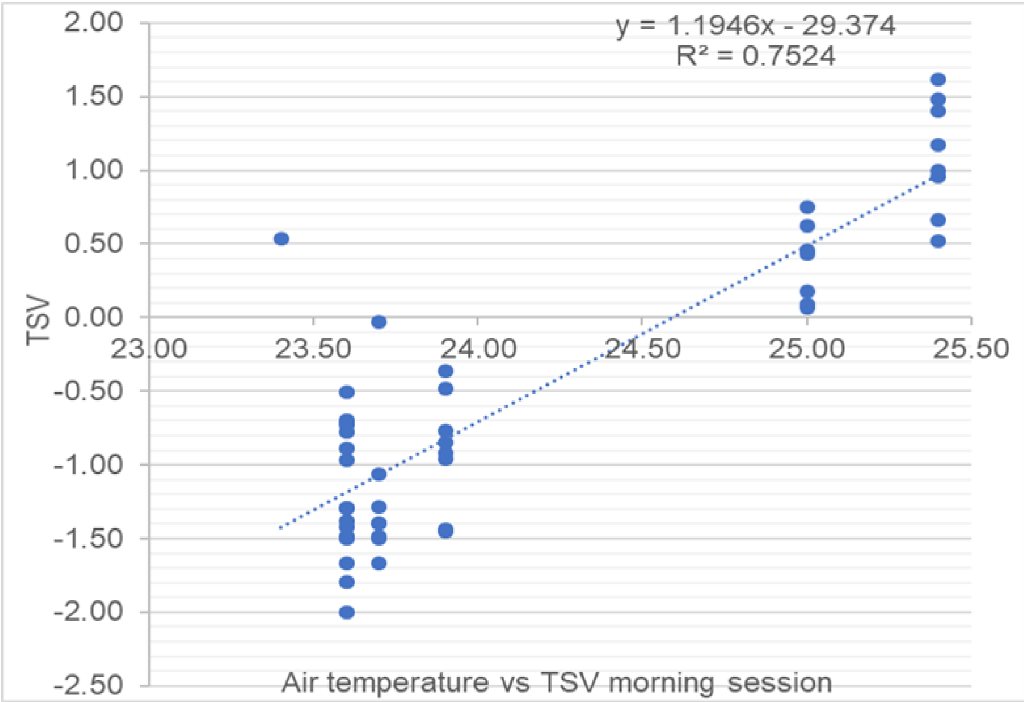

Fig. 14. Linear regression analysis of air temperature and TSV (morning session)

