Thermal Comfort Model for Educational Institutions in Kerala

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Abstract

There is a little thermal comfort research in educational institutions reported from India. Energy consumption in Indian educational institutions is one of the highest, and it is increasing at a phenomenal rate. Indian standards advocate two narrow ranges of temperatures for all building and climate types. In this context, a field study was conducted following Class-II protocols, for 10 days in November 2016, in Saintgits college of Engineering, Kerala. Over 120 subjects were involved, giving 430 datasets. The comfort band (voting within -1 and +1) based on the regression analysis was found to be 23.6°C to 32.9℃ with the neutral temperature at 28℃. This is way above the limits (23–26℃) set by Indian standards. Also, the comfort level of humidity and air velocity was found. The comfort level of relative humidity is in range of 61.9 to 91.6% with a neutral humidity at 77.82% and comfort level of air velocity is 0.43-0.49 m/s with a neutral velocity at 0.4625m/s The PMV was always found to be higher than the actual sensation vote. These findings have far reaching energy implications in a developing country like India.
Keywords: Thermal comfort, Comfort band, Thermal sensation, Globe temperature

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I. INTRODUCTION

In India, the demographic eligible for attending institutes of higher education, i.e.18-23 year old, makes up 11-12% of the national population. Actual enrolment is nowhere near 100% of this age group, yet, at the beginning of the 2010-11 academic year, India had 14.6 million students enrolled in its 544 universities (or equivalent institutes) and 31,324 colleges. Further, data shows that both the number of institutions and enrolments in them are growing at more than 5% annually [1]. For providing thermal comfort in all these classrooms spread across a country having mostly tropical weather, AC can come to mind as a tempting and quick fix solution. But Projections show India beating both USA and China by 2055 to become the world leader in energy consumption for AC [2]. So, it is not practical to increase the use of AC. More than a one third of India's electricity consumption is in residential and commercial sectors. In both of these sectors, a significant portion of the energy demand is from buildings while more than half the buildings India will have in 2030 are yet to be built. All these statistics and estimations prove a great urgency for energy saving measures in Indian buildings. National Building Code of India (NBC) [3] is the guideline for building construction in India, until 2007; there were no codes or requirements to be satisfied for energy efficiency in new buildings. When it comes to AC in classrooms, the NBC prescribes a rather narrow comfort zone of 23-26°C, 50-60% Relative Humidity (RH). Therefore, Several studies done for NV classroom occupants in tropical regions have borne out significant levels of adaptation amongst occupants. In a very early comfort study done in Calcutta, Rao reported a comfort temperature of 25.8°C DBT [4]. Sharma and Ali [5] did a very comprehensive study on comfort, developing the sole empirical index of thermal comfort based on Indian subjects and Indian conditions TSI. They found that a TSI value of 27.5°C elicited maximum percentage of comfortable votes. Considering the importance of comfort requirements in classrooms and the fast growing number of institutes for higher education in India, classroom thermal comfort needs serious attention. The study was aimed at finding the level of thermal comfort and acceptance amongst students of an undergraduate course during their regular semester classes. So we decided to survey the condition during regular class hour.

II. METHODOLOGY

A. Data Collection

During the field survey, physical measurements of environmental parameters were taken while the paper based subjective questionnaires were being filled by the occupants. Since we aimed at recording reactions to typical conditions, every effort was made not to interfere with the class schedule and thermal environment. Survey activities took a total of 15-20 min.

B. Objective Data

During Measurements were taken for dry bulb and wet bulb temperatures, relative humidity, globe temperature and air velocity. A black globe thermometer was constructed by placing a digital thermometer at the center of a black painted table tennis ball of 40mm diameter. Dry Bulb temperature was measured with help of a digital, vane anemometer. The thermometer was calibrated against a reference thermometer from Zeal (range 10 to 50°C, resolution0.5°C) over the range of 10-40°C. Air velocity was measured with a digital, vane-type anemometer (HTC Instrument AVM-06 Digital Anemometer with Temperature and Humidity Tester Meter by Supreme Traders Supertronics1989). Measurements were taken at a height of one meter. Just before taking the survey. The wet bulb temperature is calculated with the help of psychometric chart.

