Thermal comfort in Bangkok residential buildings, Thailand

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ABSTRACT: A field study of thermal comfort was conducted in Bangkok, Thailand in which 1377 responded to a questionnaire while simultaneous physical measurement-s were taken in both air-conditioned and naturally ventilated residential buildings. Sensation voting scales chosen are ASHRAE, McIntyre and air flow scale. A regression model was used to find the relationship between the ASHRAE scale votes and the variables that effect thermal comfort. The computer based statistical package SPSS10 for windows was used to perform the regression analysis. The result of this study shows comfort temperature for Bangkok's people in residential building are 25 deg C for air conditioning buildings and 28 deg C for natural ventilated buildings.

Keywords: thermal comfort, residential, Bangkok

1. INTRODUCTION

The study of energy conservation potential in Buildings has to be based on criteria of human response to the thermal environment in building interiors. The purpose of this field study is to define the range of thermal comfort and the limit of tolerance of residents in Bangkok.

In the past the great majority of thermal comfort research had been carried out in the laboratory. The laboratory offers consistent conditions for measurement not possible in the field but lacks the multidimensional reality of a real life situation. A field study avoids this problem by investigating people's thermal response to their normal activity conditions.

Thermal comfort field studies of people living in tropical climates have been carried out by some researchers such as DeDear et al, Web and Ellis in Singapore; Karyono in Indonesia, most of them were carried out in office buildings. To the author's knowledge, two main thermal comfort field studies had been carried out in Bangkok [2] [8], they are both in office buildings. Information from office buildings may not be applicable to residences. Although office buildings in Bangkok consume much energy for air conditioning, residential sector also consumes a large amount of energy for the same purpose. Perhaps smaller installations but much more numerous.

2. METHODS

This section will describe a field study conducted in Bangkok in order to determine the comfort requirements of people in residential buildings and the results will be compared with other published findings.

2.1 The respondents

This field study attempts to obtain votes from Thai people of a wide range of ages. There were slightly more male than female respondents (735 male and 642 female). Most of them are university students of 18-26 years, the remainder are university staff ranging in age from 25-59 years. There were 105 elderly people of 60-90 years old in nursing homes and private houses who were also observed. Only respondents who appeared to be in good health were selected.

Respondents are of medium build with light brown skin. The average height of the Thai male is about 165 cm. and the Thai female is about 155 cm. The average Dubois body surface of Thai people is 1.56 m^2 with a standard deviation of 0.17 [2]. Most of them were free to dress in light summer clothing such as a shirt and trousers for males; and a blouse and skirt for females. These have average a clo value of 0.5 for rainy and winter seasons and 0.4 for the summer season. Respondents were doing light work such as reading (which is the same average as watching television in a dwelling), writing, computer work, and drawing (which are the same averages as sewing or knitting in a dwelling). These types of activities have average met values of 1-1.2 (58-70 W/m^2). The figures used in the study have been drawn from "the energy expenditure in daily life" [1].

2.2 The observers

The observers are six Thai students from the Tropical Architecture program of the KMITL under the author's supervision. All of them are postgraduate students who have background in building climatology and thermal comfort.

2.3 Sites and buildings of observations

Conducting the survey of people in private homes is very difficult to organize. This is due to the natural reservation of occupants to have any intrusion into their private lives. Therefore, buildings selected in this field study are both residential and university buildings and the results from two types of buildings will be compared. The criterion for selecting buildings for the field study is as follows:

1 located in Bangkok either in a high population density zone or a low population density zone
2 in air-conditioned (A/C) and non-air-conditioned (naturally ventilated (N/V))buildings
3 types of buildings selected are grouped into students, staff and aged people categories.

Students: class-rooms, studios, libraries, Dormitories (bed rooms)
Staff: university offices
Aged people: private houses, dormitories (bed-rooms), common rooms

Thirty buildings were visited; 20 were residential buildings with 562 respondents and 10 were institutional buildings with 897 respondents.

2.4 The questionnaire

The perceived warmth of the environment depends on many factors. The main environmental factors are the air temperature, the temperature of the room surfaces, movement of the air and its humidity. Personal factors include the type of activity and the clothing. However, it may be assumed that the combined effect of the temperature of the air and the room surfaces is given sufficiently accurately by a globe thermometer and dry bulb temperature. It is assumed that at or near comfort conditions the humidity of the air has only a small effect on the perceived warmth [5]. Thus, room air temperature, air velocity, activity and clothing are the main variables to be considered in the questionnaires.

