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Thermal Comfort Investigations and Evaluation of Air-Conditioning Operations for Lecture Rooms in Tropical Climate Countries

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Abstract

Peak electricity demand in Thailand is critically high in summer. This problem was caused by high demand of room air conditioning for residential. Higher thermostat temperature set-point is a one of methods to reduce this peak. However, the higher thermostat temperature set-point should fall under acceptable range of thermal comfort for occupants.

The purpose of this research is to investigate thermal comfort zone of university's students. Four hundred and one students in Chiang Mai University were randomly selected to participate in this research. An experiment room was prepared. Thermal conditions in the room are conditioned in the following ranges; dry bulb temperature 22-29 °C, Relative Humidity 40-80 %, and air velocity less than 0.2 m/s. Data collection form was prepared according to ASHRAE standard 55-2010. Subject's data such as age, sex, metabolic rate, and clothing insulation were collected to calculate operative temperature, percentage of sensation vote, and actual mean vote (AMV). During the interview the subject's data such as dry bulb temperature, relative humidity and radiant temperature were collected.

Experiment result shows that mean clothing insulation of survey's sample is 0.47 clo. Thermal comfort zone for university students is defined in operative temperature range of 23.6-27.4 °C and relative humidity range of 40-50 %RH. Thus, it can be concluded that the higher acceptable temperature range can be used in air conditioning systems in order to reduce the electricity peak demand.

Keywords: Thermal comfort, Air-condition, University.

1. Introduction

Due to the effects of global warming, the demand for air-conditioners are rising to satisfy occupant thermal comfort. Energy consumption in air conditioning system is accounted for about 60% of the total electricity consumption for the residential section in Thailand [1]. In addition, in 2004 the total electricity consumption for the residential section was accounted for 23% of Thailand's national electricity consumption [2]. In particular, peak electricity demand was highest during summer months because of relatively high ambient temperature. The Ministry of Energy of Thailand reported that statistical data of electricity demand for air-conditioning increased 350 MW for every 1°C increased in air conditioner thermostat setting [3]. Recently, most of universities in Thailand have changed their semester dates. Therefore, universities are now opened during April and May, which is the hottest months of the year. Consequently electricity consumption and demand increase due to increasing of air conditioner using. If thermal comfort zone in lecture rooms can be increase, electricity consumption and demand can be decreased. However, information about the thermal comfort for air-conditioned lecture room of students in university is still limited and needs further investigation.

Thermal comfort zone is identified by acceptable operative temperature and humidity for occupants, in which the standard was developed by ASHRAE. However, the recommended thermal comfort of ASHRAE is provided for worldwide use. This research focuses at tropical climate region, i.e. Thailand, that definition of the region is wet and monsoon, which has the common daytime temperature of 32°C, while the minimum temperature at night not lower than 22°C. The high range of temperature is maintained with a slightly variation throughout the year.

The study of Juntakan and Ar-U-Wat (2013) showed that the thermal comfort zone for Thai people had a wider range than that presented in ASHRAE standards [4]. The non-quantifiable factors of thermal comfort that consisted of air conditioned acclimatization behavior and education level were reported by Yamtraipat, et al [5]. Moreover, Tammanoon et al. (2010) investigated the effect of thermal environmental factors, i.e. temperature and relative humidity, on the human comfort and health using Delphi technique [6]. Sekhar (1995) was investigate the acceptability of air-conditioned space conditions from thermal comfort considerations, the result was shown that the high space temperature of approximately 26°C with relative humidity of about 60% was acceptable in the tropics [7].

The objective of this study is to investigate the thermal comfort zone based on methodology and thermal environment survey sheet of ASHRAE standard 55 [8]. In this study, six primary factors of the thermal comfort were collected, which consisted of metabolic rate, clothing insulation, air temperature, radiant temperature, air speed, and humidity. In

addition, the thermal comfort zone based on operative temperature range and relative humidity range was also explored. The results of thermal comfort zone for students in university can be used to operate air-conditioners with optimum temperature. This can minimize electricity consumption and decrease electricity peak with respect to demand response program.