C. Subjective Questionnaire

The subjects were briefed regarding the nature of the survey and the questionnaires. Any queries of the students about the survey were resolved. The students were from different regions of Kerala. So, Malayalam was used as the medium for instruction. But the questionnaires were prepared in English. Table 1 presents the thermal comfort scale used in this survey. The questionnaire includes seven point ASHRAE thermal sensation scale, thermal preference, thermal acceptance, humidity sensation, velocity sensation scales and activities they are involved in 15 min before completing the survey. As the survey was being conducted in between regular operations of a class, it was of paramount concern to keep the survey questionnaire short and compact. Students took 1-5 min to fill up and return the questionnaire sheet.

D. Indoor Conditions

During the survey, indoor thermal environment was assed. The dry bulb temperature, relative humidity, air velocity and globe temperature were measured. The indoor environment followed the outer condition closely. The table 2 summarizes the indoor environmental variables recorded during this survey, with variations in individual buildings. The indoor temperature ranged between 28 to 33°C. And relative humidity varies from 63 to 76%. The indoor humidity and temperatures are slightly less than the outdoor temperature. The wet bulb temperature is calculated with the help of psychometric chart and it varies from 24°C to 28°C. The air velocity was also measured with the help of a digital, vane anemometer and it varies from 0.24 to 0.69 m/s.

Table – 1
Thermal Comfort Scale Employed

Scale Value	*Description of scales*		
	ASHRAE's Thermal Sensation(TS)	*Thermal Preference(TP)*	*Thermal Acceptance(TA)*
3	*Hot*		
2	*Warm*		
1	*Slightly warm*	*Warmer*	*Non-Acceptable*
0	*Neutral*	*No Change*	*Acceptable*
-1	*Slightly cool*	*Cooler*	
-2	*Cool*		
-3	*Cold*		

Table – 2
The Indoor Environmental Data Recorded During the Survey

Day	*DBT(°C)*	*Air Velocity(m/s)*	*Radiant temperature(°C)*	*RH (%)*	*WBT(°C)*
1	*31.60*	*0.69*	*31.87*	*67.00*	*26.44*
2	*31.70*	*0.42*	*31.93*	*65.50*	*26.27*
3	*28.87*	*0.26*	*28.60*	*76.50*	*25.49*
4	*30.50*	*0.73*	*30.80*	*63.50*	*24.85*
5	*31.13*	*0.42*	*31.73*	*68.00*	*26.19*
6	*31.30*	*0.24*	*31.53*	*63.83*	*25.62*
7	*30.50*	*0.30*	*30.80*	*68.67*	*25.73*
8	*31.60*	*0.25*	*31.73*	*68.50*	*26.7*
9	*30.60*	*0.79*	*30.60*	*71.33*	*26.27*
10	*32.37*	*0.51*	*32.13*	*69.67*	*27.6*

III. RESULTS AND DISCUSSION

A. Comfort Band and Neutral Temperature

A sensation vote outside the (-1 to +1) comfort band was recorded when a subject experienced discomfort. Therefore, the proportion of subjects voting with in the comfort band was regressed against the indoor globe temperature recorded. The distribution of comfort was approximated using the polygonal regression analysis. It gives the proportion of people comfortable at different indoor temperatures. At indoor temperatures of around 29°C all (near 90%) the subjects were comfortable. It can be inferred from fig 1 that, as temperature increases, the percentage of dissatisfaction also increases. But at every temperature the percentage of satisfaction was above 70%. That is, a comfort zone where 70% of the subjects would express thermal sensation within -1 to 1 was identified with globe temperature.

B. Comparison with Tropical Summer Index (TSI)

Tropical summer index is defined as the temperature of calm air, at 50% relative humidity which imparts the same thermal sensation as the given environment. This was developed from the multiple regression analysis of the environmental variables on thermal sensation. The data base for this index was obtained from a long term field study on office workers in Roorkie, India. It was also adopted by the Indian codes. Values of TSI for all the data sets have been computed. Polygonal regression of distribution of subjects voting with in the comfort band (voting -1 to+1 on sensation scale) on TSI was done (Fig. 2). It was found that 80% of the subjects were comfortable between 27.5–30 °C of TSI. This is in slight variation from the comfort range of 25–30°C of TSI found by Sharma and Ali. The discrepancy is due to various reasons including the differences in

1) Range of environmental conditions experienced,
2) Activity patterns, and
3) Behavioral adaptations/ limitations in office and residential environments encountered in both the studies.