The questionnaire consists of 4 sections:

Section A: background information of respondent
Section B: building's characteristics
Section C: indoor and outdoor environment parameters
Section D: comfort vote (sensation voting).

Background information of the respondent included the age, gender, ethnicity, the clothing and type of activity before entering the room and while being in the room.

Building characteristics are the building's age and type of control of indoor environment (air conditioning or natural ventilation system). Building features such as height (number of floors), walls, roof material, window material and shading type are also included in questionnaire section B.

Indoor and outdoor environment parameters

Indoor environments are measured by:

1 air temperature (DBT) (TA) (˚C)
2 globe temperature (TG) (˚C)
3 relative humidity (RH) (%)
4 air velocity (v) (m/s)

Outdoor environment data during the survey are obtained from the Meteorological Department. They are:

1 ambient temperature (DBT) (TA) (˚C)
2 relative humidity (RH) (%)
3 air velocity (v) (m/s)
4 radiation(W/m^2)

The sensation voting scales chosen are ASHRAE, McIntyre [9] and air flow scale. The ASHRAE scale is the one used in most thermal comfort studies. It is a seven point scale (from -3 to +3) which has equal intervals between each point. A seven point scale is easy to remember and understand as it is symmetrical about the zero point.

The McIntyre [9] scale is a three-point scale: answer to the question “Would you like to have it warmer (1), no change (0) or colder (-1)”. It is used to identify how the respondent would ideally like to adjust the environment and is then compared with their response to ASHRAE scale, with which it would have an inverse relationship.

Another three-point scale specifically addressing perceptions of airflow conditions is also used. Its ranges from -3(much too still) to +3(much too breezy).

2.5 Time of observations

Bangkok has 3 distinct seasons in a year. To establish the effect of seasonal change for thermal comfort sensation, field studies were conducted in 3 seasons as follows:

1 Summer season is between 20 April 2002 to 30 April 2002
2 Rainy season is between 16 September 2002 to 23 September 2002
3 Winter season is between 13 January 2003 to 23 January 2003

The time of survey visits was between 8.30 am to 17.30 pm.

2.6 Observation of climatic environment

The dry bulb temperatures (TA) and Globe temperatures (TG) were measured by 2 channels of the Opus data logger. It is a battery operated instrument: one channel is connected to a temperature sensor (Thermocouple type k); and another channel was connected to the thermocouple type k inserted in to a 10 cm. diameter copper ball painted matt black. The dry bulb and Globe temperature can be read out from the Opus data logger reading screens.

Relative humidity (RH) was measured by the thermometer and hygrometer TESTO 635 with probe 0636.9769. Measuring range is 0-100%.

Air velocity (v) was measured by the hot wire anemometer sensor series EE65 combined with Opus200 data logger. Working range is 0 to 10 m/s).Two sets of each instrument were used, calibrated with each other as well as against instruments of the Bureau of Meteorology. Each instrument set was contained in or attached to a tools basket with a handle. The hot wire anemometer probe was detached from the tool basket but was connected by two meters of cord to the Opus200. All sensors were attached vertically to maximise exposure to the room air and far enough apart to minimise interference with each other.

2.7 Conducting the observations

The observers were divided into 2 groups. One group worked in air conditioned buildings; another group worked in naturally ventilated buildings. There were 3 observers in each group: one person obtained the thermal sensation of the respondent, while the other two members measured the climatic environment and noted the features of the building and filling in the form.

Completing the questionnaire

Only respondents who had been seated at the spot for at least 15 minutes were allowed to answer questionnaires A and D. The observer explained the project, and answered respondent questions as they arose from filling out the forms.

Measurements of thermal environment

Indoor environment was measured by the two observers at each respondent's location during the completion of the questionnaires. The tools basket was placed very close the area where the respondent was seated for at least 5 minutes. The hot wire anemometer probe was held at the respondent's torso level, as close to the respondent as decorum allowed (i.e. 0.5 meter at a minimum) on the side that intercepted the strongest discernable air flow impinging on the subject. The maximum value shown on the screen for the longest period of time was used as the velocity data. After 5 minutes all the parameters were read out and were added into section C of the form.

Before starting the survey, the features of the building were observed and entered into form B. Some photos of conducting the survey are shown in Figure 1.

Figure 1: Conducting the survey

3. RESULTS

Table 1 shows the summary of the respondent samples across the 3 seasons. Table 2 shows the summation of number of respondents and mean indoor temperature in 3 seasons.

