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ASHRAE Global Thermal Comfort Database II: Thermal Comfort of Mechanically Ventilated and Naturally Ventilated Office Building

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Abstract: Thermal comfort is vital in office building for work performance improvement. This paper compares the thermal comfort in the naturally ventilated and mechanically ventilated office building in tropical wet Savanna (India) and winter Mediterranean climates (United Kingdom). The data was retrieved from the ASHRAE Global Thermal Comfort Database II and statistically analyzed by SPSS. Total of 160 samples were retrieved from the database and the correlation between thermal comfort parameters with PMV index value and linear regression analysis was conducted. Results of the study shows that for the naturally ventilated office, the thermal comfort temperature range was between 22.60℃ to 25.47℃ for India and wider range of 17.47℃ to 24.38℃ for the United Kingdom. On the other hand, the thermal comfort temperature range for a mechanically ventilated office in India was between 26.16℃ to 27.06℃ while for the United Kingdom, was between 20.63℃ to 24.94℃. In conclusion, wider thermal comfort range was found in the United Kingdom for both type of office ventilation especially for the naturally ventilated office. This was in the same agreement with the lower level or relative humidity, air velocity and higher clothing insulation value among the United Kingdom respondent.

Keywords: Thermal Comfort, Mechanically Ventilated, Naturally Ventilated, ASHRAE Database

1. Introduction

Thermally comfort environment can be achieved by keeping the comfort related parameters within the recommended range. Thermal comfort is defined as state of mind that shows contentment with existing environment [1]. Thermal comfort is a subjective matter since the state of mind is generally driven by personal condition and thermal satisfaction. It is a psychological phenomenon that has an impact on people's moods, personality, cultures, organization, and social aspects [2]. Thermal comfort also can be alternatively defined as dissatisfaction with inhabitants' warm or cool sensation of the in general, as represented by PMV (Predicted Mean Vote) and PPD (Predicted Percentage of Dissatisfied)

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indices [3]. The main objective of thermal comfort study is to design comfort zone building where most of the residents feel comfortable [4].

Fermanel & Miriel (1999) state that comfort is depends by several factors including thermal parameters, acoustical parameters, natural and artificial light quality, and the ambient air purity [5]. Air temperature, thermal radiation, relative humidity, and air velocity are four environmental factors that influence thermal sensation, as well as two personal factors, activity and clothing based on the heat balance model of the human body [1].

In tropical regions comprising many rapidly growing city buildings, high energy use is increased due to excessive air-conditioning, while natural ventilation is a historically common passive cooling technique. Thermal comfort condition is attracting growing attention in this region, but there is still a lack of comprehensive norm for this climate area [6] Despite this, many modern buildings in the tropical regions still trail the design of building as in Mediterranean climates.

Thus, this paper compares and analyze the difference of thermal comfort in mechanically ventilated and naturally ventilated office buildings in in tropical wet Savanna (India) and winter Mediterranean climates (United Kingdom).

The objective of this paper is to determine correlation between thermal comfort parameters with PMV index value in naturally ventilated building and mechanically ventilated building in tropical wet Savanna (India) and winter Mediterranean climates (United Kingdom).

2. Materials and Methods

According to Markov (2003), over 90% large proportion of population spends more than 20 hours a day in artificial environment such as home, workplace, shops, in recreation places such as restaurants, theaters, cinemas, and in transportation [7]. Hence, local and international standards were developed which concern the quality of indoor environment.

2.1 Predicted Mean Vote (PMV)

Predicted Mean Vote (PMV) is commonly used to evaluate indoor space thermal comfort conditions. Predicted mean vote has been accepted as a standard by American Society of Heating, Refrigerating, Air Conditioning Engineers (ASHRAE) and the International Standard, ISO 7730. Based on ASHRAE Standard 55 (2013), PMV model use the heat balance principles to relate the six key factors for thermal comfort. The six key factors of thermal comfort are consisting of four measurable quantities which are air temperature, mean radiant temperature, air velocity and relative humidity and the other two are estimated value of clothing and metabolic rate [1].

According to ASHRAE Standard 55 (2013), ASHRAE thermal sensation scale is developed to quantifying people’s thermal sensation. Table 1 shows the seven-point thermal sensation scale [1].

Table 1: Seven-point thermal sensation scale

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

2.2 ASHRAE Global Thermal Comfort II

The data analyzed in this paper was retrieved from the ASHRAE Global Thermal Comfort II. This database is the most recent thermal comfort database comprises of different field studies done across the world between 1995 and 2016, with raw data released by contributors to the project for greater distribution to the thermal comfort research community. After going through the quality-assurance procedure, there are a total of 81,846 rows of raw data from matched subjective comfort ratings and objective instrumental measurements of thermal environmental factor [8].

Hence, to obtain required data from thousands of raw data, the data need to be filtered. Hence, building types, heating, ventilation, air conditioning and air -conditioning (HVAC) types and climates are filtered to obtain the data. Figure 1 shows parameter filter option in the database interface.