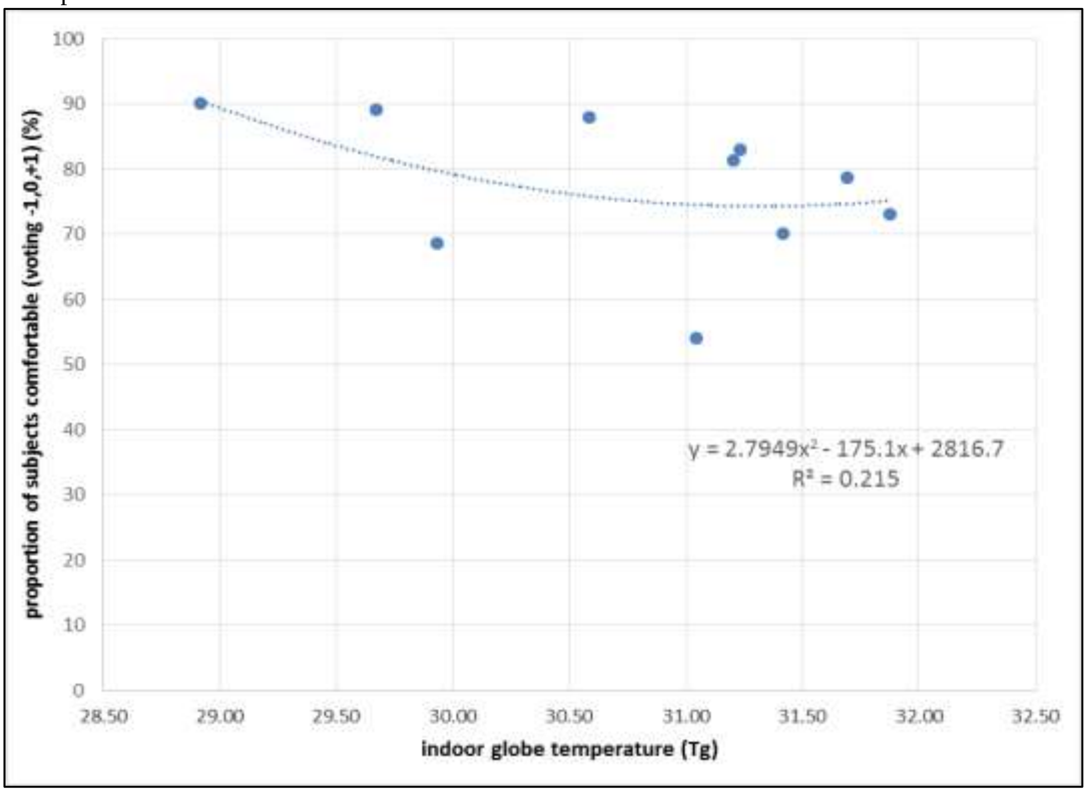

Fig. 1: Regression of proportion of subjects voting comfortable on the indoor globe temperature