Table 1: Summary of respondents' age samples for each season

Season	Students (18-24 yrs)	Staff (25-29 yrs)	Elderly (60-96 yrs)	Total
Summer	513	108	51	612
Rainy	160	103	39	302
Winter	251	120	15	386
			Total	1300

Table 2: Number of respondents and mean indoor conditions for each season

	winter		summer		rainy	
Control	A/C	N/V	A/C	N/V	A/C	N/V
Number of respondents	207	179	375	312	174	130
Mean indoor Temp. (° C)	23.8	27.6	24.5	31.2	26.0	29.8
Mean indoor air vel. (m/s)	0.25	0.47	0.22	0.74	0.15	0.32
Mean indoor RH (%)	47.1	51.9	60.4	65.6	54.9	71.4
Mean outdoor Temp. (° C)	29.9		33.05		30.55	

A/C = air-conditioned building
N/V = natural ventilation building

4. ANALYSIS OF RESULTS

4.1 Regression analysis

For this thermal comfort study a regression model is used to find the relationship between the ASHRAE scale votes as the dependent variable (response variable) and the variables that affect thermal comfort as the independent variables (predictor variables).

A linear combination of independent variables is achieved that maximises the multiple correlations (R) between independent variables and dependent variable.

The multiple regression coefficient is an index of how well the scores that are predicted from the linear combination correspond to the actual score of the dependent variable. The multiple regression coefficient and its square (R and R^2, respectively) assess the 'fit' of the regression equation to the data it describes.

The strength of relationship between dependent and independent variables can be indicated by the R and R^2 values as:

R and R^2 values for social sciences studies [10]

R	R^2	Social Sciences
.1 to .3	.01 to .09	small relationship
.3 to .5	.09 to .25	moderate
.5 to .7	.25 to .49	high
.7 +	.49 +	very high

In this study the computer-based statistical package SPSS10 for Windows was used to perform the regression analysis.

There are a number of different types of multiple regression analyses that can be used depending on the nature of the data. In this study 2 types of multiple regression analyses are used.

1 Standard or simultaneous (standard multiple regression)
2 Stepwise multiple regression

In standard multiple regression all the independent (or predictor) variables are entered into the equation simultaneously. Each independent variable is evaluated in terms of its predictive power, over and above that offered by all other independent variables [10].

In stepwise multiple regressions, the SPSS is provided with a list of independent variables and then allows the program to select which variables it will enter, and in which order they go into the equation, based on a set of statistical criteria [10].

4.2 Procedure of analysis

Multiple regression was performed between the ASHRAE scale and the independent variables to determine the strength of relationship between them.

The prediction between ASHRAE scale and independent variables shows that for every season TA and TG have the strongest relationships with ASHRAE scale with the values of .431 and .445, .657 and .645, .533 and .556 for winter, summer and rainy season. It is also shown that for all 3 seasons TA and TG have a very strong relationship with the values of .976, .972 and .965 respectively.

To produce a good regression model, when the 2 independent variables are highly correlated (r = .9 and above), one which is weaker correlated with the dependent variable has to be excluded. It appears that TA should be excluded for the winter and rainy seasons, for the summer season TG should be excluded [10].

It is decided to exclude TG from the regression model as TA data are easier to obtain and more available. The other reason is that, the summer season field study is more reliable as it has twice as many respondents than the winter and rainy seasons

When TG is excluded, other variables are entered, the program will select which variables will enter in which order they go into the equation. The results show that TA has the strongest relationship with the ASHRAE scale.

4.3 Neutral temperature

From the results of standard multiple regression and stepwise multiple regression, it is obvious that TA is shown as the best predictor of the ASHRAE thermal sensation. Table 3 summarises regression of mean ASHRAE scale response and TA through 3 seasons and all seasons.

Table 3: Regression of mean ASHRAE scale responses and Ta for season group

seasons	Type Of Control	(ASHRAE = 0) Tn ˚ C	R	R^2	N
winter	A/C	24.05	.589	.347	179
	N/V	25.24	.346	.133	207
summer	A/C	25.00	.670	.449	310
	N/V	28.00	.677	.458	372
rainy	A/C	25.95	.644	.415	130
	N/V	27.50	.624	.389	174
All seasons	A/C	24.40	.611	.373	619
	N/V	26.70	.691	.478	753

N = number of respondents

Results of neutral temperature (Tn) from regression analysis are reliable enough considering their R and R^2 values. Most of them have R values over 0.5 and R^2 over 0.25. These values are rating as high relationship between dependent and independent variables [10].

