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A Study of Response Scales for Comfort Temperature Prediction

Harimi Djamila
Faculty of Engineering. Universiti Malaysia Sabah,
Kota Kinabalu, Sabah, Malaysia

***Abstract*—This study is about investigating the preferred temperature versus the perceived neutral temperature in a typical tropical humid climate. The main aim of this research is to explore the discrepancy and to quantify the difference of subjects' votes using ASHRAE scale. A field study was carried out in the Faculty of Engineering at the Universiti Malaysia Sabah in air-conditioned classrooms. The results revealed that the students preferred cooler temperature within the range under investigation. However, some statistical issues were observed in the analyzed data. Therefore, a new procedure was designed to assess the validity of the results in each classroom. When considering all the valid votes; the students' preferred feeling slightly cool under neutrality.**

Keywords—Thermal comfort; thermal sensation; thermal perception; neutral temperature; preferred temperature; ASHRAE scale

I. INTRODUCTION

Thermal comfort is the condition of mind that expresses satisfaction with the thermal environment [2]. ASHRAE scale is widely used for comfort temperature prediction and evaluation. It is generally known by thermal sensation scale. This scale assigns numbers according to subject's votes toward the thermal environment. Those are ordinal and adjectival scales. Most of the recent investigators assigned number "0" to neutrality, "1" to slightly warm, "2" to warm and "3" to hot, "-1" to slightly cool, "-2" to 'cool', "-3" to cold. These assigned numbers are arbitrary. For instance, the original ASHRAE scale assigned different points from "1" to "7". In the past, most researchers used a seven-point Bedford scale. The ASHRAE scale was known by ASHVE scale since 1942. The zero point in the ASHVE scale was assigned "comfortable" [1]. The ASHVE scale was named thermal comfort scale. ASHRAE, ASHVE and Bedford scales are listed in Table 1. Gagge *et al.* from experimental investigation defined people dissatisfaction as those who vote 'Cool' or 'Cold', 'Warm' or 'Hot'. Thus satisfaction is referred to those voted from slightly warm to slightly cool. This is recognized by ASHRAE standard 55 [3].

According to literature, thermal sensation is developed for reporting temperature sensation regardless of being comfortable or not. The situation is different when considering thermal comfort. This is because; thermal comfort depends on the desired physiological state. For instance one may feel neutral (absence of thermal perception) but the same person may prefer feeling slightly cold [4]. Some investigators defined thermal neutrality as the condition in which the subject would prefer neither warmer nor cooler surroundings. McIntyre scale is widely used to assess the desired temperature versus the assumed comfort temperature. The assumed optimum comfort temperature when using ASHRAE scale is referred to the estimated neutral temperature. However, Humphreys in his study [5] recommended the usage of ASHRAE scale to quantify the desired temperature, so that the comparison between the neutral and the desired temperatures becomes quantifiable and meaningful.

TABLE 1: THE MOST KNOWN THERMAL COMFORT SCALES

ASHVE	**Bedford**	**ASHRAE**
Hot	Much too Warm	Hot
Warm	Too Warm	Warm
Slightly Warm	Comfortably Warm	Slightly Warm
Comfortable	Comfortable	Neutral
Slightly Cool	Comfortably Cool	Slightly Cool
Cool	Too Cool	Cool
Cold	Much Too Cool	Cold

The thermal preference versus thermal neutrality for the subject responses on ASHRAE scale might be traced back to Humphreys *et al.* [4]. In the 1970s, the authors observed that people in hot climate might prefer to feel slightly cooler than neutral. People in cold climate might also prefer to feel warmer than neutral [4]. McIntyre preferred scale has been widely used to investigate whether or not the comfort "neutral" temperature is the preferred temperature [6, 7, 8, 9, 10]. This was also used in meta-analysis study carried out by deDear *et al.* [11]. deDear *et al*. selected the Ballantine's method for analysis of the preferred temperature from the McIntyre scale. Their meta-analysis confirmed partly these observations in centrally air-conditioned buildings. The differences between the neutral and the preferred temperature were considered small and significant. However, the results in naturally ventilated buildings were not significant [4]. Humphreys *et al*. raised major issue on the methodology used for predicting the preferred temperature. According to the authors the uncertainties in the regression coefficients and the weakness of the Ballantyne's method may lead to large errors and uncertainties in the results. The authors provided further insight in their latest published book (Pages 319 to 330) [4].