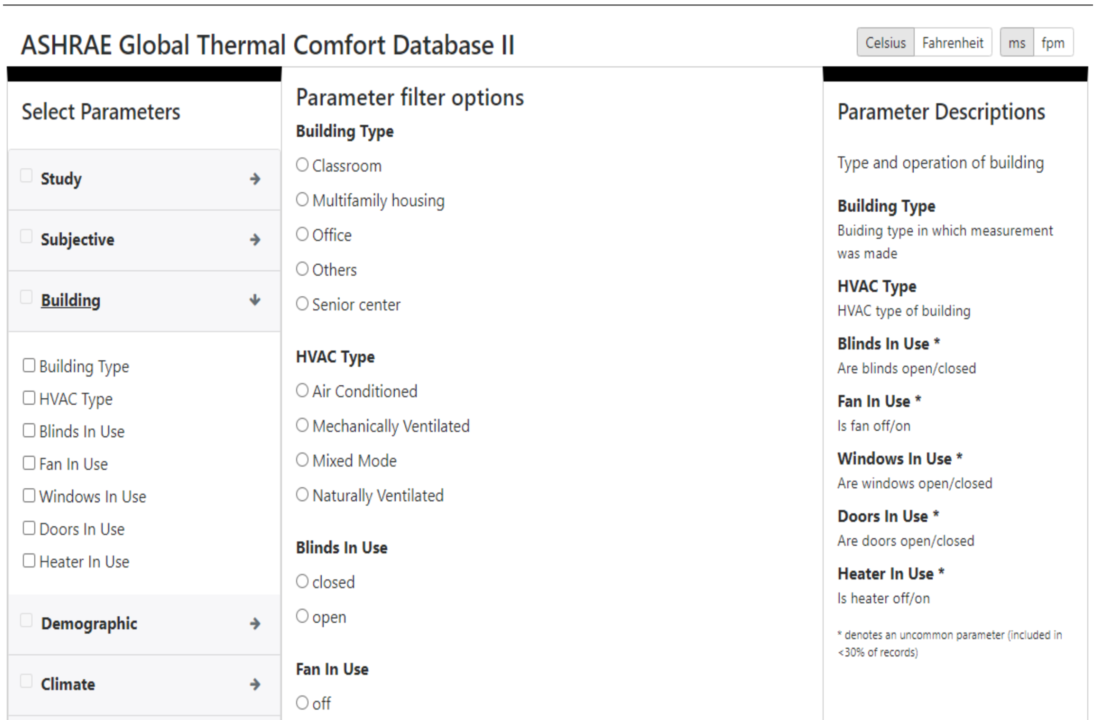

Figure 1: Parameter filter option in the database

2.5 Statistical anaysis

SPSS statistical software is used to analyze the retrieved data from ASHRAE Global Thermal Comfort Database II. 160 samples of data were analyzed according to ventilation types, building types and climates. To compare relationship between two numerical variables, scatter plot is chosen in analyzing the data. Table 2 shows the number of samples for each climate according to building types and ventilation types.

Table 2: Number of samples for each climate

Climate	Building types	Ventilation types	Country	No. of samples
Tropical wet Savanna	Office	Naturally ventilated	India	40
		Mechanically ventilated		40
Winter Mediterranean	Office	Naturally ventilated	United Kingdom	40
		Mechanically ventilated		40

Descriptive statistics were performed to obtain minimum, maximum, mean and standard deviation for each sample. Next, the normality test was conducted to identify either the data is normally distributed or not normally distribute. Normally distributed data was analyzed using parametric correlation which is Pearson correlation test while the not normally distributed data was analyzed using non-parametric correlation which is Kendall Tau-b and Spearman correlation test.

The normality of the data was identified through the value of the p-value. If the p-value is greater than 0.05, the hypotheses H_o is accepted and the data is normally distributed whereas if the p-value is lower than 0.05, the hypotheses H_o is rejected and the data is not normally distributed. Figure 2 shows example of the normality test result.

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Standardized Residual for PMV	.150	40	.024	.972	40	.409

a. Lilliefors Significance Correction

Figure 2: Test of normality

The significant value in the results from Pearson or Kendall Tau-b and Spearman correlation indicates the correlation of the data. If the significant value lower than 0.05, it indicates the data have significant correlation and if the significant value is greater than 0.05, it indicates the data did not have significant correlation between independent variable with dependent variable. Figure 3 shows the example of correlation test.

Correlations

		Predicted Mean Vote	Clothing
Predicted Mean Vote	Pearson Correlation	1	.768**
	Sig. (2-tailed)		.000
	N	40	40
Clothing	Pearson Correlation	.768**	1
	Sig. (2-tailed)	.000	
	N	40	40

**. Correlation is significant at the 0.01 level (2-tailed).

Figure 3: Pearson correlation test

Linear regression analysis was performed when there is significant correlation between independent variable with the dependent variable. Regression analysis is used to analyze the relationship between independent variable and dependent variable. Regression analysis produce coefficient of determination (r^2) which indicates the effect of changes independent variable to dependent variable.

3. Results and Discussion

3.1 Descriptive statistics

Descriptive statistics were analyzed according to ventilation types for each climate in the office building. Tables 3 shows summary of descriptive statistics for naturally ventilated office in India and United Kingdom.