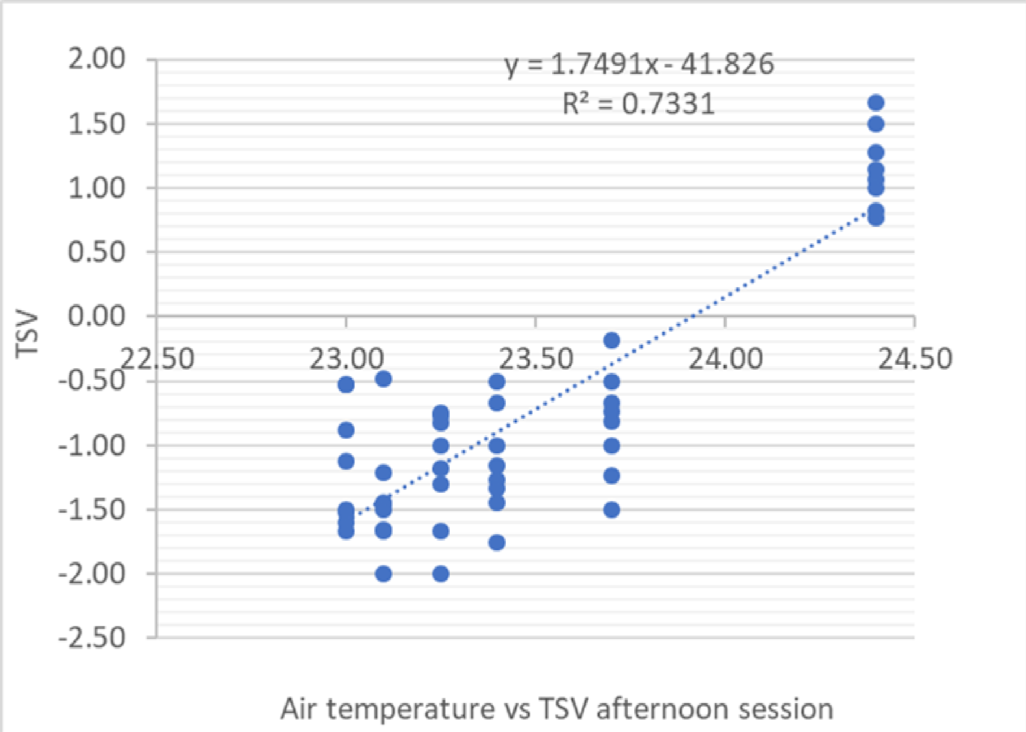

Fig. 15. Linear regression analysis of air temperature and TSV (afternoon session)

6.2 Physical Measurements
6.2.1 Predicted mean value (PMV)

PMV were estimated based on the six parameters measured through physical measurement, air temperature, mean radiant temperature, air velocity, relative humidity, metabolic rate and clothing value. The data was collected for 6 days for all indoor open space places from 28 May 2019 to 19 June 2019 as shown Measurements were carried out on the sitting position of the occupant when sitting which is the 0.60 m height from the floor as stated in (ASHRAE, 2013). Data collected include air temperature, relative humidity, air velocity and mean radiant temperature. Data collection was conducted in the morning (9 am to 11 am) and afternoon (2 pm to 4 pm) for each day. the total average data for 6 days of indoor open space of UTHM library. Together with occupant's metabolic rate and clothing values. The metabolic rate of the occupants fixed at 1 Met (55 W/m2), The total average of air temperature for morning sessions 23.71 and minimum 23.50°C, and maximum 24 .7 °C respectively. The total average of temperature for afternoon session is 23.49°C. and minimum 23.39 and maximum 23.66 °C. The total average of mean radian temperature for morning session is 24.07 °C and minimum 23.59 °C and maximum 24.71°C. Hence, the total average mean radiant temperature for afternoon session is 23.73 °C minimum 23.59°C and maximum 24.18°C. Thus, the total average of air velocity for morning session is 0.09 m/s and minimum 0.08 m/s, and maximum 0.09 m/s. The total average of air velocity for afternoon session is 0.10 m/s and minimum 0.09 m/s and maximum 0.12 m/s. In addition, the total average of relative humidity for morning session 72.57 %, and minimum 68.46 % and maximum 83.78 %. The total average relative humidity for afternoon session is 73.61 % and minimum 67.06 % and maximum 85.80% respectively.

6.2.2 Linear regression analysis of air temperature and predicted mean vote (PMV)

The PMV is used to determine whether a given thermal environment complies with comfort criteria of thermal neutrality and to establish requirements for different levels of acceptability [35]. Figure 16 and 17 shows the comparisons of air temperature with PMV. The linear regression analysis of air and PMV for both more morning session and afternoon session respectively. By analyzing the linear regression between air temperature and PMV for morning session a strong relation (R^2 =0.7068) was found with Eq. (6) y₌0.8936 x – 21.977 in Figure 16, while the linear regression of air temperature and PMV for afternoon session shows strong regression (R^2 =0.7823) was found with Eq. (7) y₌1.2994 x –31.301 as shown in Figure 17. The regression analysis helped to predict the PMV value for different air temperature. It can be inferred that this study finds in agreement with many studies that have emphasized the role of PMV model. Therefore, thermal comfort can be achieved at scale of zero which can be termed as the ideal thermal condition, when the conditions of -0.5<PMV<+0.5 is satisfied by the result of the PMV. The PMV predicts the mean value of the thermal votes of a large group of people exposed to the same environment. But individual votes are scattered around the mean value, and it is significant to be able to predict the number of people likely to feel uncomfortable warm or cool.

