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ASHRAE Global Thermal Comfort Database II: Comparison of Thermal Comfort Conditions in Different Type of Building

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Abstract: Thermal acceptability among students and workers in the school and office are essential as it may affect their productivity and performance. ASHRAE Global Thermal Comfort Database II have lots of data related to thermal comfort conditions of various type of building, such as classrooms and offices in different climate. Limited studies had been conducted to compare these data. Analysis was done by using statistical packages for social science (SPSS) for 200 data related to two types of air conditioning building (air- classrooms and office) in two different climates (Monsoon-influenced hot-summer humid continental and hot-summer Mediterranean climates). Descriptive and regression analysis were done based on four main parameters (predicted mean vote (PMV), air temperature, air velocity, and operative temperature). The Monsoon-influenced hot-summer humid continental for the classroom has the lowest range of temperature and PMV which were 17.5℃ to 21.0℃ and range of PMV were -3 to -1 (cold to slightly cool). The optimum temperature for classrooms and offices with hot- summer Mediterranean was 26.08℃ and 24.81℃ respectively. Meanwhile, for Monsoon-influenced hot-summer humid continental was 20.38℃ for classroom and 25.06℃ for office. It can be concluded that, optimal thermal comfort temperature in office was almost similar for both climates, but the classroom for Monsoon-influenced hot-summer humid continental had lower optimal thermal comfort temperature. However, regression analysis showed low R-square value which concluded that both air velocity and air temperature were not significant parameter to predict PMV for both type of building in the two investigated climates.

Keywords: ASHRAE Database, Thermal Comfort, PMV, Building Type, Climate

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1 Introduction

Thermal comfort has increasingly become an important study area, providing vital support to build a good environment. Thermal comfort can be described as the state of mind that expresses satisfaction with the thermal environment and is assess by subjective evaluation [1]. The building design process is crucial as modern workers and students spent most of the day indoors [2]. Thermal comfort is also related to the comfort temperature range of the building or room.

According to Fanger, the steady-state models of thermal comfort indices are Predictive Mean Vote (PMV) and Percentage of People Dissatisfied (PDD) [3]. The PMV model is generally used as a design tool for thermal comfort prediction. Thermal comfort standards recommend PMV to be apply equally to different building types of building such as office and classroom.

The method of assessment for thermal comfort can be referred to ASHRAE Standard 55. Six variables are related to thermal comfort: four physical parameters, and two physiological conditions. Air temperature, mean radiant temperature, relative humidity, and air velocity are related to the thermal environment; meanwhile, metabolic rate and clothing insulation are related to the occupants in the room [4]. The PMV scale range from -3 (cold) to +3 (hot), where 0 represents the thermally neutral sensation [5]. Student's and worker performance is also affected by thermal comfort. ASHRAE 55 states that thermal comfort difference in winter and summer months within the same country, but it does not consider thermal preference differences of individuals from different countries [6].

The ASHRAE Global Thermal Comfort Database II project was launched in 2014 under the Indoor Environmental Quality (IEQ) Laboratory of the University of California at the Berkeley Centre for the Built Environment and the University of Sydney [7]. This database follows up on the 'ASHRAE Global Thermal Comfort I' (ASHRAE RP-884 project) data source used to develop the ASHRAE adaptive thermal comfort. This new Comfort Database is intended to support further and more detailed inquiries about thermal comfort. A systematic compilation and harmonization of raw data from the last two decades of field thermal comfort studies worldwide started with the exercise. It comprises data from different types of buildings (office, residential, classroom) conditioned using different cooling strategies.

2 Background of Study

2.1 Thermal Comfort Model

2.1.1 Predicted Mean Vote (PMV) and Predicted Percentage Dissatisfied (PDD)

Predicted Mean Vote (PMV) is an index that attempts to estimate the mean value of votes on the seven-point thermal sensation scale of a group of occupants. Thermal equilibrium is achieved when the inner heat output of an occupant is the same as its heat loss. An individual's heat balance can be affected by physical activity levels, clothing insulation, and the parameters of the thermal environment. Table 1 shows the seven-point PMV thermal sensation scale of occupant’s thermal sensation [8].