Table 3: Descriptive statistics for naturally ventilated office

	Tropical wet Savanna				Winter Mediterranean			
Variable	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD
Predicted Mean Vote (PMV)	-0.10	1.50	0.77	0.36	-1.10	1.20	0.35	0.52
Air Temperature (°C)	24.80	27.50	26.23	0.78	20.10	27.10	23.34	1.98
Relative Humidity (%)	61.20	68.80	64.69	2.13	20.50	40.70	29.46	6.00
Air Velocity (m/s)	0.04	0.38	0.18	0.09	0.01	0.18	0.08	0.05
Clothing Insulation (Clo)	0.57	0.94	0.77	0.11	0.72	1.73	1.20	0.36

In tropical wet Savanna climate, based on a seven-point thermal sensation scale, the mean average of PMV for naturally ventilated office is 0.77 close to slightly warm, while the mean average of predicted mean vote for naturally ventilated office in the winter Mediterranean is 0.35 which close to neutral. The minimum and maximum air temperature for naturally ventilated office in tropical wet Savanna are between 24.80°C to 27.50°C while for naturally ventilated office in winter Mediterranean air temperature falls between 20.10°C to 27.10°C. The air temperature in tropical wet Savanna is slightly higher than the air temperature in the winter Mediterranean. Relative humidity for naturally ventilated office in tropical wet Savanna is between 61.20% to 68.80%. For naturally ventilated office in the winter Mediterranean, the minimum and maximum relative humidity fall between 20.50% to 40.70%. The descriptive data shows the clothing insulation for naturally ventilated office in the winter Mediterranean is greater than for naturally ventilated office in tropical wet Savanna.

Tables 4 shows summary of descriptive statistics for mechanically ventilated office in India and United Kingdom and descriptive statistics for mechanically ventilated office in India and United Kingdom. In a mechanically ventilated office, based on a seven-point thermal sensation scale, the mean average of predicted mean vote (PMV) for tropical wet Savanna is 1.65, which close to warm, while the mean average of predicted mean vote in the winter Mediterranean is 0.05, which close to slightly warm. The minimum and maximum air temperature for mechanically ventilated office in tropical wet Savanna are between 26.90°C to 31.80°C. In contrast, for a mechanically ventilated office in the winter Mediterranean air temperature falls between 21.30°C to 26.20°C. The air temperature in tropical wet Savanna is higher than air temperature in the winter Mediterranean. Relative humidity for mechanically ventilated office in tropical wet Savanna is between 39.00% to 68.00% while for mechanically ventilated office in winter Mediterranean, the minimum and maximum relative humidity falls between 19.30% to 42.00%. The descriptive data shows the clothing insulation for mechanically ventilated office in winter Mediterranean is slightly higher than for mechanically ventilated office in tropical wet Savanna since the mean clothing insulation is 0.85 while for tropical wet Savanna is 0.74.

Table 4: Descriptive statistics for mechanically ventilated office

	Tropical wet savanna				Winter Mediterranean			
Variable	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD
Predicted Mean Vote (PMV)	0.50	2.50	1.65	0.79	-0.80	1.00	0.05	0.42
Air Temperature (℃)	26.90	31.80	29.67	2.11	21.30	26.20	23.02	1.21
Relative Humidity (%)	39.00	68.00	55.75	12.08	19.30	42.00	31.64	7.39
Air Velocity (m/s)	0.01	0.24	0.08	0.07	0.01	0.08	0.06	0.02
Clothing Insulation (Clo)	0.59	0.97	0.74	0.09	0.66	1.41	0.85	0.16

3.4 Correlation and regression analysis for naturally ventilated office in India and United Kingdom

This section discusses the linear regression graph, the correlation and regression analysis between thermal comfort parameters and PMV index value can be seen for naturally ventilated office in India and the United Kingdom. Hence, the difference between tropical wet Savanna and Winter Mediterranean climate can be seen based on the comparison between a naturally ventilated office in India and the United Kingdom.

3.4.1 Air temperature

Figure 4 shows the effect of air temperature changes with PMV index for naturally ventilated office between India and United Kingdom. The air temperature for naturally ventilated office in India was higher compared to air temperature for naturally ventilated office in the United Kingdom. The PMV index value for naturally ventilated office in India also greater than the PMV index value for naturally ventilated office in the United Kingdom. It is shown that occupants in India's naturally ventilated office felt hotter than occupants in United Kingdom's naturally ventilated office. The comfort temperature for India's naturally ventilated office was between 22.60℃ to 25.47℃ while for United Kingdom's naturally ventilated office was between 17.47℃ to 24.38℃. It indicates that during winter season, winter Mediterranean has lower air temperature compared to air temperature in tropical wet Savanna.