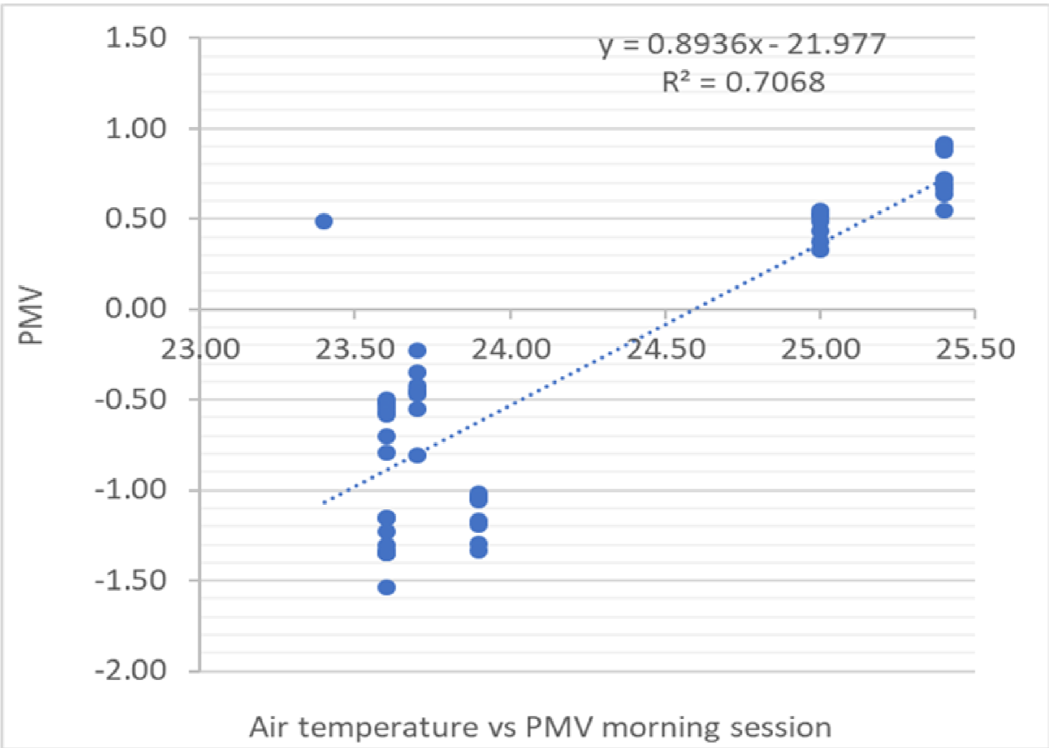

Fig. 16. Comparison of air temperature with PMV (morning session)

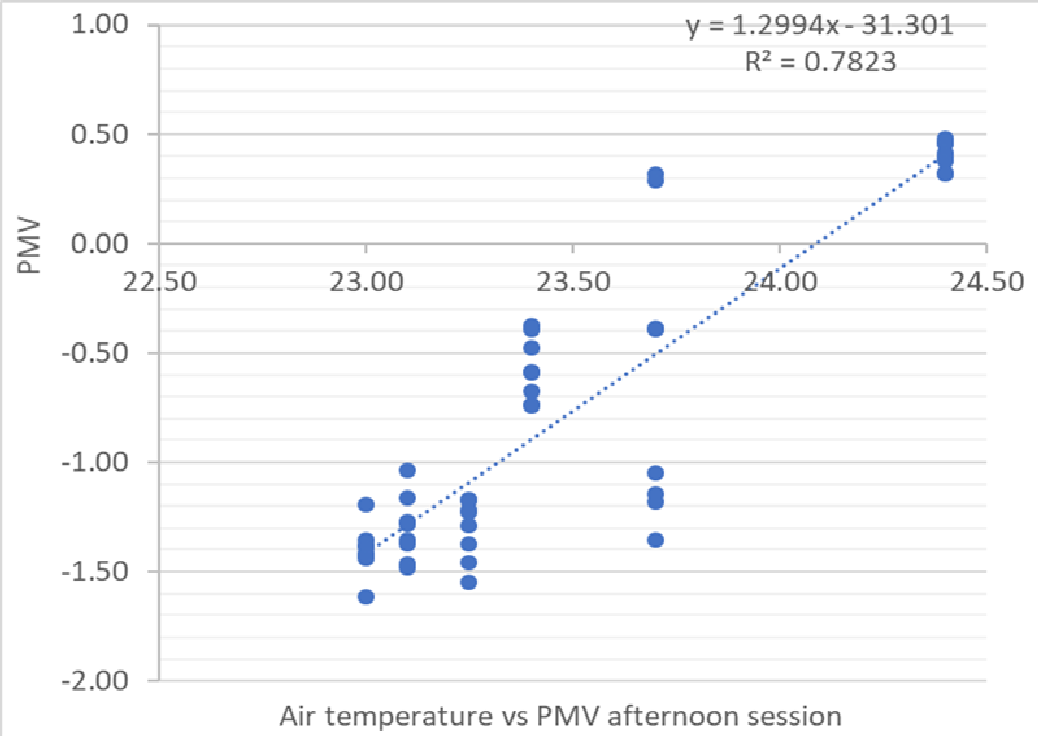

Fig. 17. Comparison of air temperature with PMV (afternoon session)