The comfort zone is defined by a range of the operative temperature (t_0) for acceptable thermal environment condition. The general form of the operative temperature is given by:

$$t_0 = \frac{(t_a + t_r)}{2} \quad (1)$$

where,

t_a is the average air temperature, °C
t_r is the mean radiant temperature, °C

The statistical result of the thermal comfort factor (such as the actual mean vote) can be calculated by an arithmetic mean equation as,

$$\bar{x} = \sum_{i=1}^{n} x_i \quad (2)$$

where,

$\bar{x}$ is arithmetic mean
n is the number of terms
x_i is the value of each individual item in the list of numbers being averaged

The actual mean vote (AMV) of thermal sensation is used to evaluate an exact neutral temperature, this parameter are linear relationship with respect to the operative temperature, the AMV can be determine from linear equation as,

$$y = mx + c \quad (3)$$

where,

m is slope
c is y-intercept

In this study, a survey sample size was calculated using the Yaname sample size calculation [9], that expressed as

$$n = N/(1 + Ne^2) \quad (4)$$

where,

n is the sample size
N is the population size
e is the acceptable sampling error

The values of operative temperature for occupant's activity were ranged from 1.0 to 1.3. Moreover, the assumptions were made that occupant will not receive the direct sunlight and not expose to the air velocity greater than 0.2 m/s. The ASHRAE Standard 55-2010 defined the comfort zone from numerical calculation for clothing insulation ranged between 0.5 and 1.0 clo (1.0 clo=0.155 $m^2 \cdot °C$ /W). ASHRAE assumed that clothing insulation of the winter business suit has about 1 clo, while the summer short-sleeved shirt and trousers have about 0.5 clo. Additionally, ASHRAE Standard 55-2010 showed no lower humidity limit for the thermal comfort. However, the upper humidity limit of 0.012 $kg_{water}/kg_{dry\ air}$ was used, which corresponds to dew point temperature of 16.8°C at the standard pressure of 101.3 kPa. The results of operative temperature were 80% of occupant acceptability and 10% dissatisfaction recommend by ASHRAE. The range of operative temperature and relative humidity acceptable were have to plot in psychrometric chart as graphical method. The ASHRAE Standard 55-2010 graphical method for acceptable range of operative temperature and humidity is shown in Fig. 1

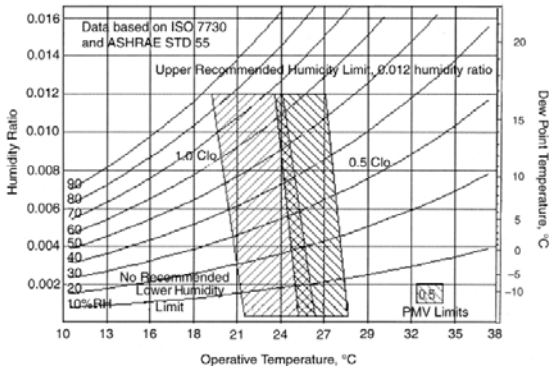

Fig. 1 ASHRAE Standard 55-2010 acceptable range of operative temperature and humidity

2. Methodology

2.1 Experiment Set Up

The experimental room was located in Faculty of Engineering, Chiang Mai University. In the air-conditioned room, space temperature was controlled by two-conditioners. Room air temperature was controlled using 12,000 Btu/hr Air Conditioner (3,516.86 W). Humidity was controlled by a humidifier that can add water vapor at the rate of approximately 150 liter/hr. The maximum relative humidity of the room is 80%. Room temperature was measured using T-type thermocouples, which had an error of ±0.5 °C. The thermocouples were also used to collect an average air temperature of the spatial at three different levels for seated occupants. These three levels were the ankle level, waist level and the head level. Thus the thermocouples were placed at 0.1, 0.6, and 1.2 m above the floor respectively. In order to find out the relative humidity of air-conditioned space, the thermocouples were used to measure both dry bulb temperature and wet bulb temperature. The mean radiant temperature was measured at the waist level of 0.6 m using a globe thermometer with an error of ±2 °C. Hotwire anemometer was used to measure average air speed using the spatial averaging as the same as used for air temperature. The accuracy of the hot wire anemometer is 95%. The data from the thermocouples were collected every 1 minute and stored in data logger.

2.2 Survey Set Up

With the total bachelor's degree students of 28,125 students in Chiang Mai University (2015) and the confidence level of 95% or the acceptable sampling error of 5%, the number's sample size of surveys should be at least 395. Thus, random sample of 401 students was used in the survey.

2.2.1 Survey Methodology

Two different factors were taken into account. The first factor was thermostat setting ranged from 22 to 29 °C, while the second factor was humidity set point and it ranged between 40 to 80 %RH. A maximum of 10 students was randomly assigned each condition. The experimental room was conditioned to preferred temperature and relative humidity 30 minutes before the survey began. Clear explanation on the objectives of this study was given to the chosen students before starting the survey. The students were asked to provide information such as name, date and time, approximate outside air temperature, clear sky/overcast, seasonal conditions, occupant's clothing, occupant's activity level, general thermal comfort level, and occupant's location.