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Brager *et al.* [12] stated that the central categories of the McIntyre scale are very strict in defining thermal satisfaction. Thus the former scale lacks precision. The preferred Macintyre scale is too narrow for an accurate estimation of the discrepancy between neutral temperature and preferred temperature. Moreover, a study carried out by the present investigator showed some statistical issues when using McIntyre scale in the humid tropics [23]

The McIntyre scale as further explained by Humphreys and Honckok provides only the desired sensation when a respondent desires "no change". The use of ASHRAE scale [5] to assess the preferred temperature versus the neutral temperature has the advantage of recording immediate information about the desired sensation.

Earlier the authors of the present article addressed the same issue in the humid tropics of Malaysia [13]. However, the investigators used a limited data size of 127 records for quantifying the desired thermal preference versus the neutral temperature. This was due to the reliability issues in data collection. In this investigation, we carry out further analysis of the desired neutral temperature using different sample size and rigorous statistical analysis.

This study aims to analyze, discuss the concepts about the preferred thermal perception on ASHRAE scale in air-conditioned classrooms in the humid tropics of Malaysia.

II. MATERIALS AND METHODS

This study was carried out in the Faculty of Engineering at the Universiti Malaysia Sabah. The location of the University is shown in Fig. 1. The Façade of block A, of the faculty of engineering is shown in Fig. 2.

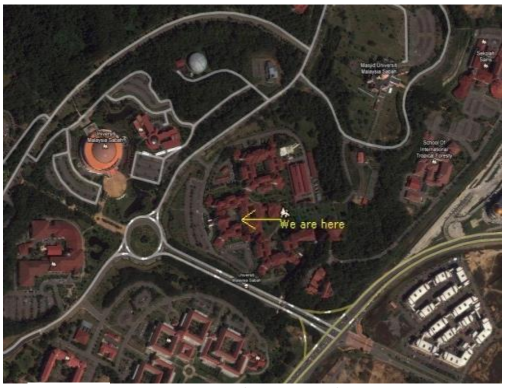

Fig.1. The Location of Faculty of Engineering

Fig. 2. The Façade of block A, Faculty of Engineering

All the surveyed classrooms are located at the ground floor. The surveyed classrooms are air-conditioned type. The air-conditionings in a few classrooms were not properly operating. All classrooms have accessible windows which can be easily opened by the students seating nearby. The classrooms are mostly protected from direct radiation with thick curtains. Fig. 3 shows a typical classroom where the survey was carried out. All the selected subjects for this study are UMS students

Fig. 3. Typical Classroom

Questionnaires were used to investigate the thermal sensation and the desired thermal sensation on ASHRAE scale. This investigation is a replication of the study carried out in the U.K. [4]. This study further investigated thermal acceptability scale. Other relevant thermal comfort parameters were analyzed and discussed. The subjective assessment-questionnaire and the objective indoor environmental data monitoring were conducted simultaneously. The survey design is transversal. The survey was conducted nine times in several classrooms. The data used in this investigation were collected during March and April 2015.

After a brief introduction about the aim of the survey, the questionnaires were distributed and filled by the students. The survey was conducted while the measurements of the indoor environmental parameters were recorded. Air temperature, relative humidity, air movement, and carbon dioxide were all recorded during the time of the survey. The measurements were taken at about 0.6 m from the floor. The measurements were made at the four corners and the center of each classroom. The average reading was taken for further analysis. In this investigation, two instruments were used. An anemometer type test 425 was used for recording indoor air temperature and air movement. Datalogger type ST-501 was also used to measure carbon dioxide and relative humidity. These instruments are shown in Fig. 4. The resolution and accuracy of the indoor instrument used in this investigation is listed in Table 2.