7. The Overall Comparison of PMV and TSV for Six Days Morning and Afternoon Session

Table 10 shows the overall result of PMV and TSV comparisons of six days morning and afternoon session. The overall analysis generally contains the four environmental parameters, air temperature, mean radiant temperature, air velocity, relative humidity for morning and afternoon sessions. Including PMV and TSV for morning and afternoon session. As content indicates the average relative humidity value that exceeded the recommended limit. This was due to the rainy weather during data collection. In theory air conditioning should have the ability to control the humidity, however, high humidity level could cancel out the cooling effect [36]. In addition, most of the respondent tend to vote slightly cool (-1) during afternoon session because the average air temperature of the library is lower in afternoon session compared to the morning session as shown in Table 10. The average value of air temperature in the morning session were 23.71 ºC and 23.49 ºC for afternoon session. The minimum air temperature value was 23.50 ºC and maximum value was 24.00 ºC. In the afternoon, the minimum air temperature was 23.39 ºC and maximum air temperature value was23.66 ºC. The average mean radiant temperature was higher in morning session which was 24.07 ºC compared to the afternoon session 23.73 ºC, due to intensity of sunlight in the morning which increase the radiant emissivity throughout the large window glass of the library which is identified as most occupants sitting area. The minimum air velocity value was 0.08 m/s. and, maximum 0.09 m/s for morning session with average value of 0.09 m/s. While for afternoon, the minimum air velocity was 0.09 m/s and maximum 0.12m/s, with average of 0.10 m/s The minimum PMV value was -1.30 for morning session and maximum value was 0.74. In addition to minimum value of PMV afternoon session is -1.64 and maximum was 0.40. The average value of PMV in the morning session is -0.38 and in the afternoon is -0.87 respectively. The TSV average value in the morning session is -0.50 and -0.80 in the afternoon. Thus, the minimum TSV value for morning session was -1.43 and maximum 1.10 respectively. Comparing with TSV value in the afternoon session, the minimum and maximum value were-1.47 and 1.16 respectively.

Table 10
Overall of PMV and TSV comparison of six days morning and afternoon session

Day	Session	Air temp.	Mean radiant temp.	Air velocity	Relative humidity	PMV	TSV
1	Morning	23.81	24.71	0.08	83.78	0.74	1.10
2	Morning	24.00	24.15	0.08	72.69	0.46	0.39
3	Morning	23.51	23.95	0.09	69.84	-0.59	-1.43
4	Morning	23.50	23.99	0.08	72.04	-0.47	-1.18
5	Morning	23.65	24.04	0.08	68.46	-1.30	-0.97
6	Morning	23.81	23.59	0.09	68.63	-1.14	-0.90
Average		23.71	24.07	0.09	72.57	-0.38	-0.50
Min		23.50	23.59	0.08	68.46	-1.30	-1.43
Max		24.00	24.71	0.09	83.78	0.74	1.10
1	Afternoon	23.45	24.18	0.09	73.85	0.40	1.16
2	Afternoon	23.66	23.63	0.10	67.73	-0.61	-0.83
3	Afternoon	23.46	23.59	0.12	75.45	-0.64	-1.23
4	Afternoon	23.39	23.63	0.10	71.80	-1.31	-1.19
5	Afternoon	23.43	23.66	0.11	85.80	-1.64	-1.47
6	Afternoon	23.58	23.68	0.10	67.06	-1.40	-1.24
Average		23.49	23.73	0.10	73.61	-0.87	-0.80
Min		23.39	23.59	0.09	67.06	-1.64	-1.47
Max		23.66	24.18	0.12	85.80	0.40	1.16

