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Thailand ventilation comfort chart

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Abstract

The paper presents a ventilation comfort chart that has been developed under Thailand climate and using Thai volunteers. 183 male and 105 female college-age subjects were exposed to different thermal conditions in order to investigate the effect of air velocity on thermal comfort in ventilated "non-conditioned" spaces. To this end, commercial electric fans were used to control the air velocity near the subjects. The air velocity varied between 0.2 and 3 m/s. Room conditions varied between 26°C and 36°C (D.B.T.) and 50–80% relative humidity. Thermal sensation vote was recorded through a questionnaire. The Predicted Mean Vote was used to determine the indoor neutral temperature. This developed chart could be used to design ventilation system for offices and classrooms. © 2000 Elsevier Science S.A. All rights reserved.

Keywords: Thermal comfort; Air velocity; Relative humidity; Temperature; Classroom building

1. Introduction

There is a large body of literature about thermal comfort [1–3] — and a complete review is out of the space of this paper. Worldwide thermal comfort is recognized not as an exact concept, nor it occurs at an exact temperature. Apart from common "quantifiable" factors such as temperature and humidity, air velocity, activity, etc., the state of comfort depends on a wide range of factors which are "not quantifiable", such as mental states, habits, education, etc. Thus, comfort preferences of people in different locations vary in terms of acclimatization to a particular climate. The long-term several generation experience of a humid and warmer climate may result to a tolerance of the people of that environment to higher temperatures as compared with people in colder regions. This has been demonstrated in Ref. [4] where the Bangladesh comfort zone was larger than that of ASHRAE in covering higher air temperature and higher velocity. A study conducted in Japan [5] has showed that Fanger's thermal model was not adequate for predicting thermal comfort under hot and humid climate in naturally ventilated space or in places where fans have to be used. A recent study conducted in Pakistan [6] — where indoor design temperature for building, as well as in Thailand, is based on American standards — concluded that the ASHRAE standard does not apply in practice as the climatic variation is very large and people perception of comfort is influenced by habits and varies between regions.

In Thailand, two studies [7,8] conducted on thermal comfort showed that the thermal acceptability exists over a broad range of temperatures, pushing the summer comfort outward by a few degrees celsius (4°C [7], 5.5°C [8]). Although both air-conditioned and non-air-conditioned were included, surveys were performed for a limited range of outdoor conditions (30°C, 85% RH) and indoor air velocity (mean values: 0.21 m/s (AC), 0.17 m/s (NV) [8], 0.13 m/s (AC), 0.33 m/s (NV) [7]). The analysis of data was mainly done for finding out the neutral temperature for the corresponding season.

On the other hand, on the face of today's energy–economic crises, Thailand is looking for solutions to reduce electricity demand in both commercial and industrial sectors. The commercial sector's need for air-conditioners leads to a major demand for electricity. Likewise today's trend is to turn on air-conditioners year-round, such as in Bangkok. However, the reading on the monthly daily

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average mean dry bulb temperature and relative humidity for 15 years in Bangkok, plotted on Fig. 1 at two times of the day (7 a.m. and 1 p.m.), gives us the following:

- –The monthly lines on the chart never cross the ASHRAE comfort zone; it means that the local conditions always require design and fabric devices, so as to achieve comfort.
- –One can observe that evaporative cooling could not be useful to achieve comfort, the climate being already humid, and it would not work well enough to be efficient.
- –The monthly mean daily temperature does not exceed the human body core temperature (37°C), except for a few hours during the summer season (March–May). This indicated that air ventilation, below 34°C, air movement might be one of the most useful and least expensive methods to provide a comfortable indoor climate.

The impact of air movement on comfort sensation has been studied continuously [9–12]. Ref. [13] outlines the current state of this discussion and provides a comprehensive list of research investigating the effect of air movement on thermal comfort and the development of air velocity limits. In our knowledge, there were no studies on this topic in Thailand.

Therefore, the aim of this research work was to study the potential of providing thermal comfort for Thai people by using commercial electric fans instead of air-conditioners and to develop a ventilation comfort chart for

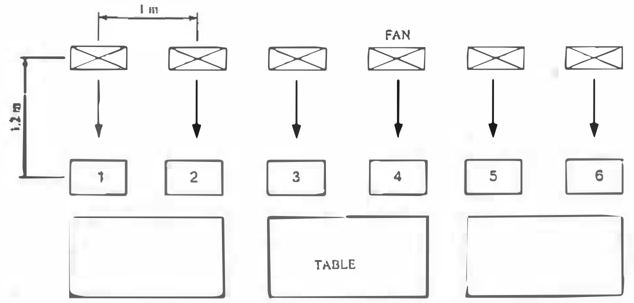

Fig. 2. Schematic representation of position of subjects.