Table 1: Seven-point PMV thermal sensation scale

+3	+2	+1	0	-1	-2	-3
Hot	Warm	Slight warm	Neutral	Slight cool	Cool	Cold

The number of thermally dissatisfied individuals within a large group of people is predicted by the predicted percentage dissatisfied (PDD). The PMV index calculation can only valid for values between -2 and +2. With the PMV value determined, the predicted percentage dissatisfied (PDD) can be calculated by using Eq. 1.

$$PPD = 100 - 95 \cdot \exp\left(-0{,}03353 \cdot PMV^4 - 0{,}2179 \cdot PMV^2\right) \qquad \text{Eq. 1}$$

Figure 1: below shows the approximate relationship between PDD and PMV

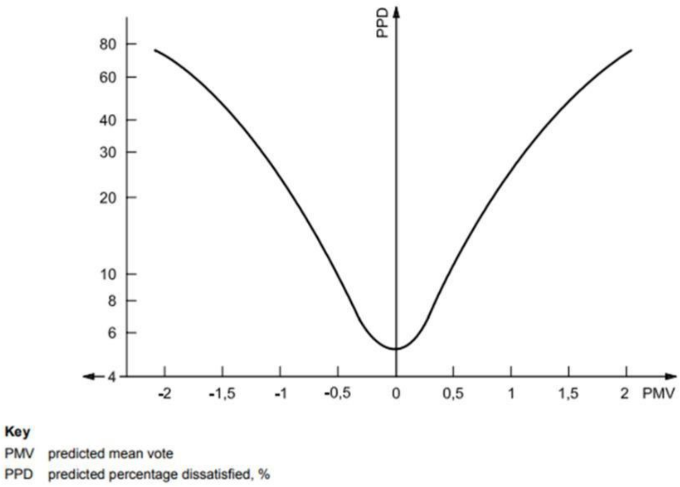

Figure 1: The relationship between PDD and PMV

2.1 The Parameters that Affect Thermal Comfort

2.1.1 Air Temperature

Air temperature is the temperature of the air around the body [9]. Air temperature is the temperature expressed in degrees Celsius (°C) or Fahrenheit (°F) of the surrounding air. It is the most influential factor of all environmental variables when talking about air temperature. It is because human beings are very temperature sensitive. Higher classroom temperatures (above 30 ° C) can affect students' skill and their achievements during the classroom [3].

2.1.2 Air Velocity

Air velocity is described as the speed of air moving across the worker, and if it is more relaxed than the environment, it can help cool the worker. Air velocity is a very significant consideration since it is susceptible to humans. As a result, depending on the given indoor condition, such as indoor temperature and relative humidity, it may lead to cooling or heating the room. These two variables and the speed of air have the most significant influence on human thermal comfort indoors. ISO-7730 states that the main point of air velocity is that it affects the convective heat exchange between a person and the atmosphere, which will impact the general heat loss. Having more than 0.2 m sec-1 indoors, based on experience, could lead to disturbance even if the indoor air temperature is high and the need for skin convective with the atmosphere is essential [10]

2.1.3 Operative Temperature

The operative temperature is the mean temperature of the air and the mean radiant temperature, weighted by the convective heat transfer coefficient and the coefficient of linearized radiant heat transfer for the occupant. For occupants with nearly sedentary physical activity (with metabolic activity rates between 1.0 and 1.3 met), not exposed to direct sunlight or air velocities greater than 0.20 m/sec (40 fpm), it is allowable to estimate the relationship with acceptable accuracy by Eq. 2 [10].

$$t_o = (t_a + t_r) / 2 \qquad \text{Eq. 2}$$

where,

to = operative temperature
ta = air temperature
tr = mean radiant temperature

3. Methodology

Figure 2 shows the methodology chart conducted in this study.