The occupants must to have a light activities such as sedentary activities at least one hour before rest in survey room. After the occupants were rested for 15 minutes in the experimental room, they were asked to vote thermal sensation and humidity sensation. The thermal sensation and humidity sensation scales were defined in Table. 1. During the survey, it was assumed that metabolic rate of 1.2 met (60 W/m^2) for office activities is applied.. At the end of each survey, data, such as total clothing insulation and metabolic rate, were collected again.

Table. 1 thermal sensation and humidity sensation scale

Value	Thermal Sensation	Humid Sensation
+3	Hot	-
+2	Warm	Humid
+1	Slightly warm	Slightly humid
0	Neutral	Just right
-1	Slightly cool	Slightly dry
-2	Cool	Dry
-3	Cold	-

2.2.2 Thermal Environment Survey Sheet

The thermal environmental survey sheet was prepared based on ASHRAE standard 55-2010 survey sheet with additional factors, which were congenital disease, education level, native district, and air-conditioners used at home. The survey sheet was divided into 2 sections as followed.

1) Occupants information: in this section, the occupants had to fill by themselves. Personal information included date and time, age, sex, weight, height, clothing, additional factors, thermal sensation, and humidity sensation.
2) Surveyor's information: in this section, the surveyors had to fill the specific details of the survey, which included clothing insulation, metabolic rate, outside temperature, outside relative humidity, thermostat setting, humidity set point, and total number of occupants.

3. Result and Discussion

The results of thermal comfort for air-conditioned room of students in university can be divided into 2 parts as follows.

3.1 Statistical Result

The survey was performed in the period of February 2016 to April 2016. The subject's data was collected and analyzed. In total, 401 subjects (occupants), who study at Chiang Mai University, were completed this survey. These 401 subjects consisted of 212 male and 189 female. The statistical result of survey subject is shown in Table. 2.

Table. 2 Statistical result of survey subjects

	Age (years)	Weight (kg)	Height (cm)	Clothing (clo)
Max	23	113	185	0.80
Min	18	38	150	0.20
Average	21.49	62.15	167.27	0.47
S.D.	1.05	12.72	7.87	0.12

3.2 The statistical results of thermal sensation vote

Effects of temperature and relative humidity on human thermal sensation vote are shown with respect to frequency number, percentage of neutral vote and actual mean vote (AMV). The results of thermal sensation vote are shown in Table. 3.

The results of actual mean vote in relation to different operative temperatures are shown in Fig. 2. The correlation between mean thermal sensation vote and operative temperature can be expressed by a linear relationship. According to ASHRAE standard 55, the acceptable thermal sensation ranged between -0.5 to 0.5, the result can express to an acceptable temperature range of 24.61 to 27.98°C. An exact neutral temperature, which is the point of intercept of linear relationship with respect to the neural value of x-axis, was 26.3°C. The coefficient of determination (R^2) of linear relationship is 0.95.

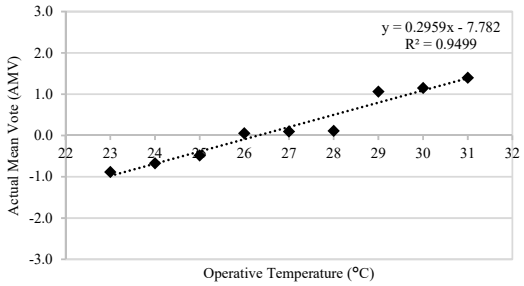

Fig. 2 The actual mean vote of thermal sensation

To define the thermal comfort zone boundary, relationship between the percentages of occupant

voting with the operative temperature was considered. Additionally, these percentages of occupant voting were analyzed using the thermal sensation, which ranged from slightly cool (-1) to slightly warm (+1) as shown in Fig. 3. According to the occupant acceptability of 80%, the operative temperatures ranged from 22.5 to 28.9°C. However, the values of operative temperature were ranged from 23.6 to 27.4°C when the occupant acceptability was considered at 90%. The higher occupant acceptability is recommended to define maximum operative temperature or temperature set-point for air-conditioned room.