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Fig. 4. Instrument used in this investigation
Left (Anemometer-thermometer), Right (CO2 Temp/Rh Monitor)

TABLE 2: ACCURACY OF THE INDOOR INSTRUMENT

Sensor	Accuracy	Resolution
Air temperature	±0.5 ^{0}C	0.1 ^{0}C
Relative humidity	±3.0%RH(20~80%) ±5.0%RH(80%)	0.1%
Air movement	±0.03 m/s + 5% of mv	0.01 m/s
Carbon dioxide	± 75ppm, ± 8% of reading (0~2000 ppm)	±1 ppm

III. RESULTS AND DISCUSSION

In this investigation, there was little screening of the data prior analysis. However, we opted to different method to assess the students' responses in each surveyed classroom. One of the challenges in carrying out surveys in classrooms is the difficulty of having face to face discussion with each student. It was also difficult to estimate the clothing insulations worn by the students during the time of the survey.

Therefore, different approach was used to tackle these issues and to assess the reliability of subjects' votes.

A. Environmental Parameters

The mean values of the measured environmental parameters are listed in Table 3. Overall, the range of temperature under investigation was 25.4^{0}C -28.9^{0}C in those air-conditioned classrooms. The relative humidity was about 61.5%.

TABLE 3. ACCURACY OF THE INDOOR INSTRUMENT

Class	Avg. CO2	Avg. Relative Humidity	Avg. Temperature	Avg. Air Movement
1	959.6	68.9	27.8	0.1
2	854.2	62.1	28.4	0.1
3	1476.2	57.2	25.4	0.1
4	828.0	59.1	28.5	0.1
5	2473.2	59.9	28.2	0.1
6	648.4	68.3	25.8	0.1
7	1164.6	NA	28.9	0.1
8	1638.4	53.8	26.8	0.1
9	952.0	62.4	26.6	0.1
Total	**1295.3**	**61.5**	**27.6**	**0.1**

B. Subjects Background

The number of the subjects was about 278. The mean age was 22.35 (Confidence Interval: 22.17 to 22.52). The range varied from 19 to 28. The median and the mode were 22. The sample standard deviation of subject age was 1.48. There were six high outliers. However, they were not discarded.
In this investigation, students were asked to provide information about their height and weight. The average surface area of the subjects was calculated according to Dubois formula. It is expressed by Equation [14].

$$A_{Du}=0.202.w^{0.425}/h^{0.725} \quad (1)$$

(w) is the weight of the subjects in kg and (h) is the height of the subject in m.

The average surface area of the subjects under investigation is 1.63 m^2. This is in close agreement with the previous study carried out by Harimi [15] in residential buildings of Kota Kinabalu area. This is more representative of a Malaysian body proportion. Similar results were found for the Indonesian subject which was 1.6m^2 [16]. Therefore, it is recommended to be used for Malaysian typical average surface area when necessary. The worldwide average surface area is 1.8m^2.

BMI index is a simple indicator of a person's fitness. It can be estimated from Equation (2) [17].

$$BMI = w/ h^2 \quad (2)$$

Table 4 summarizes the frequency distribution of the calculated BMI of the subjects under investigation. The BMI is classified according to the World Health Organization (WHO). In this analysis there were nine missing values of height and/or weight. These were excluded. About 65% of the subjects were categorized under normal weight.

TABLE 4. CLASSIFICATION OF THE SUBJECTS IN THE BMI INDEX

BMI Index	Range	Number of Subjects	Percentage
Under Weight (UW)	BMI <18.5	34	12.6
Normal Weight (NW)	18.5≤BMI≤24.9	175	65.1
Over Weight (OW)	25≤BMI≤29.9	41	15.2
Obesity (O)	BMI≥30	19	7.1
Blank		9	
Total		278	

C. Clothing Insulation

Clothing is an important factor when considering behavioral adjustment to achieve comfort [18]. The effect of clothing on human thermal sensation depends on the body motion, air movement, the number of clothing layers, the trapped air layers in the clothing ensemble and between skin and the clothing, fabrics permeability and thickness, porosity and water vapour transfer of the clothing, and clothing

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coverage [19, 20, 21]. These factors make the estimation of clothing insulation with sufficient accuracy almost impossible.