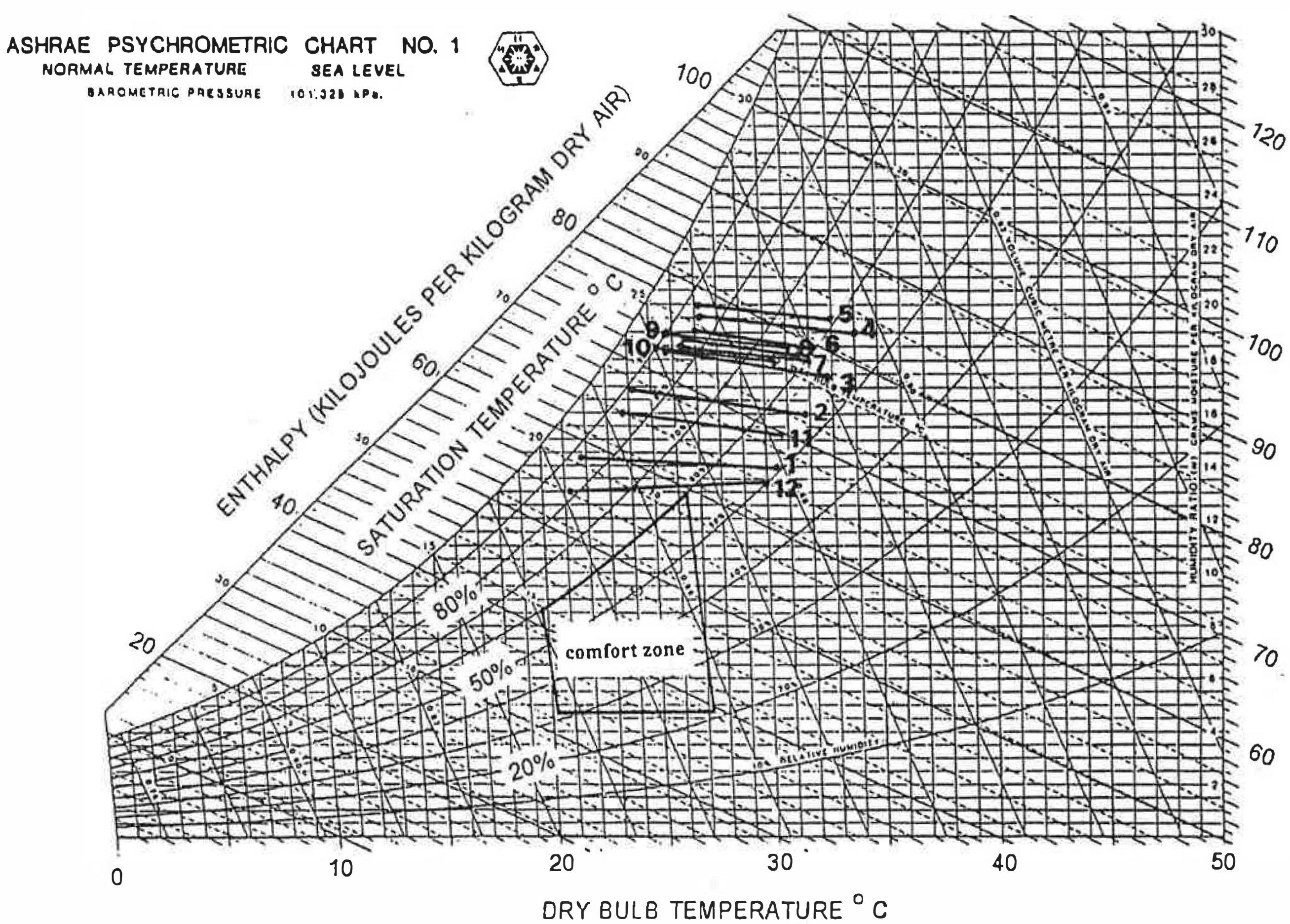

Fig. 1. Monthly daily mean of Bangkok (14°N) climatic conditions at two times of the day and ASHRAE recommended comfort zone.