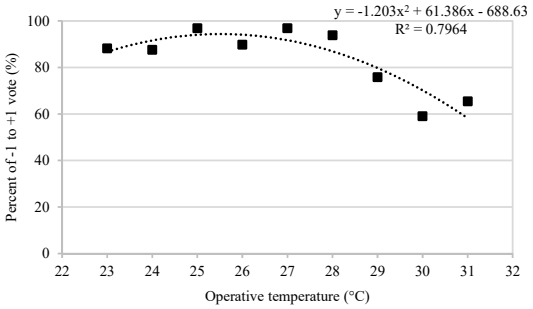

Fig. 3 The percentage of vote for thermal sensation

3.3 Statistical results of humidity sensation vote

The frequency of humidity sensation vote were analyzed to define the percentages of occupant voting and the actual mean vote (AMV) as presented in Table. 4.

The results show that the highest average percentage of humidity sensation was found at a relative humidity range of 40-50%RH under both conditions. , i.e. AMV value of "0" and AMV value of -1 to +1, according with the average AMV that have closest 0 value (Just right) at relative humidity range of 40-50 % also.

It can be concluded that students in university prefer the relative humidity of 40-50%RH. The average percentages of humidity sensation vote as show in Table. 5.

Table. 5 The average percentages of humidity sensation vote

RH (%)	Average percent of 0 vote	Average percent of -1 to +1 vote	Average AMV
40-50	57.1	95.51	-0.1
50-60	56.3	95.47	0.2
60-70	31.9	79.55	0.7
70-80	40.8	83.89	0.6

The results obtained in this study was compared with the acceptable range of operative temperature and humidity from ASHARE standard. The values of operative temperature ranged of 23.6 to 27.4°C at an occupant acceptability of 90% were used. Comparison of operative temperature and relative humidity was plotted in the psychrometric chart as shown in Fig. 4.

Table. 3 The results of thermal sensation vote

Operative Temperature (°C)	RH (%)	Number of thermal sensation vote							Frequency Number	Percent of 0 vote	Percent of -1 to +1 vote	Actual Mean Vote
		Cold (-3)	Cool (-2)	Slightly cool (-1)	Neutral (0)	Slightly warm (+1)	Warm (2)	Hot (3)				
23 ±0.5	50-60	-	2	11	4	-	-	-	17	23.53	88.24	-0.88
24 ±0.5	40-50	-	1	6	3	-	-	-	10	30.00	90.00	-0.80
	50-60	-	1	8	5	-	-	-	14	35.71	92.86	-0.71
	60-70	-	2	1	7	-	-	-	10	70.00	80.00	-0.50
25 ±0.5	40-50	-	-	7	6	-	-	-	13	46.15	100.00	-0.54
	50-60	-	-	8	19	-	-	-	27	70.37	100.00	-0.30
	60-70	-	-	1	2	-	-	-	3	66.67	100.00	-0.33
	70-80	1	-	3	4	-	-	-	8	50.00	87.50	-0.75
26 ±0.5	40-50	-	-	1	5	4	-	-	10	50.00	100.00	0.30
	50-60	-	2	8	7	2	2	-	21	33.33	80.95	-0.29
	60-70	-	-	6	13	4	3	-	26	50.00	88.46	0.15
27 ±0.5	40-50	-	-	6	9	6	3	-	24	37.50	87.50	0.25
	50-60	-	-	5	11	10	-	-	26	42.31	100.00	0.19
	60-70	-	-	4	15	3	-	-	22	68.18	100.00	-0.05
	70-80	-	-	1	3	1	-	-	5	60.00	100.00	0.00
28 ±0.5	40-50	-	-	6	16	6	3	-	31	51.61	90.32	0.19
	50-60	-	-	2	11	5	1	-	19	57.89	94.74	0.26
	60-70	-	-	1	12	6	2	-	21	57.14	90.48	0.43
	70-80	-	-	4	2	1	-	-	7	28.57	100.00	-0.43
29 ±0.5	40-50	-	-	-	3	3	-	-	6	50.00	100.00	0.50
	50-60	-	-	-	4	10	6	-	20	20.00	70.00	1.10
	60-70	-	-	-	-	1	-	2	3	0.00	33.33	2.33
	70-80	-	-	1	-	2	-	-	3	0.00	100.00	0.33
30 ±0.5	40-50	-	-	-	2	2	1	-	5	40.00	80.00	0.80
	50-60	-	-	1	7	3	2	1	14	50.00	78.57	0.64
	60-70	-	-	-	-	2	3	1	6	0.00	33.33	1.83
	70-80	-	-	1	-	3	5	-	9	0.00	44.44	1.33
31 ±0.5	50-60	-	-	-	1	9	1	-	11	9.09	90.91	1.00
	60-70	-	-	-	1	3	3	3	10	10.00	40.00	1.80

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Table. 4 The results of humidity sensation vote