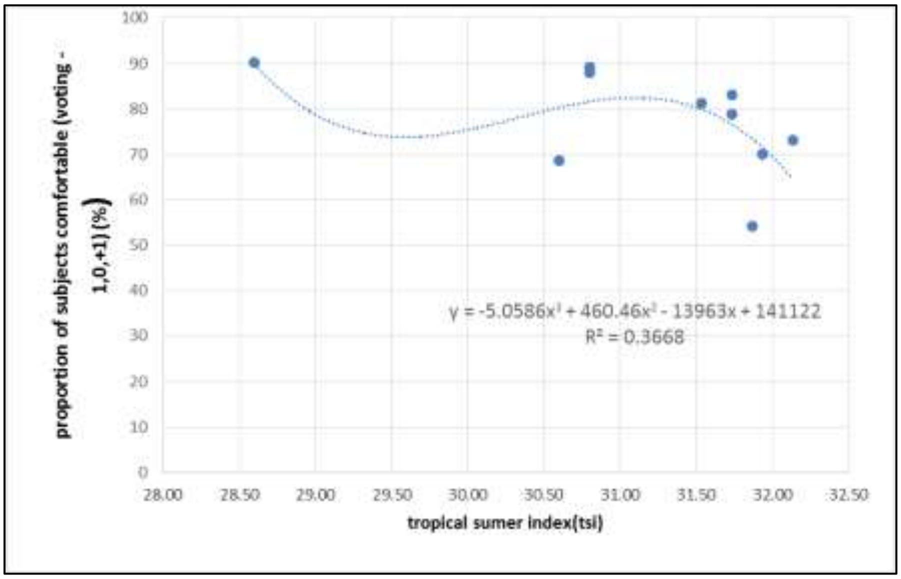

Fig. 2: Regression of proportion of subjects voting comfortable on TSI

C. *Linear Regression Analysis*

Neutral temperature is defined as the indoor temperature at which an average subject will vote neutral on the sensation scale. Regression analysis is used in field studies to examine the trend of the mean response over the range of temperatures experienced and to predict the comfort temperature. The Linear regression of thermal sensation on globe temperature across the sample group was done in this research to yield the regression equation 1. It is shown in Fig 3. A neutral temperature of 28.28°C and a comfort band of 23.6 to 32.9° C, coinciding with -1 and +1 sensation vote have been obtained using this regression equation. This was found to be way above the narrow range of temperatures (23–26°C) specified in the Indian standards. This finding has far reaching consequences on the way indoor environments and controls are designed and maintained using various conditioning systems. It also lays emphasis on the importance of adaptation in achieving thermal comfort.

$$TS = 0.21362Tg - 6.0425 \quad (1)$$

The study also tried to find out the comfort band of relative humidity and air velocity by using linear regression. The linear regression of thermal sensation on the relative humidity across the sample group was done in this research to yield the regression equation 2.it is shown Fig 4. A neutral relative humidity of 77.82% and a comfort band of 61.9 to 91.6%, coinciding with -1 and +1 sensation vote have been obtained using this regression equation.

$$TS = -0.06303Tg + 4.9029 \quad (2)$$

The air velocity also influences the thermal comfort of a person. An attempt was made to find out the neutral air velocity and comfort band in air velocity. The linear regression of thermal sensation on air velocity across the sample group was done in this research to yield the regression equation 3.It is shown in Fig 5. A neutral air velocity of 0.4625m/s and a comfort band of 0.43 to 0.49, coinciding with -1 and +1 sensation vote have been obtained using this regression equation.

$$AV = 0.03171TS + 0.46252 \quad (3)$$

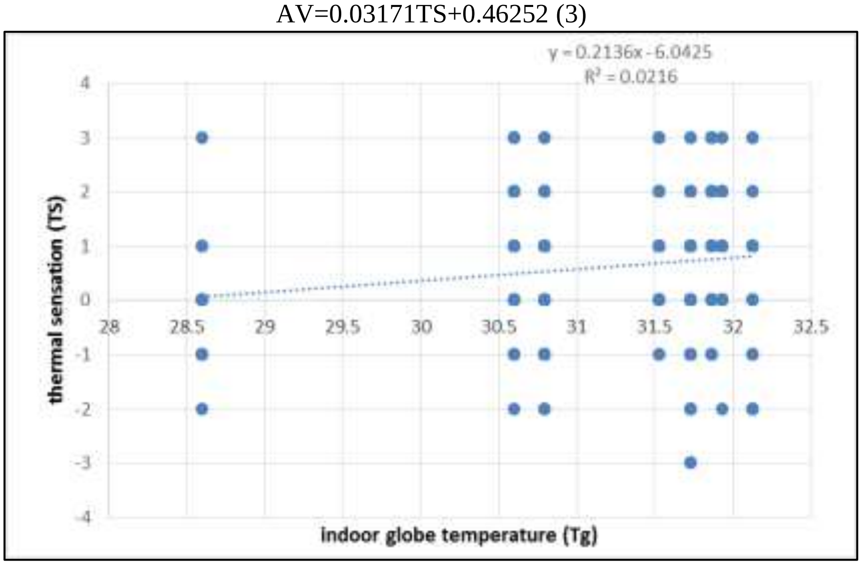

Fig. 3: Regression of thermal sensation.