The results show a difference of Tn with season and type of buildings' control (A/C or N/V). The neutral temperature in summer for N/V buildings shows the highest value of 28˚C.

Neutral temperature for A/C buildings shows lower values than N/V buildings in all seasons. These observations are the same as the results from other thermal comfort field studies. This phenomenon supports the adaptive theory which may be due to occupants' acclimatisation to the cool indoor environment and expectation of lower temperature than in N/V buildings. The example of computer output charts are shown in Figure 2, 3 and 4,

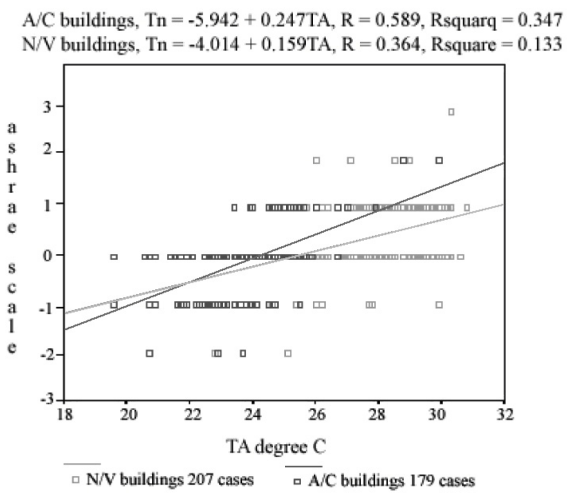

Figure 2 Neutral temperature for winter season.

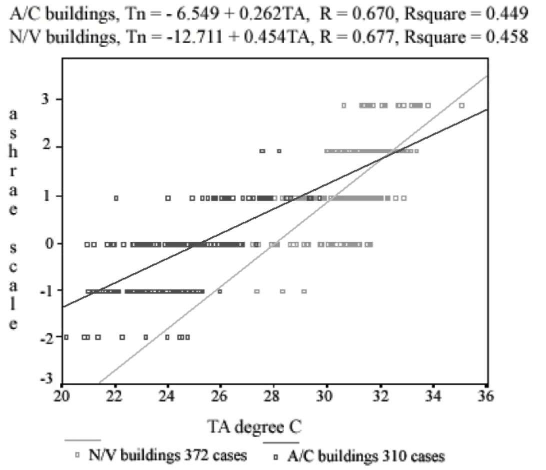

Figure 3 Neutral temperature for summer season.

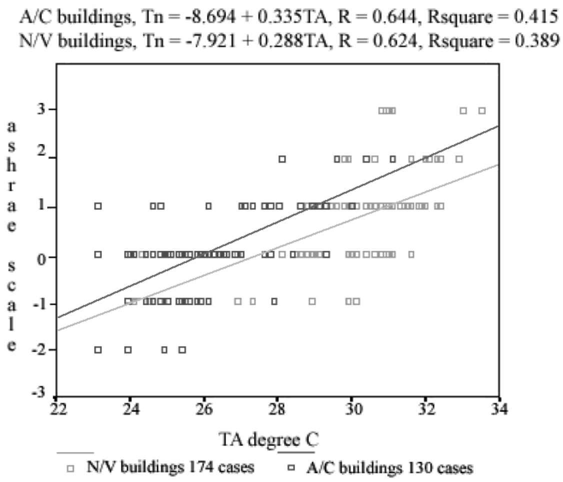

Figure 4 Neutral temperature for rainy season.

4.4 Discussion of results

In order to support the reliability of the Tn results in Table 4, the SPSS program were also used to perform the regression of mean ASHRAE scale and TA for different groups of samples in summer. They are gender, subject's age and buildings' age groups.

Table 4: Regression of mean ASHRAE scale responses and TA for gender group, age group and building age group in summer

		Tn ˚ C	R
Gender group	male	25.2	.83
	female	25.3	.84
Age group	15-24	25.4	.84
	25-59	24.6	.59
	60-90	27.3	.49
Bldg age group	1-10	25.6	.79
	11-20	25.8	.79
	21-30	24.7	.87
	31-50	25.4	.66

For gender groups, the results shows that Tn for males is 25.2˚C and for female is 25.3˚C which is considered as not different.