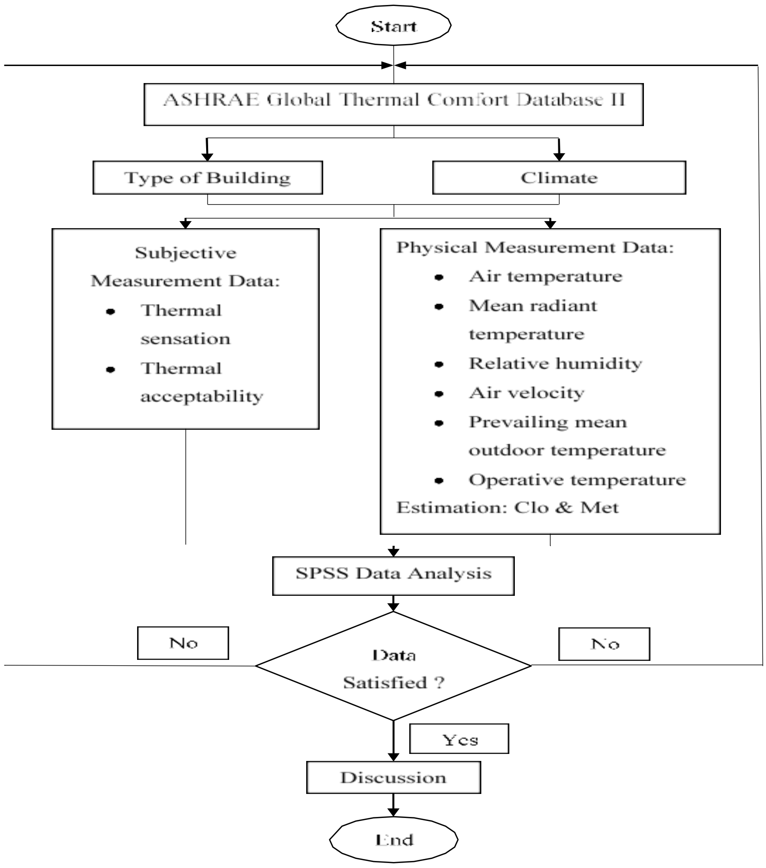

Figure 2: Methodology flowchart

3.1 ASHRAE Global Thermal Comfort Database II

A systematic compilation and harmonization of raw data from the last two decades of field thermal comfort studies worldwide started with the exercise. The ASHRAE Global Thermal Comfort Database II (Comfort Database), now an online open-source database, contains approximately 81,846 complete sets of objective indoor temperature measurements supplemented by subjective "right-here-right-now" judgments by the occupants the building who were exposed to them. ASHRAE Global Thermal Comfort Database II combines biological and subjective measurement data by the previous researcher. The database can be accessed through the website. The database was intended to help complex thermal comfort inquiries in field settings. A simple web-based database interface allows several parameters to be sorted, including building typology, occupancy type, demographic variables of subjects, subjective thermal comfort states, indoor thermal environmental criteria, measured comfort indices, criteria for ecological regulation, and meteorological information from the outside. As for the study, the type of building, type of ventilation, and climate will be filtered in the database to get the exact data. Figure 3 indicated the selection criteria to filter the database.

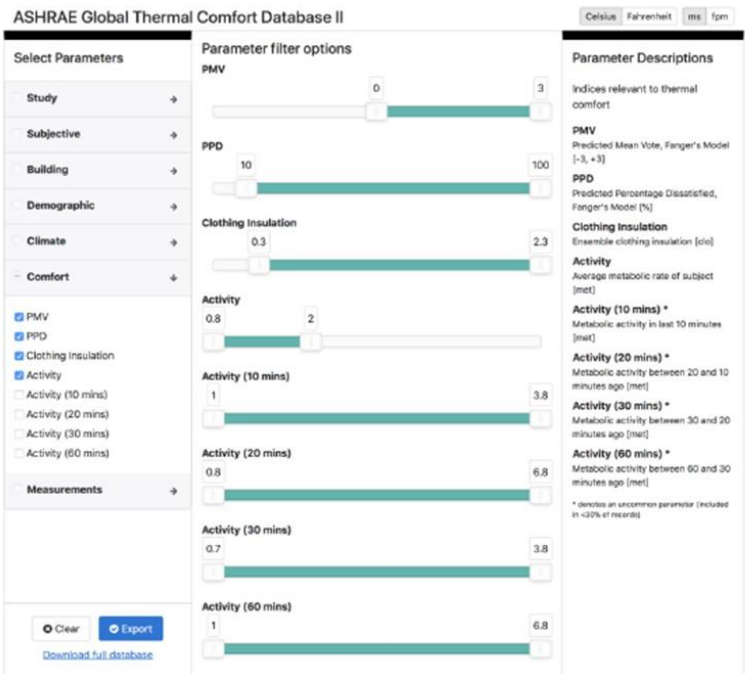

Figure 3: Selection criteria to filter the database

3.1.1 Type of Building

The data based on the ASHRAE Global Thermal Comfort Database II need to be screen out based on the type of building. Thermal comfort data were categorized into five main buildings. The building were offices, classrooms, senior centers, multifamily, and others. As for the study's design, there was only two types of the building were selected: classrooms and offices. As for classroom building, there are 12,755 data meanwhile for office is 55,238. The data have also been collected based on the cooling type used in the buildings. The proportion of measurement was from facilities using air-conditioned (n = 28,544).