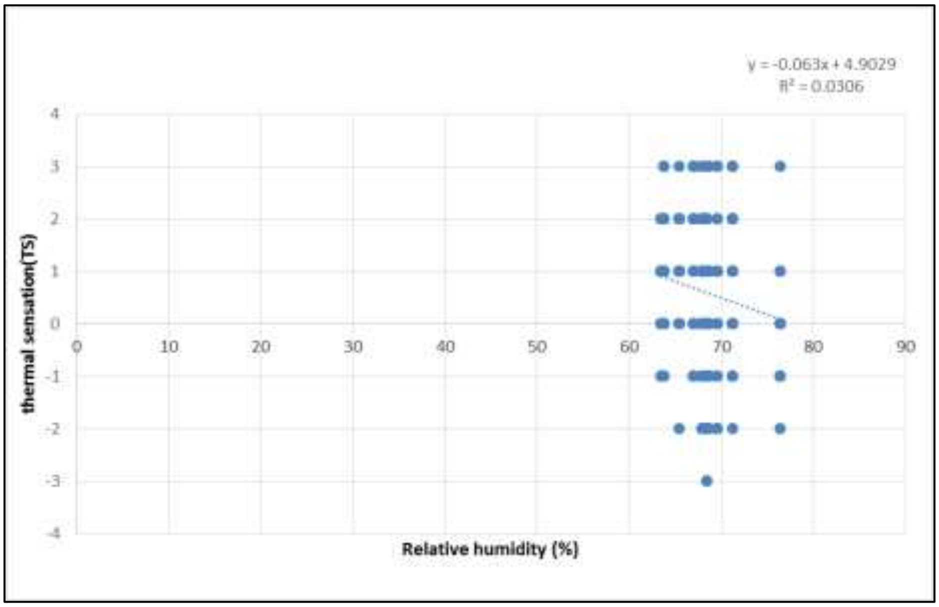

Fig. 4: Regression of thermal sensation on relative humidity (%)