The reliability and the usability of the insulation values and their effects on the accuracy of thermal comfort studies have been raised by several authors [19, 22, 11]. Therefore, this study used different approach to evaluate the effect of clothing on subjects' thermal perception and thermal preference. The students were asked to select one out of three choices, if they are wearing "More cloths than wanted, "OK", or "Less cloths than wanted". This scale was taken from literature; however, the author did not keep the reference from where the scale was taken. The results are plotted in Fig. 5.

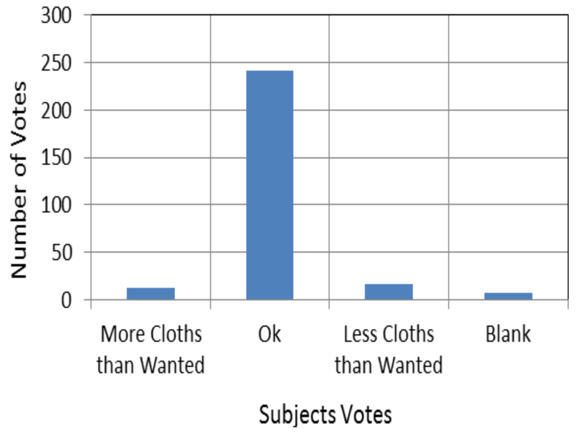

Fig. 5: Subjects votes on clothes worn during the survey

The analysis revealed that 87% of the students were neither wearing less or more cloths than wanted. This was reflected by those voting "Ok". This represents the percentage of those who were fine with their clothing insulation level regardless of the indoor thermal environment.

D. Metabolic Rate

To ensure uniformity of students' votes, the survey was conducted at least 30 minutes after starting their classes. The students were engaged in sedentary activity, the metabolic rate was assumed 1.2 met (sedentary activity).

E. Subjects Responses on ASHRAE Scale

In order to quantify the discrepancy between the neutral and the preferred temperature, ASHRAE scale was used. The analyzed results on how the students perceived the indoor thermal environment at the moment of the survey versus how they would like to feel at that moment are listed in Table 5.

A close observation in Table 5 revealed that the highest records of the subjects preferred feeling slightly cooler and neutral rather than warmer. When the students were asked about how they feel at the moment of the survey, about 45.4% voted neutral, whereas when they asked about how they would like to feel at the moment of the survey, the highest percentage of 39.8% voted slightly cool and followed by those voted neutral representing 31.2 %.

TABLE 5. PREFERRED AND PERCEIVED VOTES ON ASHRAE SCALE

How would you like to feel at this moment → / How do you feel at this moment ↓	-3	-2	-1	0	1	2	3	Total
-2		6	3	6				15
-1	1	15	27	14	1			58
0	2	15	46	53	6			122
1	2	7	18	7	1			35
2	1	7	8	4		5		25
3	3	3	5			1	2	14
Total	9	53	107	84	8	6	2	269

(-3) Cold; (-2) Cool; (-1) Slightly Cool; (0) Neutral; (1) Slightly warm; (2) Warm; (3) hot

In order to assess thermal perceptions and preferences of subjects' votes toward the indoor environment, the average votes in each classroom were plotted versus the indoor air temperatures in Figures 6 and 7.

On average; students' votes were below neutrality for indoor temperatures below 27.3^{0}C (Fig. 6). The situation is reversed when the indoor temperature was above 27.3^{0}C. This is close to the overall mean outdoor air temperature in Kota Kinabalu of about 27.5 °C. However, the variability of votes by classroom is apparent. When considering the preferred thermal perception, Fig. 7 revealed that the students preferred slightly lower temperature than neutrality. This is regardless of the indoor temperature. It is also apparent from the same figure that there is no clear pattern on subject preferred thermal perception toward the indoor thermal environment.