8. Determination of the Thermal Comfort Range
8.1 Air Temperature PMV and TSV Relationship

Thermal comfort becomes a most interesting topic in a cooling system. The effectiveness of the cooling system in indoor open space application is very important to keep the temperature of occupants from exceeding limits imposed by DOSH (2010) and ASHRAE (2013). Thermal comfort is the condition which occupant feel comfort with their surroundings. Table 10 summarizes the thermal comfort temperature ranges of TSV and PMV for morning and afternoon session. Thermal comfort calculations were according to ASHRAE Standard 55 (2013). The calculation of the acceptable thermal comfort temperature range for PMV must be within the range of -0.5 and +0.5. The logic behind this definition was encapsulated in the Predicted Percentage Dissatisfied (PDD) index. In classic thermal comfort theory, PDD reaches its minimum value when PMV equals to zero (neutrality). That is when average person feels thermally neutral, that can be expect a minimum of complains from the entire group in the environment. Therefore, the calculation based on regression equation for both TSV and PMV value between -0.5 and +0.5 had been conducted and the thermal comfort temperature range as shown in Table 11. The result show that the thermal comfort temperature range for the afternoon was slightly lower compared to the morning session. Both the thermal comfort ranges from TSV and PMV were in the same agreement. This scenario happens due to the dramatic changes on relative humidity percentage throughout the days due to the rain. However, based on the findings, the average relative humidity was 72.57 % in the morning and 73.61 % in the afternoon and maximum 83.78 % in the morning session and 85.80 % in the afternoon session which by far exceeded the allowable limit stated by DOSH (2010) and ASHRAE Standard 55 (2013). Relative humidity of air has a major effect on thermal comfort air conditioning processes in general [37]. As air conditioning systems use cooling to absorb heat from the air and deliver this to the conditioned space. The more humid the air is, the more indoor open space occupants feel stuffy and uncomfortable. the PDD percentage will increase. the PPD model is an index determined from PMV that establishes a quantitative prediction of the percentage of thermally dissatisfied people who feel too cool or too warm. ISO O. 7726 (1998) states that, thermally dissatisfied people are those who will vote hot (+3), warm (+2), cool (-2) or cold (-3) on the ASHRAE 7-point thermal sensation scale [38]. In addition, high percentage of relative humidity in the indoor open space required more energy to cool the air, as the condensation of water vapour actually draws a lot more energy from the coil than the air component. Furthermore, in tropical regions such as Malaysia, the moisture condensed is significant, in as such environment, energy consumption is much greater even when the actual air temperature may be lower. Limiting relative humidity level within buildings in tropical regions is very important for improving thermal comfort level of indoor open space and in reducing energy consumption [39].

Table 11
Summary of thermal comfort temperature ranges based on TSV and PMV for morning and afternoon session

Vote	session	thermal comfort temperature range (°C)
TSV	Morning	24.17 - 25.01
	Afternoon	23.63 - 24.20
PMV	Morning	24.03 - 25.15
	Afternoon	23.70 - 24.47

9. Conclusions

A comprehensive thermal comfort analysis in indoor open spaces of second level of UTHM library building had been successfully carried out to investigate the thermal comfort temperature range. Conclusions drawn from this work were as follows

i. The subjective measurement, TSV value for morning session and afternoon session of indoor open space of UTHM library met the requirement of the ASHRAE Standard 55 as it was identified to meet ≥ 80 acceptability by the occupants.
ii. It was found that, the measured profile of thermal comfort conditions of the indoor open spaces UTHM library met the requirements of available standards such as Malaysia Industry Code of Practice on Indoor Air Quality 2010 and ASHRAE Standard 55.
iii. The average mean radiant temperature was higher in morning session which was 24.07 ºC compared to the afternoon session which was 23.73 ºC due to intensity of sunlight in the morning which increase the radiant emissivity throughout the large window glass of the library this identified as most occupant sitting area.
iv. The average relative humidity of the indoor open space of UTHM library for morning and afternoon session were exceeding 70%. Thus, exceeding the acceptable limit recommended both by DOSH (2010) and ASHRAE Standard 55 (2013).
v. Despite the multiple differences between air temperature against PMV and TSV for both sessions morning and afternoon there is strong interrelated liner connection between the variables with a high R^2 value of 0.7 for comparisons of TSV against air temperature and PMV against air temperature for morning and afternoon sessions.
vi. Based on the PMV regression analysis, the thermal comfort temperature range for morning session was 24.03 ºC to 25.15 ºC and 23.70 ºC to 24.47 ºC for afternoon session.
vii. Based on the TSV regression analysis, the thermal comfort temperature range for morning session was 24.17 ºC to 25.01 ºC and 23.63 ºC to 24.20 ºC for afternoon session.
viii. Both TSV and PMV value were in the same agreement suggesting that PMV calculation able to predict the actual TSV from the occupant for open space area in tropical climate.

This study demonstrated that occupants perceived their condition to be comfortable. Technically, higher relative humidity beyond the recommended value would affect the cooling condition. It is suggested that further study should focused on the effect of relative humidity to the TSV and PMV of the occupant

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