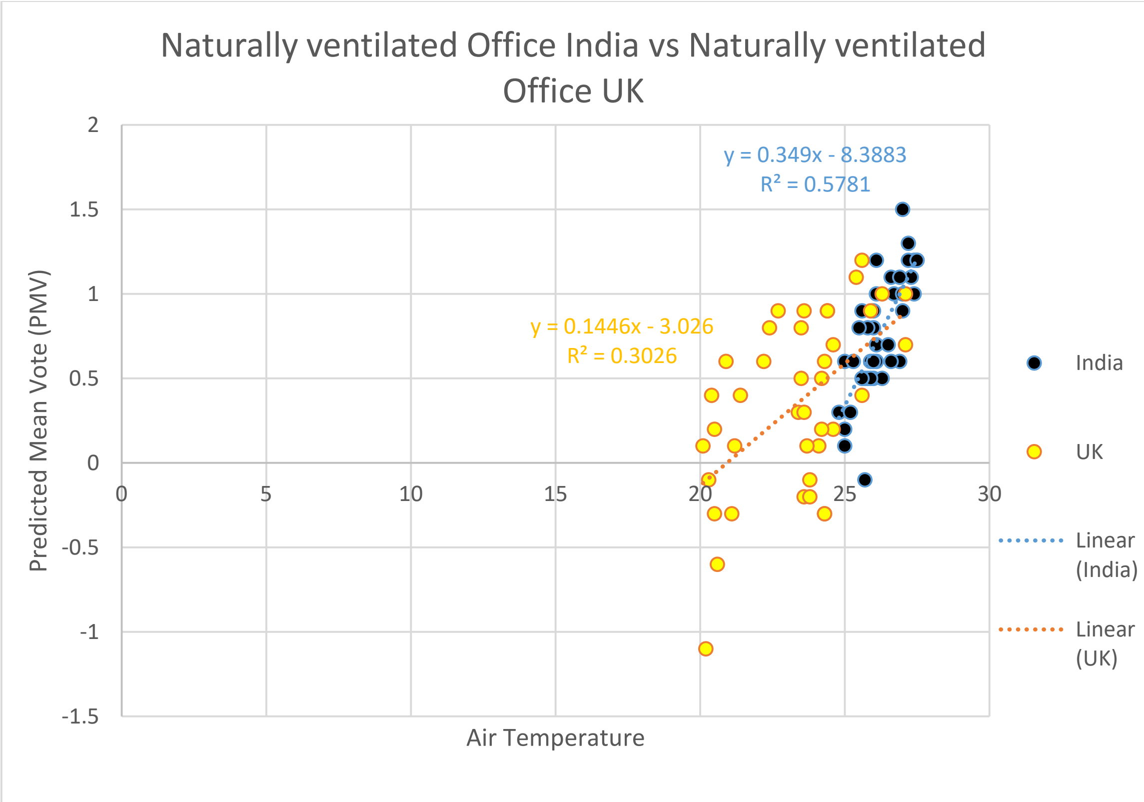

Figure 4: Effect of air temperature changes with PMV index for naturally ventilated office between India and United Kingdom

3.4.2 Relative humidity

Figure 5 shows that relative humidity in naturally ventilated office in India was higher than relative humidity in naturally ventilated office in the United Kingdom. It also shows that the PMV index value for naturally ventilated office in India was greater than the PMV index value for naturally ventilated office in the United Kingdom. It indicates that occupants in India's naturally ventilated office felt hotter than occupants in naturally ventilated office in the United Kingdom. Due to high relative humidity, sweat cannot evaporate efficiently and leave the body feeling hot and sticky. It can be seen that the relative humidity in tropical wet Savanna was greater than relative humidity in winter Mediterranean even though during the winter season.