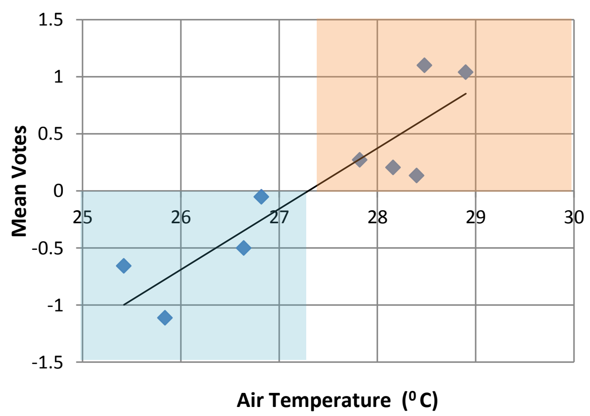

Fig. 6. Thermal perception votes on ASHRAE scale

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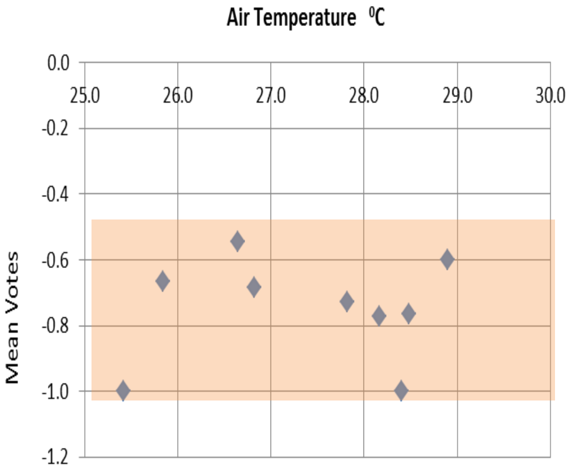

Fig. 7. Thermal preference votes on ASHRAE scale

F. Assessment of Subjects Votes

It has been reported that the least square linear regression might not be an appropriate method for the prediction of neutral temperature [24]. In this investigation, the number of collected data at various temperatures was considered small for a reliable prediction. When considering the least square linear regression method, the predicted neutral temperature was 27.3^{0}C. Some investigators may argue that the neutral temperature should be predicted in Kelvin. This is because there is no true zero when considering degree Celsius scale. However, both scales provided similar results. Additionally, in this study statistical analysis was conducted for the evaluation of the regression parameters. The results are listed in Table 6. It is apparent from the table that the 95% confidence interval for the slope and the intercept of the obtained equation was too big for an accurate prediction. This was despite that the coefficient of determination was 0.81. The obtained *P-value* was very significant but not meaningful. It is reflected by the 95% confidence interval. The 95% confidence interval for the slope varied from 0.302 to 0.760. It might be important to highlight, the assumptions of linear regression were not taken into account in this study. In fact the developed model lacked precision. This shows, that plotting graphs and generating neutral temperature with a significant *P-value* is not necessary precise nor necessary valid.

TABLE 6 EVALUATION OF THE REGRESSION PARAMETERS

		Unstandardized Coefficients			*95.0% Confidence Interval for B*	
Model		B	Std. Error	Sig.	Lower Bound	Upper Bound
1	*Constant)*	*-14.493*	*2.658*	*.001*	*- 20.778*	*-8.209*
2	*Temp*	*.531*	*.097*	*.001*	*.302*	*.760*

For further investigation on subjects' votes, the mean, median, standard deviation, and the standard deviation ratio (Standard deviation/Number of subjects)*100) were estimated in each classroom. In this study, small variability in students' votes in each classroom is desired.

The results of subjects' perception and preference on ASHRAE scale are listed in Tables 7 and 8. It was possible to investigate the variability of subjects' votes using the coefficient of variation (Relative dispersion). The coefficient of variation is the ratio of the standard deviation to the arithmetic mean expressed as a percent [25]. The only issue with the coefficient of variation is in estimating the mean values. The sample mean in thermal comfort field studies can be close or equal zero. Additionally, the coefficient of variation cannot be always determined due to division by zero.