3.1.2 Climate Zone

Physiological acclimatization, behavioral adaptation and indoor comfort expectations can be influenced by seasonal changes and prevailing weather. Thermal comfort field measurements from 16 separate Köppen climate groups are available in the database. The hot-summer Mediterranean (n = 23,192), humid subtropical (n = 15,536), hot semi-arid (n = 8,471), and tropical wet savannah (n = 6,633) are the climate zones with the highest thermal comfort data. Other samples were listed as Monsoon-influenced hot-summer humid continental (n = 3,809), Mediterranean warm-summer (n = 5,980), temperate ocean (n = 4,968), continental humid hot-summer (n = 3,809), continental humid warm-summer (n = 2,990), hot desert (n = 2,084), tropical monsoon (n = 2,075), subtropical humid- influenced monsoon (n = 1,588) and Mediterranean cool-summer (n = 1,408) regions.

3.2 Data Extracted from Database

Table 2 shows the classification of data extracted from the database. From the database, the descriptive statistical analysis was conducted. The function of descriptive statistics is to know the minimum, maximum, mean, and standard deviation of every parameter. Then, the test of normality was used. The function of the test was to identify whether the data can be tested using parametric or non-parametric testing of correlation coefficient. The data was normally distributed when the p-value was more significant than 0.05 and the hypothesis H_o is accepted. If the parameter was normally distributed, Pearson's parametric test was used. If not, Kendall tau-b non-parametric test was chosen.

Table 2: The number of samples of each building and climate

Building Type	Climate	Country	No. of Samples	Types of Ventilation
Classroom	Monsoon-influenced hot-summer humid continental	China	50	Air-conditioning
	Hot-summer Mediterranean	Greece	50	
Office	Monsoon-influenced hot-summer humid continental	China	50	Air-conditioning
	Hot-summer Mediterranean	United Kingdom (UK)	50	

After that, regression analysis was conducted. Regression analysis can be explained as a statistical tool to investigate, evaluate, and analyze the relationship between the independent and dependent variables of concern. The usage of regression was to come out with the best fitted line and came out with the model equation. R-square value indicates how the independent variable was explained in the variation of the dependent variable.

4. Results and Analysis

4.1 Descriptive statistics

The data were summarized and organized using descriptive statistics. Table 3 shows the summary of descriptive statistics from the sample in the classroom and Table 4 shows the descriptive statistics of the sample in air-conditioning office from ASHRAE Global Thermal Comfort Database II.

Table 3: Descriptive statistics of the analyzed sample in the air-conditioning classroom from ASHRAE Global Thermal Comfort Database II

	Monsoon-influenced hot-summer humid continental				Hot-summer Mediterranean			
Variable	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD
Predicted Mean Vote (PMV)	-3.00	-1.00	-2.04	0.60	-0.20	1.40	0.64	0.39
Predicted Percentage of Dissatisfied (PPD)	27.00	99.00	72.68	22.77	5.00	45.00	16.78	10.35
Air Temperature ℃	17.50	21.0	19.46	0.92	21.60	28.70	25.43	2.0
Air Velocity (m/s)	0.08	0.42	0.2	0.12	0.10	0.40	0.13	0.05

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Operative Temperature ℃	18.73	20.48	19.71	0.46	24.05	27.60	25.97	1.0

Min: minimum; Max: maximum; SD: standard deviation

Table 4: Descriptive statistics of the analysed sample in air-conditioning office from ASHRAE Global Thermal Comfort Database II

	Monsoon-influenced hot-summer humid continental				Hot-summer Mediterranean			
Variable	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD
Predicted Mean Vote (PMV)	-0.30	1.20	0.49	0.26	-0.60	1.10	0.34	0.42
Predicted Percentage of Dissatisfied (PPD)	5.00	36.00	11.30	5.80	5.00	29.00	11.19	6.18
Air Temperature ℃	25.3	29.7	26.95	0.90	24.40	29.00	22.42	1.42
Air Velocity (m/s)	0.01	0.48	0.29	0.13	0.03	0.40	0.21	0.09
Operative Temperature ℃	25.36	27.56	26.19	0.45	23.60	27.75	26.19	1.20

Min: minimum; Max: maximum; SD: standard deviation

4.2 Correlation and Regression Analysis

A statistical measure that determines the co-relationship or linkage of two variables is a correlation. There are two types of tests for correlation which are parametric and non-parametric tests. Parametric tests involve Pearson's correlation coefficient, and non-parametric tests are Spearman and Kendall's tau-b. The higher the value of the correlation coefficient, the stronger the relationship between the variable.