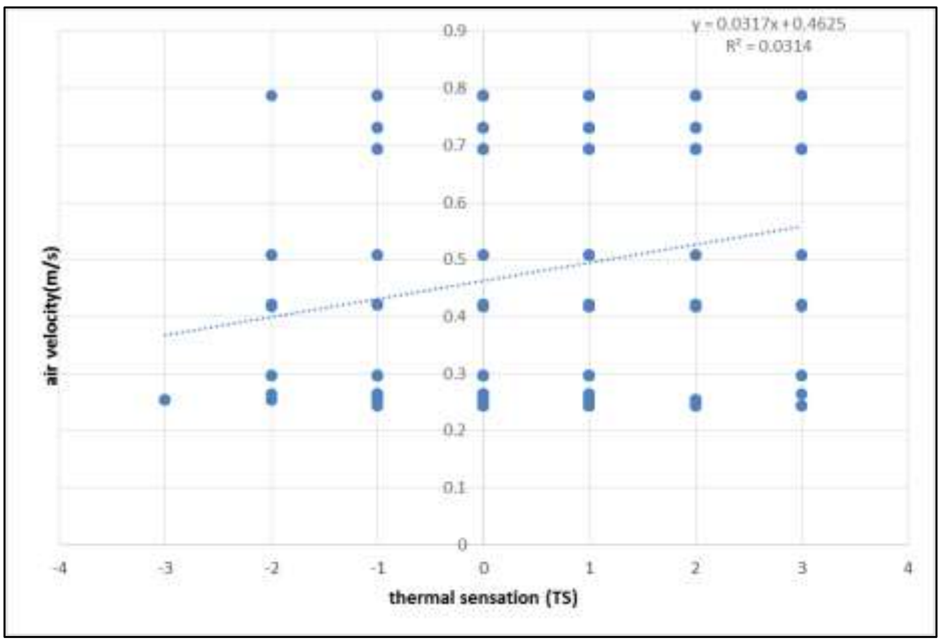

Fig. 5: Linear regression of thermal sensation on air velocity

D. Comparison with Other Thermal Comfort Studies

This regression line matched closely with the regression lines obtained by other researchers under similar conditions. The regression line slope is 0.2136. A comparison of the adaptive models by other researchers [6-12] is presented in Table 5.3. Ogbonna's Nigerian study [6], Karyono's Jakarta study[7] and Indraganti's Hyderabad study [8] returning a neutral temperature of 26.13°C ,26.34°C and 29.23°C are the closest match to the present study giving neutral temperature of 28.28°C. The slope of the regression line indicates how quickly people felt too warm or too cool, as temperatures deviated from the optimum. In addition, the inverse of the slope indicates the perturbation required in the temperature for unit rise in sensation vote. Ye et al[9] and Rijal [10] have obtained a regression line slope much smaller (0.13 and 0.058) as against 0.2136 found in this study. A lower slope also suggested that the occupants of the study were tolerant of a wider range of temperatures, that is, it defined the width of the comfort band. For example, in Shanghai study [9] the comfort band was found to be 14.8– 30.5°C, while in Nepal study [10] it was 4.7–39.13°C. As these studies were long term studies, a wider range of temperatures and sensations formed the database for the regression analysis. While these two studies were done in relatively colder climates, the y- intercept of the regression line was found to be much smaller than the present and other studies.

The neutral temperature found in these studies was also lower than that of the current study as shown in table 3.A comparison of the adaptive models obtained by various researchers is presented in table 3. Thermal sensation vote in field study hinges primarily on the use, access and perceived access to the adaptive controls and several psychological parameters in addition. Several simultaneous actions are taken by the individuals as the temperature increases. Therefore, the indoor temperature seldom correlates robustly with thermal sensation. The correlation between the thermal sensation and temperature obtained in this study didn't match well with the other study mentioned. The reason for this must be less control of subjects over the adaptive techniques in order to adjust increase in temperature and also the current study was conducted only for a period of 10 days in November. Moreover, mean thermal sensation of acclimatized populations does not vary directly with temperature, resulting in moderate correlation.

Table – 3
Comparison of the adaptive models obtained by various researchers

Researcher and location	*Regression equation*	*Correlation coefficient (r)*	*Neutral temperature (Tn)*
Present study	*y = 0.2136x - 6.0425*	*0.147*	*28.28*
Indraganti, hyderabad,2010	*y = 0.310x - 9.06*	*0.65*	*29.23*
Ye et al., Shanghai, 2006	*y = 0.13x - 2.92*	*0.69*	*22.5*
Mallick, Dhaka, 1996	*y = 0.18x - 5.11*	*0.5*	*28.4*
Nicol, Pakistan, 1999	*y = 0.154x + 0.09 (on a 1–7 scale)*	*0.74*	*25.45*
Karyono, Jakarta, 2000	*y = 0.32x - 8.43*	*0.61*	*26.13*
Ogbonna,Jos-Nigeria, 2008	*y = 0.313x -8.41*	*0.61*	*26.13*
Rijal et al., Nepal, 2002	*y = 0.058x - 1.27*	*0.44*	*21.9*

Using ASHRAE's comfort calculator [13], the Fanger's Predicted Mean Vote (PMV) for all data sets was calculated. PMV was regressed with the globe temperature as shown in Fig 6. In our study, the PMV was higher than the actual sensation, similar to Ogbonna, Indraganti and Harris. Conceivably, the regression of PMV on indoor temperature yielded a much lower neutral temperature of 25.41°C. Similar discrepancy was observed by others.