For age groups, the Tn values seem to be reliable by considering the R values but they may not be reliable to generalise the different of Tn in different age groups. The reasons are that while conducting the survey most of young group (students) were in N/V rooms, most of the middle group (office workers) were in A/C rooms and most of old group were in N/V rooms and there are only 50 samples for the old group. The Tn of young and middle-aged groups are taken as the same and the Tn of the 'old' group is higher than the young and middle groups.

For buildings' age groups, the results are not significantly different between new buildings of 1-10 years, 11-20 years and old buildings of 31-50 years with the Tn values of 25.6˚C, 25.8˚C and 25.4˚C respectively. Only buildings of 21-30 years have low Tn value of 24.7˚C which is about 1˚K different from the 3 groups. This may be due to the reason that, most of the samples in this group (about 60%) were in only one building which was an A/C building (library) and this building operated the indoor temperature around 21-22˚C all day. Therefore, it may be taken that there is no significant difference of Tn among the 4 building's age groups.

Table 5 are the cross tabulation of ASHRAE scale response and TA. It shows that most occupants in the air-conditioned rooms (163 in summer, 374 in all seasons) were more satisfied with the thermal condition of the rooms than for those in the natural ventilation rooms. Most of occupants in natural ventilation rooms (153 in summer, 297 in all seasons) voted as hot (2) for summer and rather hot (1) in all seasons. This observation is similar to Busch's (1992) [2] field study in Bangkok.

Table 5: Cross tabulation of ASHRAE scale response and TA for summer

Summer	ASHRAE scale							total
	-3	-2	-1	0	1	2	3	
A/C TA°C								
20.0		1						1
21.0		3	6	2				11
22.0		1	15	8	1			25
23.0		1	25	35				61
24.0		2	18	45	1			66
25.0		2	13	50	5			70
26.0			1	20	14			35
27.0				3	6			9
28.0					8	3		11
29.0					10			10
30.0					7			7
Total		10	78	163	52	3		306
N/V TA°C								
27.0			1	3				4
28.0			1	7	4			12
29.0			1	7	13			21
30.0				9	28	9		46
31.0				12	70	37	4	123
32.0				3	24	78	10	115
33.0					2	29	14	45
34.0							3	3
35.0							1	1
Total			3	41	141	153	32	370

4.5 Comparison between neutral temperature and other published results

Results from the field study are compared to other comfort studies in the South East Asian Region, which include Indonesia, Malaysia, Singapore and New Guinea. The neutral temperature of South East Asian subjects were found to be above 24˚C for A/C buildings and 28˚C and above for N/V buildings [7].

The present field study shows that, for all seasons the neutral temperature for Thai people in residential buildings in the A/C environment found to be 24.4˚C and in the N/V environment to be 26.7˚C. For only summer season, the neutral temperatures were slightly higher, 25 ˚C for A/C environment and 28 ˚C for N/V environment.

These results of neutral temperature during summer for N/V buildings of 28.0˚C agree well with the finding of Busch (1992) [2] for office workers in Bangkok, DeDear et al (1991) [3] for office workers in Singapore and Santosa (1988) [13] for residents in Indonesia. The neutral temperature value of Busch's field study is 28.5˚C, De Dear is 28.5˚C and Santosa finding is slightly lower with the value of 27.4˚C.

The values of neutral temperatures in an A/C environment also compare well with each other in these regions. A neutral temperature in A/C environment of Ismail and Barber [6] is 24.6˚C, De Dear [3] is 24.2˚C, Busch [2] is 24.5˚C and present study is 24.4˚C -25.0˚C. Thus it can be suggested that there is no significant different.

5. CONCLUSION

From the present field study the finding can be stated as follows:

1 This field study found the comfort temperatures for Thai people in residential buildings are 25.0˚C with the range of 22.5˚C to 27.5˚C (90% acceptability) for air-conditioned buildings and 28.0˚C with the range of 25.5˚C to 30.5˚C (90% acceptability) for natural ventilation buildings. These values are taken only from the field study during summer season. It is more reliable as it had larger samples than other seasons and summer is the most uncomfortable season of the year. Furthermore, Bangkok's climatic condition is very similar throughout the year.

2 Neutral temperatures were found to be different between building's controls (A/C or N/V) and age groups. Old people prefer higher temperatures than young.

3 The difference of neutral temperatures by building types (residential building or other), in this study it was found to be same as the difference in building's control (A/C or N/V). This is because residential buildings in the field study were mostly N/V and other buildings were A/C.

4 There was no difference found of neutral temperature by gender and by building's age groups.

5 The results confirm the ‘adaptability model’ and ‘acclimatization’.

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