4.2.1 Predicted Mean Vote (PMV) and Air Temperature

The analysis between predicted mean vote (PMV) against air temperature was done with two different types of building and climate. Figure 4 displays the graph for overall building types and climate for PMV against air temperature.

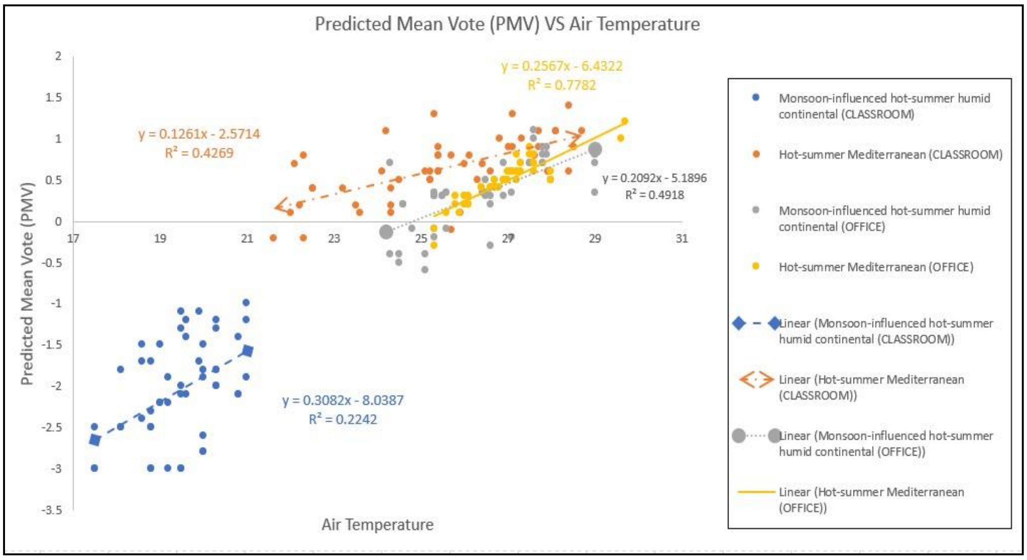

Figure 4: Predicted Mean Vote (PMV) vs. Air Temperature

The predicted mean vote (PMV) was being affected by the air temperature from the graph above. The higher the air temperature, the higher the PMV value. The slope of the graph also affects the range of comfortable temperature. The more increase the slope of the graph, the higher the range of thermal comfort. The student's thermal sensation in the Monsoon climate has the lowest PMV index. Besides, the classroom with a hot-summer climate has the lowest minimum and maximum comfort temperature, between 15.9°C and 23.62°C compared to others. For air-conditioning, classrooms also have significant differences of optimum and comfort temperature between the climates. From the analysis, a student in Monsoon-influenced hot-summer humid continental tends to tolerate more to a higher temperature for comfort in the classroom.

4.2.2 Predicted Mean Vote (PMV) and Air Velocity

The rate of heat transmission between the air and neighboring surfaces was affected by air velocity. Heat transfer is increased as the speed of the air passing across a surface increase. The analysis was made to identify the effect of the velocity on the PMV of people in different buildings and climates. Figure 5 shows the overall comparison graph between the different types of buildings and climate.

The graph for all the building types and climate was in cubic or polynomial three degrees because it has the highest value of the R-square compared to linear and quadratic. Table 5 shows the comparison value of R-square for all building types and climates.