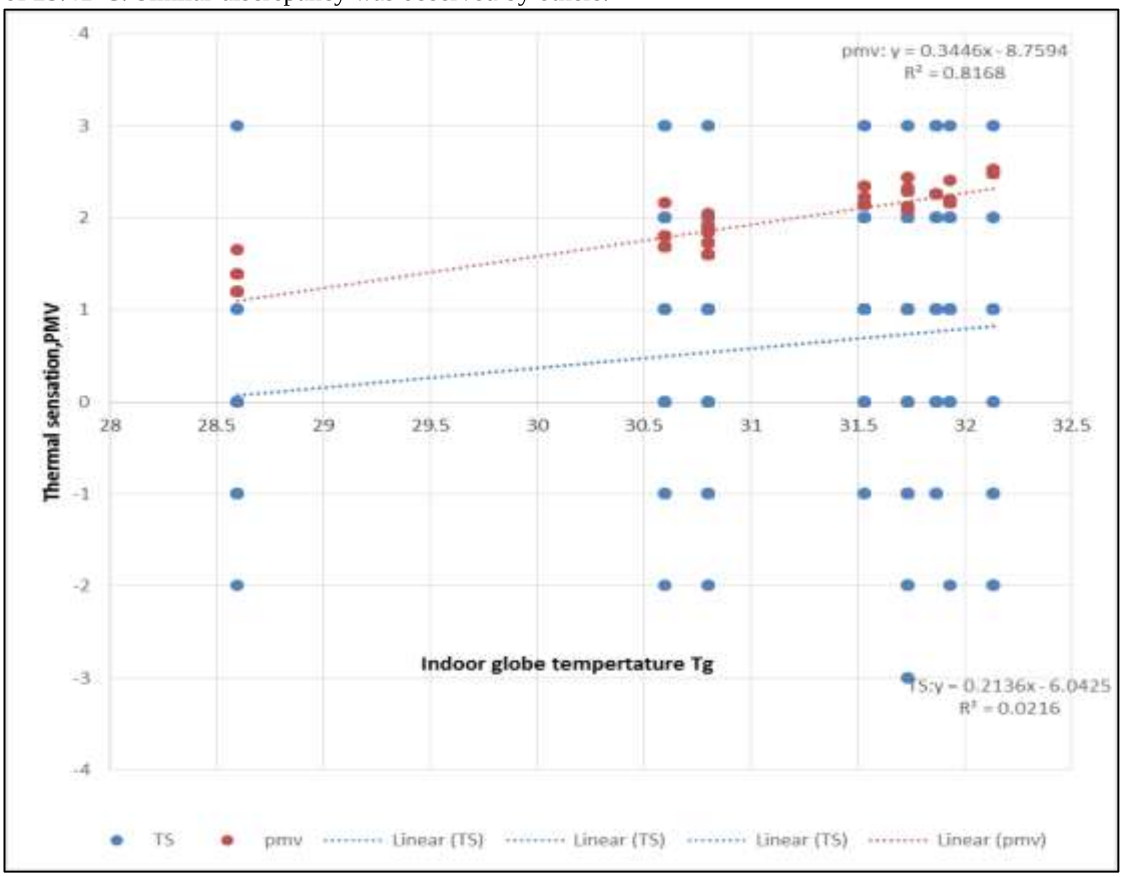

Fig. 6: Regression of thermal sensation and PMV with the indoor globe temperature

IV. Conclusion

A thermal comfort study was conducted in "Saintgits College of Engineering' in Kottayam. Over 120 subjects were participated in the questionnaire survey conducted for 10 days started from 11th November 2016 to 22nd November 2016. The survey was conducted during regular working hours. Prior to the survey the indoor and thermal environment were assessed with the help of a globe thermometer and a digital vane anemometer. The instruments were calibrated according to ASHRAE class-II protocols for field studies. The clothing insulation (0.6clo), and metabolic rate (1–1.9 Met) were recorded in the field using the standard checklists. The regression analysis were used to find the thermal comfort band in present study neutral temperature, humidity and air velocity were found to be 28.28°C ,77.82% and 0.4625 m/s respectively. The comfort band 23.6°C to 32.9°C found in this study is way above the narrow range of temperatures (23-26°C) specified in the Indian standards. This finding has far reaching consequences on the way indoor environments and controls are designed and maintained using various conditioning systems. It also lays emphasis on the importance of adaptation in achieving thermal comfort.

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