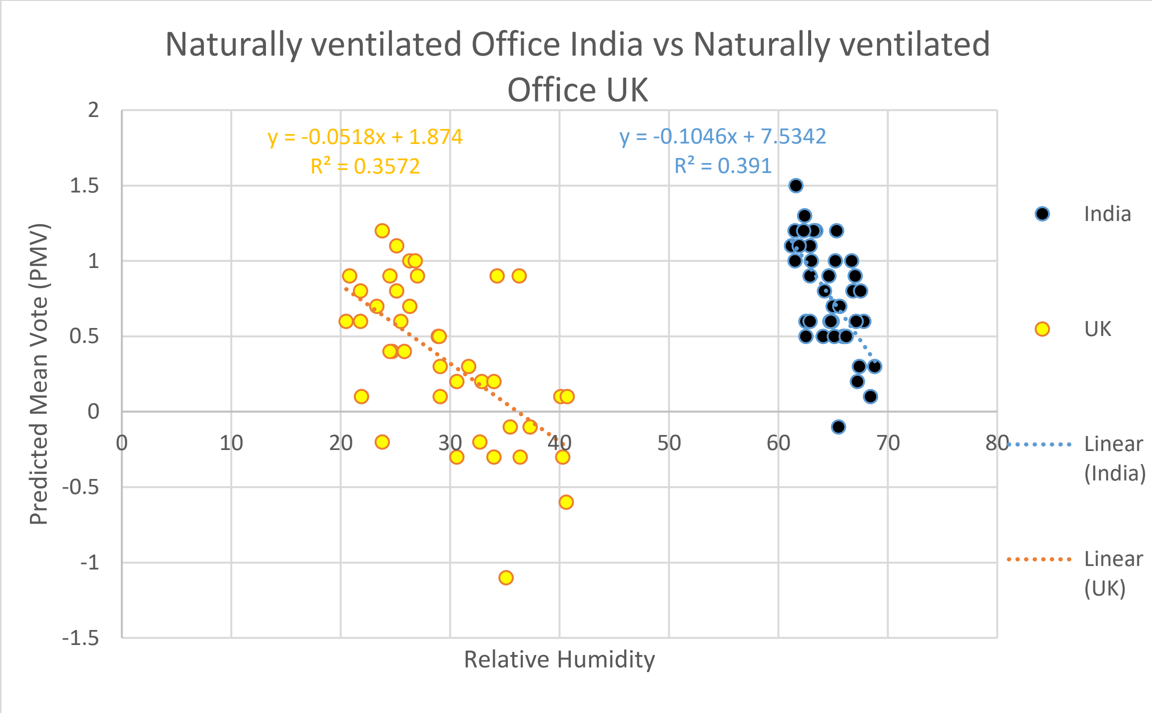

Figure 5: Effect of relative humidity changes with PMV index for naturally ventilated office in India and United Kingdom

3.4.3 Air velocity

Figure 6 shows that air velocity in naturally ventilated office in India was greater than air velocity in naturally ventilated office in the United Kingdom. It also shows that the PMV index value in naturally ventilated office in India was higher than the PMV index value in naturally ventilated office in the United Kingdom. It indicates that occupants in United Kingdom's naturally ventilated office was cooler than occupants in India's naturally ventilated office. It also means that the air velocity in tropical wet Savanna was higher than air velocity in the winter Mediterranean.

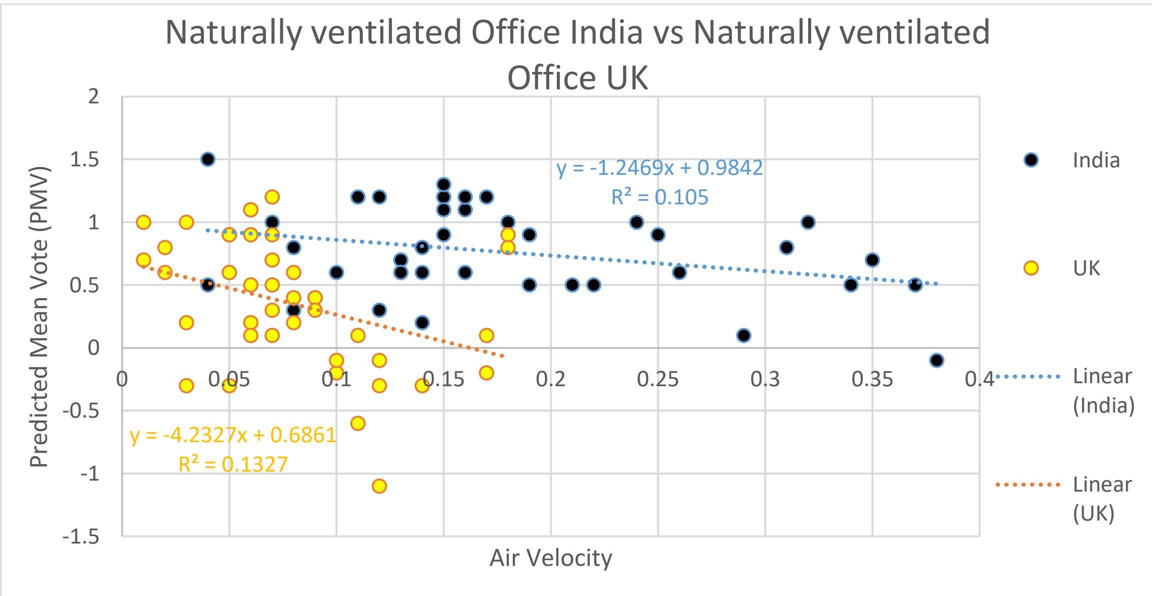

Figure 6: Effect of air velocity changes with PMV index for naturally ventilated office in India and United Kingdom

3.4.4 Clothing insulation

Figure 7 shows that clothing insulation in naturally ventilated office in the United Kingdom was higher than clothing insulation in naturally ventilated office in India. It also shows that the PMV index value in naturally ventilated office in United Kingdom was lower than the PMV index value in naturally ventilated office in India. Since in winter season, thick clothing insulation makes occupants in naturally ventilated office in the United Kingdom feel comfortable even though at low air temperature.