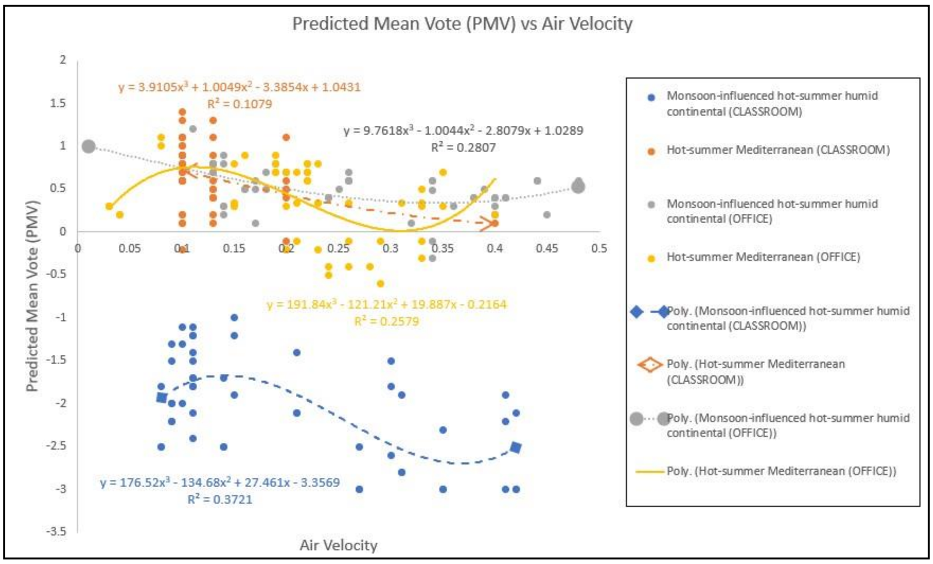

Figure 5: Predicted Mean Vote (PMV) vs. Air Velocity

Table 5: Comparison Value of R-square

Building types	Climate	Equation	R-square
Classroom	Monsoon-influenced hot-summer humid continental	Linear	0.313
		Quadratic	0.313
		Cubic	0.372
Classroom	Hot-summer Mediterranean	Linear	0.105
		Quadratic	0.108
		Cubic	0.108
Office	Monsoon-influenced hot-summer humid continental	Linear	0.147
		Quadratic	0.274
		Cubic	0.281

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Office	Hot-summer Mediterranean	Linear	0.084
		Quadratic	0.099
		Cubic	0.258

From the analysis, the value of correlation coefficient or R-square indicates that the velocity has a weak factor that affect the predicted mean vote (PMV). The highest percentage value of R-square was only 37.2%. The lower the air velocity, the higher the predicted mean vote (PMV) of students or workers. In air-conditioning building, the local thermal discomfort, as an example, draught, can occur when the velocity of air is higher.

4.2.3 Predicted Mean Vote (PMV) and Operative Temperature

Operative temperature (formerly known as resultant temperature or resultant dry temperature but renamed to conform to ASHRAE and ISO standards) is a simplified measure of human thermal comfort derived from air temperature, mean radiant temperature, and airspeed or air velocity. The major factor that affects thermal comfort also includes operative temperature. The study of correlation and regression between predicted mean vote (PMV) against operative had been done. Figure 6 shows the graph PMV versus operative temperature for a both buildings and climates.