The standard deviation ratio has been used in this study to provide insight on the consistency and variability of the collected data. For instance, while the standard deviation in classrooms 1, 3, and 7 is the same of 0.8 (Table 7). The vote in classroom 7 has less variability and more data. This was reflected by the standard deviation ratio of 1.6. The standard deviation ratio for classroom 2 was 11.7. This occurred due to the small data collection in this classroom. It has only 9 students. In classroom 8, despite the number of votes was 30, however, the inconstancy of students' votes was apparent. It is reflected by the standard deviation ratio of 4.3. Another requirement was set in this study. There should be about 25 subjects or above in a classroom for further analysis. It must be highlighted a close observation of data by the investigator must be carried out carefully prior any statistical methods. For instance, a close observation of subjects' votes in classroom 8 revealed that there were only 2 students voted slightly warm and 11 students' voted warm, whereas only 10 students voted for neutrality. This means there is inconsistency in students' votes. It was not possible to trace back the reason of the inconsistency and therefore, such cases were excluded. This certainly helps in analyzing data under uniform conditions.

The discrepancy of the results when considering the mean votes versus the median was further investigated. In this study, classrooms having median votes close to the mean were selected for further analysis. The numbers of subjects in classrooms 2, 3 and 4 were too small. Therefore, the results should be analyzed with caution. There was also inconsistency in students' votes in classroom 8 and 9. After excluding classrooms 2, 3, 4, 8 and 9, it was apparent that the students voted slightly cool when the temperature was about 25.5^{0}C. They also voted neutral when the temperature was almost 28^{0}C to 28.5^{0}C. However, they preferred a slightly cool temperature. Overall, when considering all classrooms, the highest number of students perceived the indoor temperature as neutral. This was followed by slightly cool, then warm. However, the highest number of students preferred feeling slightly cool, followed by neutral and then slightly warm.

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TABLE 7. STATISTICAL ANALYSIS OF THERMAL PERCEPTION VOTES

Class	Tem	-3	-2	-1	0	1	2	3	N_{br} of Votes	Mean	Median	Std.	Std. Ratio
1	25.42		5	16	11	3			35	-1	-1.0	0.8	2.4
2	25.84		4	3	**1**	1			9	-1	-1.0	1.1	11.7
3	26.64		4	3	15				22	-1	0.0	0.8	3.6
4	26.82		1	5	10	1	1	1	19	0	0.0	1.1	**5.9**
5	27.82			2	22	7	2		33	0	0.0	0.7	**2.0**
6	28.16			13	18	7	3	3	44	0	0.0	1.2	2.6
7	28.4			11	27	10	4		52	0	0.0	0.8	**1.6**
8	28.48			3	10	2	11	4	30	1	1.5	1.3	4.3
9	28.9		1	2	8	4	4	6	25	1	1.0	1.5	5.9
	Total		15	**58**	**122**	35	25	14	269				

TABLE 8. STATISTICAL ANALYSIS OF THERMAL PREFERENCE VOTES

Class	Tem	-3	-2	-1	0	1	2	3	N_{br} of Votes	Mean	Median	Std.	Std. Ratio
1	25.42	2	9	12	11	1			35	-1	-1.0	1.0	2.8
2	25.84		2	2	5				9	-1	0.0	0.9	**9.6**
3	26.64		5	3	13	1			22	-1	0.0	0.9	4.1
4	26.82		1	11	7				19	-1	-1.0	0.6	3.1
5	27.82		6	14	11	2			33	-1	-1.0	0.8	2.5
6	28.16		11	17	13	2		1	44	-1	-1.0	1.0	2.3
7	28.4	1	12	26	12	1			52	-1	-1.0	0.8	1.5
8	28.48	4	4	12	5	1	4		30	-1	-1.0	1.5	4.9
9	28.9	2	3	10	7		2	1	25	-1	-1.0	1.4	5.7
	Total	9	53	**107**	**84**	8	6	2	269				

Finally, the deviation between neutrality and thermal preference on ASHRAE scale was estimated in table 9.

Only classrooms with the standard deviation ratio less or close to 2 (Less variability in their votes) with at least 30 students were considered for further analysis.

On average, the discrepancy between neutrality and preference thermal perception votes was close to one unit. Students preferred cooler thermal perception. Unfortunately, it was not possible to quantify the discrepancy at various indoor temperatures. This is due to statistical issues as reported above.