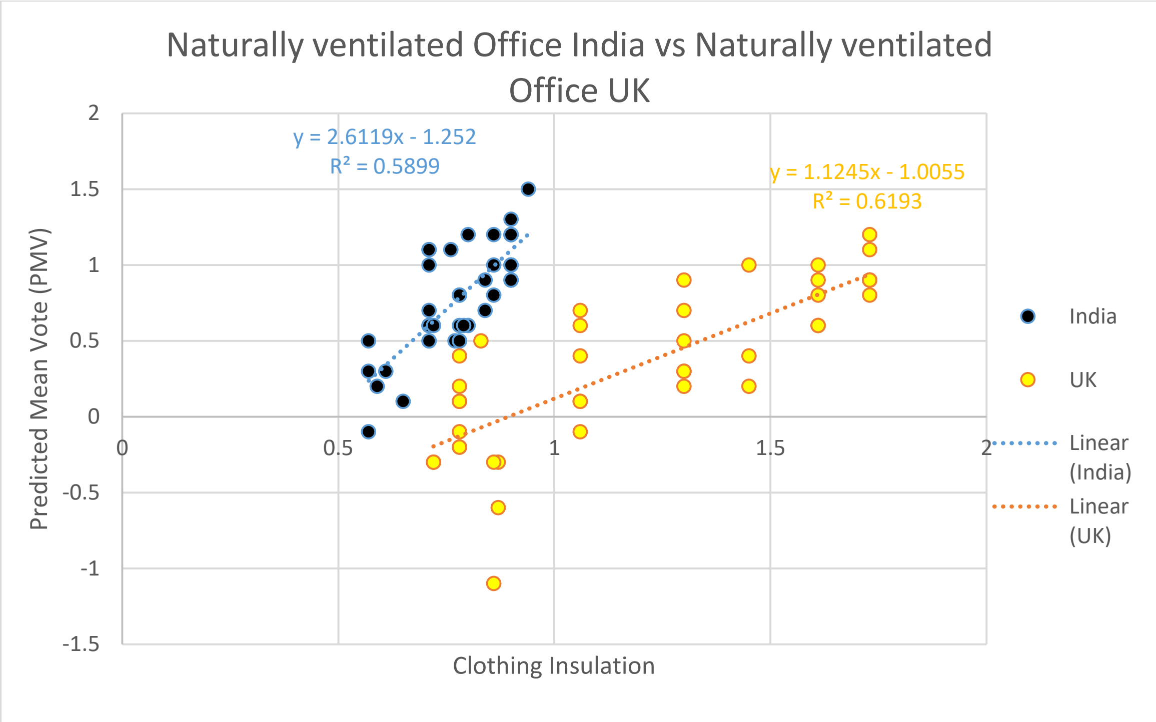

Figure 7: Effect of clothing insulation changes with PMV index for naturally ventilated office in India and United Kingdom

3.5 Correlation and regression analysis for mechanically ventilated office in India and United Kingdom

This section discussed on linear regression graph, the correlation and regression analysis between thermal comfort parameters and PMV index value can be seen for mechanically ventilated office in India and United Kingdom. Hence, the difference between tropical wet Savanna and winter Mediterranean climate can be seen based on the comparison between mechanically ventilated offices in India and the United Kingdom.

3.5.1 Air temperature

Figure 8 shows that the air temperature for mechanically ventilated office in India was higher compared to air temperature for naturally ventilated office in the United Kingdom. The PMV index value for mechanically ventilated office in India was also greater than the PMV index value for mechanically ventilated office in United Kingdom. It is shown that occupants in India's mechanically ventilated office felt hotter than occupants in the United Kingdom's mechanically ventilated office. The comfort temperature for India's mechanically ventilated office was between 26.16°C to 27.06°C. While for United Kingdom's mechanically ventilated office was between 20.63°C to 24.94°C.

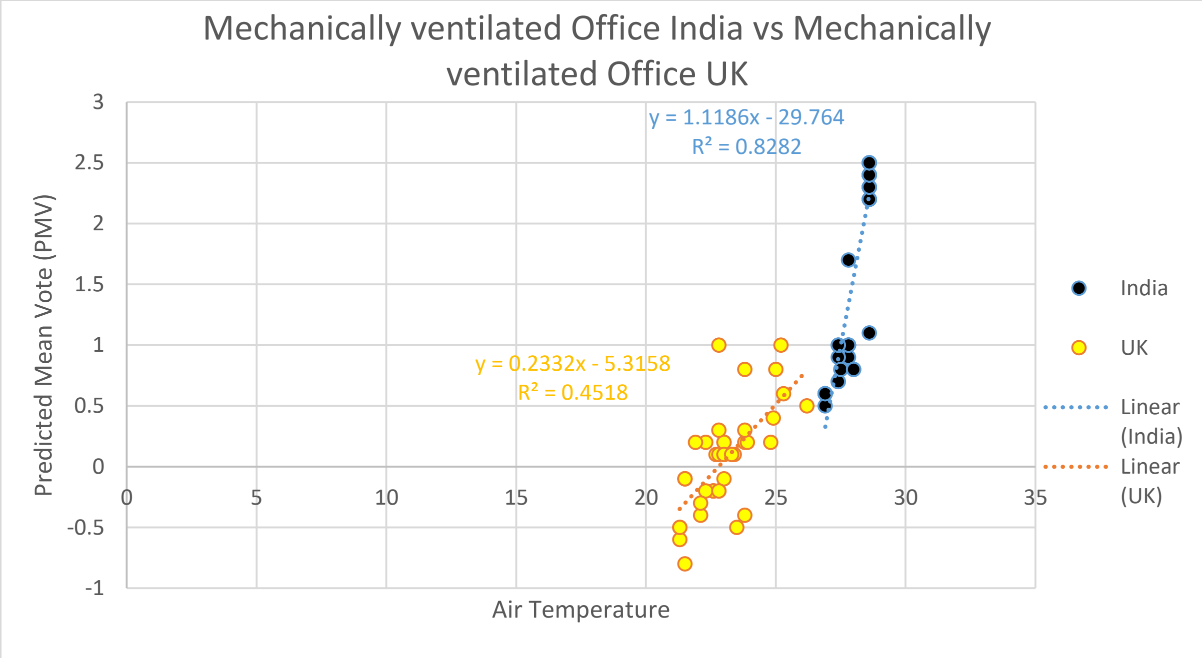

Figure 8: Effect of air temperature changes with PMV index for mechanically ventilated office in India and United Kingdom