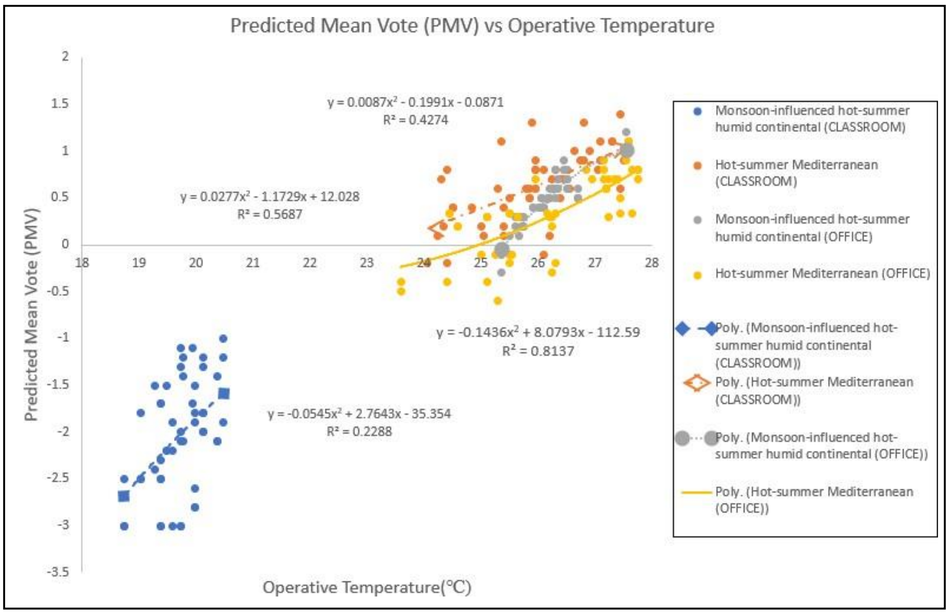

Figure 6: Predicted Mean Vote (PMV) vs. Operative Temperature

All the graph above were plotted is directly proportional with two degrees of the polynomial. The two degrees of the polynomial graph are chosen because the coefficient of determination or R-square value for regression analysis is the highest. 81% of the analysis for correlation analysis has high degree of correlation between PMV and operative temperature for office building in Monsoon-influenced hot-summer humid continental climate. From the graph, the higher the operative temperature, the higher the predicted mean vote (PMV).

4.2.4 Predicted Percentage Dissatisfied (PPD) and Air Temperature

The percentage of people who were expected to feel local discomfort was calculated using PPD. Unwanted cooling or heating of an occupant's body were the leading causes of local discomfort. The others factor of discomfort was extremely high or low air temperature. The correlation and regression analysis are made to know the pattern of a graph for air temperature toward the PPD.

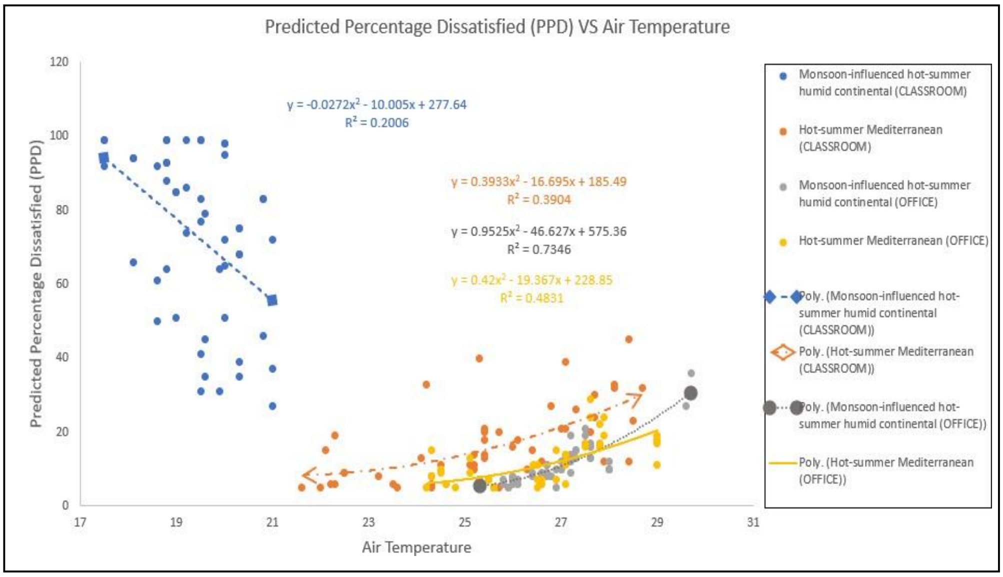

Figure 7: Predicted Percentage Dissatisfied (PPD) vs. Air Temperature

Regression analysis shown in Figure 7 was directly proportional with two degrees of the polynomial except for classroom with Monsoon-influenced hot-summer humid continental. It is an inversely proportional graph which means that the higher the air temperature, the lower the predicted percentage of dissatisfaction (PPD). The minimum air temperature for the climate is 17.5℃, and the maximum is 21℃, and it was still the lowest compared to other climates and buildings. The quadratic graph is plotted because of the highest value of R-square. Most of the analysis for correlation analysis has a strong high degree of correlation between PMV and operative temperature except for Monsoon-influenced hot-summer humid continental climate for the classroom with medium correlation.

4.2.5 Predicted Percentage Dissatisfied (PPD) and Predicted Mean Vote (PMV)

PMV is an index that attempts to estimate the mean value of votes on the seven-point thermal sensation scale of a group of occupants; meanwhile, the number of thermally dissatisfied individuals within a large group of people is predicted by the PPD. Figure 8 shows the PPD against PMV for both buildings and climate.