Operative Temperature (°C)	RH (%)	Number of humidity sensation vote					Frequency Number	Percent of 0 vote	Percent of -1 to +1 vote	Actual Mean Vote
		Dry (-2)	Slightly dry (-1)	Just right (0)	Slightly humid (1)	Humid (2)				
23.0 ±0.5	50-60	-	2	14	1	-	17	82.4	100.0	-0.06
24.0 ±0.5	40-50	-	4	6	-	-	10	60.0	100.0	-0.40
	50-60	-	4	9	1	-	14	64.3	100.0	-0.21
	60-70	-	1	7	-	2	10	70.0	80.0	0.30
25.0 ±0.5	40-50	-	3	10	-	-	13	76.9	100.0	-0.23
	50-60	-	7	15	5	-	27	55.6	100.0	-0.07
	60-70	-	2	-	1	-	3	0.0	100.0	-0.33
	70-80	-	-	1	5	2	8	12.5	75.0	1.13
26.0 ±0.5	40-50	-	4	3	3	-	10	30.0	100.0	-0.10
	50-60	-	1	13	5	2	21	61.9	90.5	0.38
	60-70	-	2	16	8	-	26	61.5	100.0	0.23
27.0 ±0.5	40-50	2	6	14	2	-	24	58.3	91.7	-0.33
	50-60	-	2	19	5	-	26	73.1	100.0	0.12
	60-70	-	-	13	6	3	22	59.1	86.4	0.55
	70-80	-	1	3	1	-	5	60.0	100.0	0.00
28.0 ±0.5	40-50	1	5	21	3	1	31	67.7	93.5	-0.06
	50-60	-	1	7	11	-	19	36.8	100.0	0.53
	60-70	-	-	10	11	-	21	47.6	100.0	0.52
	70-80	-	-	3	4	-	7	42.9	100.0	0.57
29.0 ±0.5	40-50	1	-	4	1	-	6	66.7	83.3	-0.17
	50-60	-	-	6	11	3	20	30.0	85.0	0.85
	60-70	-	-	-	2	1	3	0.0	66.7	1.33
	70-80	-	-	2	-	1	3	66.7	66.7	0.67
30.0 ±0.5	40-50	-	-	2	3	-	5	40.0	100.0	0.60
	50-60	1	1	8	4	-	14	57.1	92.9	0.07
	60-70	-	-	1	1	4	6	16.7	33.3	1.50
	70-80	-	1	2	4	2	9	22.2	77.8	0.78
31.0 ±0.5	50-60	-	-	5	5	1	11	45.5	90.9	0.64
	60-70	-	-	-	7	3	10	0.0	70.0	1.30

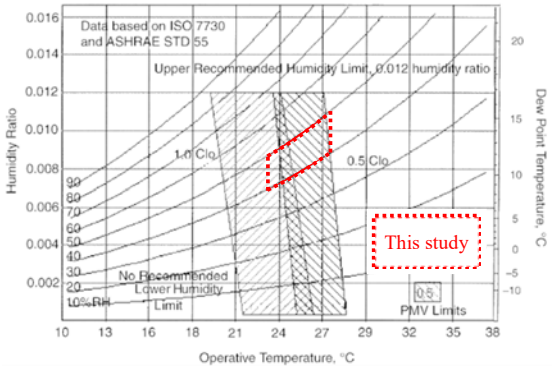

Fig. 4 Comparison of operative temperature and relative humidity

From Fig. 4, it is obvious that temperature for thermal comfort zone of this research is slightly greater than acceptable operative temperature of ASHRAE standard for summer. The acceptable humidity obtain in this study is in the limit of ASHRAE standard. The results show that the different between this research and ASHRAE standard are affect from the different of numerical calculation and actual survey. From the effect of acclimatization of occupant the actual survey is more reliable than numerical calculation.

Results from this study was used to compare with result from Yamtraipat, et al study. In Yamtraipat study, it is recommended that nationwide indoor set-point for air-conditioning for building in Thailand is 26.6°C. This temperature is lower than the temperature set-point of this study (27.4 °C at 90% acceptability) about 5.11%. On the other hand, this study found that relative humidity range (40-50%) for student in university is the same range as reported by Yamtraipat, et al. (40-50%).

4. Conclusions

The 401 university students in participated in this study. The survey document base on ASHRAE standard survey check sheet was made in this investigate. The primary factor to investigate thermal comfort zone was collected. The actual mean vote use to apply to investigate thermal comfort. The result show that operative temperature range is 23.6-27.4°C at 90% occupant's acceptability. The most occupants preferred relative humidity range of 40-50%.

5. Acknowledgement

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