3.5.2 Relative humidity

Figure 9 shows that relative humidity in mechanically ventilated office in India was higher than relative humidity in a mechanically ventilated office in the United Kingdom. It also shows that the PMV index value for mechanically ventilated office in India was greater than the PMV index value for mechanically ventilated office in the United Kingdom. It indicates that occupants in India's mechanically ventilated office felt hotter compared to occupants in a mechanically ventilated office in the United Kingdom.

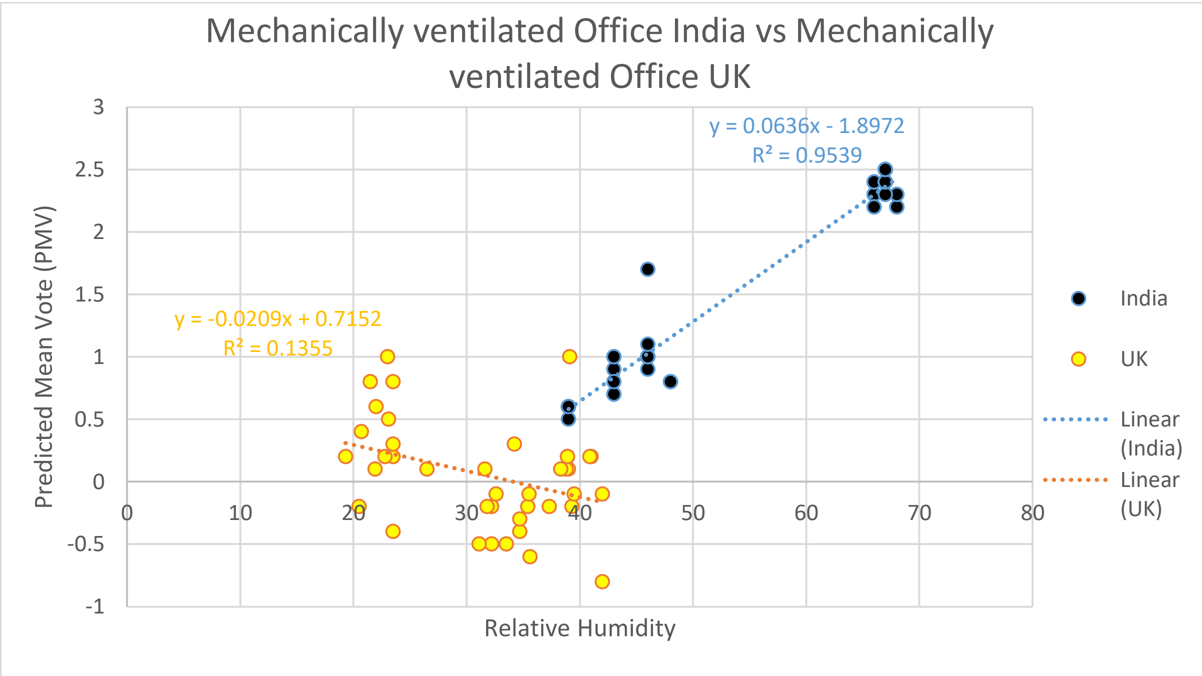

Figure 9: Effect of relative humidity changes with PMV index for mechanically ventilated office in India and United Kingdom

3.5.3 Air velocity

Figure 10 shows that air velocity in a mechanically ventilated office in India was greater compared to air velocity in a mechanically ventilated office in the United Kingdom. It also shows that the PMV index value in a mechanically ventilated office in India was higher than the PMV index value in a mechanically ventilated office in United Kingdom. It indicates that occupants in United Kingdom's mechanically ventilated office felt cooler than occupants in India's mechanically ventilated office.