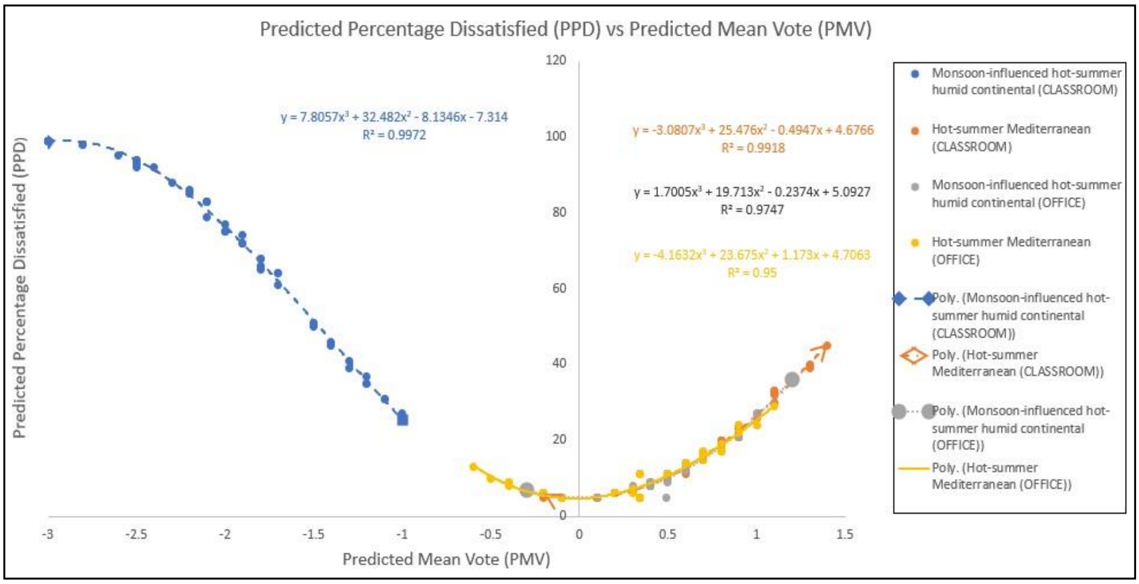

Figure 8: PPD against PMV for both buildings and climate

In Figure 8, a cubic graph was plotted. The higher R-square value indicated the shape of the graph.

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All cases had the strong correlation coefficient between the variables. Somehow, only classroom building with Monsoon-influenced hot-summer humid continental has a negative correlation which means that the higher PMV value will affect the PPD to become low in index. The PMV value lies between the scale of -3 and -1, which was cold and slightly cool. So, people tend to have more discomfort when the temperature was extremely high or low.

5. Conclusion

In conclusion, the study's objective was to analyze the thermal comfort level of different types of buildings and climate based on ASHRAE global thermal comfort database II data. The analysis was done using statistical packages for social science (SPSS) for 200 data related to two types of building (air-conditioning classrooms and air-conditioning office) in two different climates (Monsoon-influenced hot-summer humid continental and hot-summer Mediterranean climates). Data was analyze using descriptive statistics, normality test, correlation, and regression based on four main parameters of predicted mean vote (PMV), air temperature, air velocity, and operative temperature. Most of the data were normally distributed and the coefficient correlation were identified with parametric testing. The data were normally distributed when the p-value is more significant than 0.05 and the hypothesis H_o is accepted. Most of the data has normally distributed and being identified by coefficient correlation with parametric testing. Based on descriptive statistics, the Monsoon-influenced hot-summer humid continental for the classroom has the lowest range of temperature and PMV which were 17.5°C to 21.0°C and range of PMV were -3 to -1 (cold to slightly cool). The optimum temperature for classrooms and offices with Monsoon-influenced hot-summer humid continental is 26.08°C and 24.81°C. Meanwhile, for another climate hot-summer Mediterranean is 20.38°C for classroom and 25.06°C for office. It can be concluded that, optimal thermal comfort temperature in office was almost similar for both climates, but the classroom for Monsoon-influenced hot-summer humid continental had lower optimal thermal comfort temperature. However, regression analysis showed low R-square value which concluded that both air velocity and air temperature were not significant parameter to predict PMV for both type of building in the two investigated climates.

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