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TABLE 9 DEVIATION BETWEEN NEUTRALITY AND PREFERRED TEMPERATURE

Mean Temperatures	Mean Thermal Perception	Mean Thermal Preference
25.42	-0.7	-1.0
27.82	0.3	-0.7
28.16	0.2	-0.8
28.4	**0.1**	-1.0
Average	0.0	-0.9
Round up	0	-1

G. Thermal acceptability versus Thermal Perception

The subjects' votes on thermal acceptability scale at various indoor temperatures were also investigated. The results are plotted in Fig. 8. When considering the temperature range from 25.42 to 28.4^{0}C, the number of subject's votes on thermal acceptability scale dropped considerably in classrooms 8 and 9. There was no obvious explanation about this sudden drop. However, the inconsistency of student votes on ASHRAE scale in classroom 8 and 9 was reported earlier in this article.

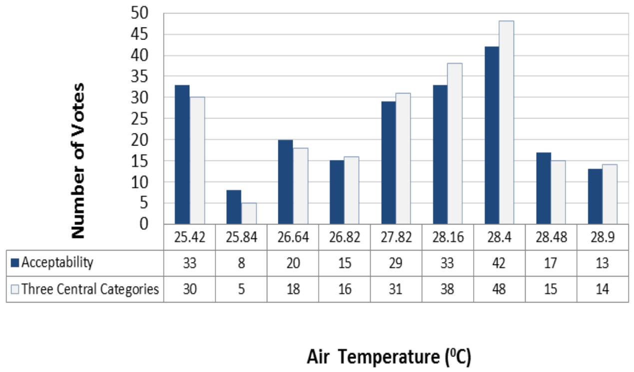

Fig. 8. Thermal Acceptability Versus the three central categories of ASHRAE scale*

* The three central categories is related to subject votes on their thermal perception on ASHRAE seven-point scale

It was surprising to find that the students votes on ASHRAE scale (Those voted from slightly cool to slightly warm) was close to those voted acceptable on thermal acceptability scale (Figure 8). This confirmed the observation made by some investigators [26, 27, and 28]. Therefore, in this study the number of those voted 'Cool' or 'Cold', 'Warm' or 'Hot' was close to those who found their thermal environment unacceptable.

IV. CONCLUSIONS AND RECOMMANDATIONS

This study was about investigating scales for comfort temperature prediction. Field study was carried out in classrooms in the humid tropic of Malaysia. The main aim was to investigate the preferred thermal perception versus thermal preference from ASHRAE 7-point scale. This study also made a comparison between thermal acceptability versus subjects' votes on ASHRAE scale. The following conclusions were made:

- Thermal perception and thermal sensation have different meaning [26]. However, in this investigation thermal sensation and thermal perception are used to convey the subjects feeling at the moment of the survey. This clarification is required because thermal sensation has been used widely in thermal comfort field studies to convey subjects' votes on ASHRAE scale.

- Despite, it was much easier to collect data in classrooms than in residential buildings; however the main issue faced the investigator is assessing the quality of the collected data in classrooms.

- Clothing insulation values worn by the students were difficult to estimate; therefore this study opted for different procedure to assess the clothing effects on subjects' votes. Overall, more than 80% were comfortable with the clothing insulation levels during the conducted survey

- A new procedure was developed to assess the consistency of students' votes in each classroom. Therefore a statistical procedure was used to eliminate some of the data prior addressing the objective of this study.

- Overall, it has been found that the students preferred feeling slightly cool under neutrality. In this study, the three central categories on ASHRAE scale coincided with thermal acceptability.

- Despite students preferred feeling slightly cool. It should not be recommended in adjusting the thermostat to a lower temperature. This is because it has implication on energy consumption and a negative effect on the environment.

- When considering evaluating thermal comfort scales. There are two approaches for the evaluation. The first approach is about evaluating response scale. A response scale is about how the subjects responses using a scale. For instance, this study was about investigating a response scale. However, little has been done about developing and assessing a scaling procedure. Therefore, it is highly recommended for further investigation in the near future.

- The carryover of subjects thermal perception on ASHRAE scale from one judgment to another remains unresolved. This means there is no true calibration when considering subjects votes. Therefore, it requires further investigation.

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V. ACKNOWLDGEMENT

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