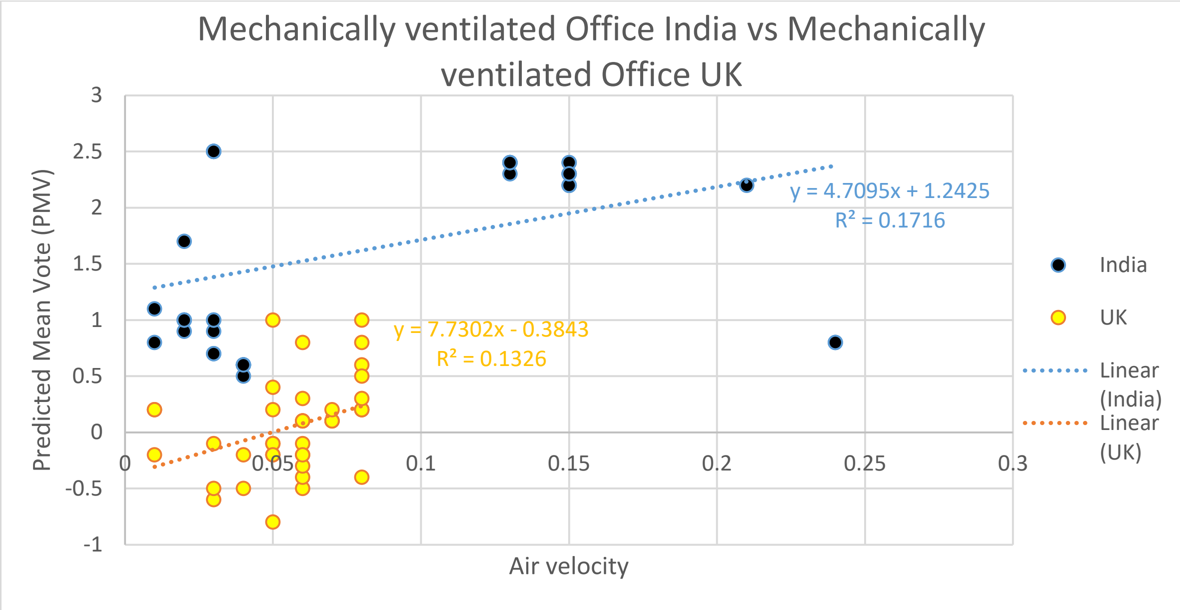

Figure 10: Effect of air velocity changes with PMV index for mechanically ventilated office in India and United Kingdom

3.5.4 Clothing insulation

Figure 11 shows that clothing insulation in the mechanically ventilated office in the United Kingdom was thicker than clothing insulation in the mechanically ventilated office in India. It also shows that the PMV index value in a mechanically ventilated office in the United Kingdom was lower than the PMV index value in a mechanically ventilated office in India.

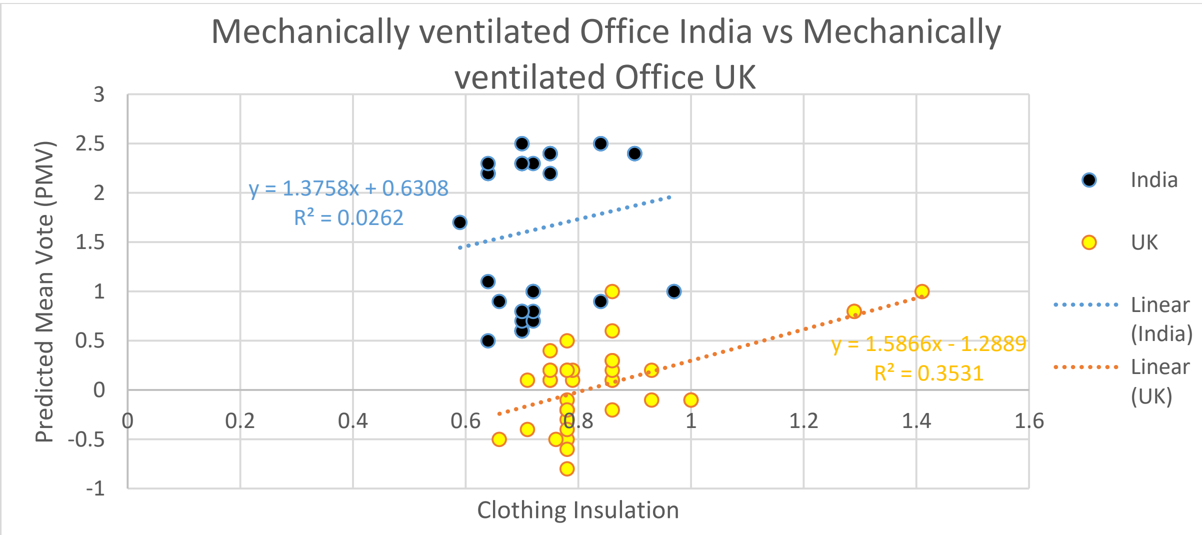

Figure 11: Effect of clothing insulation changes with PMV index for mechanically ventilated office in India and United Kingdom

4. Conclusion

In a naturally ventilated office in India, the thermal comfort temperature range was between 22.60℃ to 25.47℃ with optimum thermal comfort temperature was at 24.04℃. While, for naturally ventilated office in the United Kingdom, the optimum thermal comfort temperature was at 20.93℃ with thermal comfort temperature range between 17.47℃ to 24.38℃. Thus, the optimal temperature difference between naturally ventilated office in India and United Kingdom is 3.11℃. On the other hand, for a mechanically ventilated office, the optimum thermal comfort temperature was 26.21℃ and 22.79℃ for India and United Kingdom respectively. While the thermal comfort temperature range was between 26.16℃ to 27.06℃ and 20.63℃ to 24.94℃ for India and United Kingdom respectively. The difference in optimum thermal comfort temperature between mechanically ventilated office in India and United Kingdom was 3.42℃. In conclusion, the difference climate did show difference preference of thermal comfort temperature range on both naturally ventilated and mechanically ventilated office building with optimal thermal comfort temperature difference of approximately 3℃. This was in the same agreement of the difference between relative humidity, air velocity and clothing insulation of the respondent from these two different countries.

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