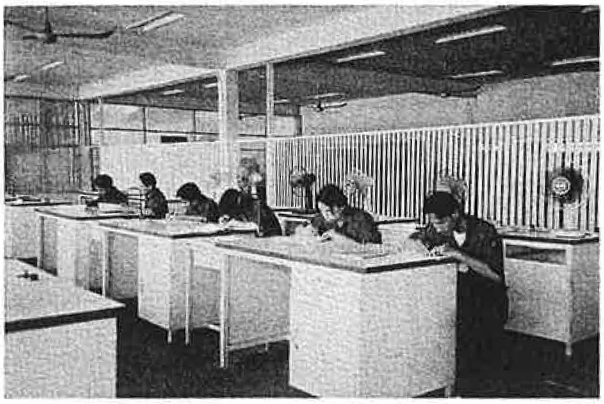

Fig. 3. Position of subjects setting in the experiment.

Table 2
Thermal sensation scales

Fanger		Rohles and Nevins		Experiment	
Scale	Meaning	Scale	Meaning	Scale	Meaning
−3	Cold	−4	Very cold	−2	Cool
−2	Cool	−3	Cold	−1	Slightly Cool
−1	Slightly Cool	−2	Cool	0	Neutral
0	Neutral	−1	Slightly Cool	1	Slightly Warm
1	Slightly Warm	0	Neutral	2	Warm
2	Warm	1	Slightly Warm	3	Hot
3	Hot	2	Warm	4	Very Hot
		3	Hot		
		4	Very Hot		
		5	Painful		

Thailand that could be used for designing ventilating system of non-conditioned buildings.

2. Methodology

The experiments were performed in a classroom without air-conditioner at Mahanakorn University of Technology [14]. The total number of college-age subjects (19.3–22 years old) in the experiment were 288 (183 males and 105 females). All of them wore normal cloths (0.54–0.55 clo) under sedentary activity (1 met). Six subjects per group were in each experiment. The arrangement was shown in Figs. 2 and 3. Among the available commercial electric fans (fixed ceiling fan, oscillating ceiling fan, wall fan, desk fan), desk fans were chosen. In fact, a preliminary survey was conducted among volunteers about the fan which they would prefer with regard to the type of activity (classroom). It was concluded that desk or wall fans installed at the rear of subjects are the most suitable as they would not disturb the subjects, such as when the air flows onward the subject. Thus, six electric fans were installed behind the volunteers. Speed controllers allowed us to adjust the air velocity at six levels: 0.2, 0.5, 1, 1.5, 2 and 3 m/s. The environmental conditions were summarized in Table 1. During experiments, air velocity was increased gradually from 0.2 to 3 m/s. For each air velocity, the volunteers were exposed for a time that was determined from preliminary tests on average thermal response times, which is discussed in Section 3.1. The duration of each experiment was about 40 min including the first 10 min for acclimatization of subjects at the beginning of the test.

Thermal sensations votes were recorded through a questionnaire. The thermal sensation scale of this experiment was selected based on common scales Fanger [1] and Rohles and Navins reported in Ref. [15], excluding the extreme scales: i.e., the numbers −3, −4, and 5, as shown in Table 2. In fact, under ambient conditions of Bangkok, people who lived in houses without air-conditioners hardly feel cold but often feel hot/very hot.

Table 1
Experimental indoor conditions data

Period	December 1997–August 1998
Temperature (°C)	27.5–35.4
Relative humidity	50–78%

Then, analysis of the 288 surveys conducted here was done to determine the neutral temperature corresponding to the prevailing indoor conditions and air velocity. Finally, a ventilation comfort chart was plotted. It allows determination of the required air velocity that would give comfort sensation under given indoor conditions.

3. Results and discussion

3.1. Thermal response time

Although some procedures for comfort survey are known, to the best of our knowledge, there is no procedure for air movement impact on comfort sensation of Thai subjects. Thus, a preliminary study was conducted to determine the thermal response time; i.e. the required time to express steady sensation comfort of subjects under given indoor conditions. Then, an average time which was used to record the thermal sensation vote of volunteers during all surveys was calculated (Table 3).

It should be pointed out that the higher the air velocity is, the less the thermal response time will be, because heat transfer from the human body is faster.

Table 3
Average thermal response time

Air velocity (m/s)	Average time (min)	Room conditions
0.2	8.66	31.7°C, 53.5%RH
0.5	7.33	
1	5.67	
1.5	5.33	
2	4.66	33.2°C, 67.5%RH
3	4.33	

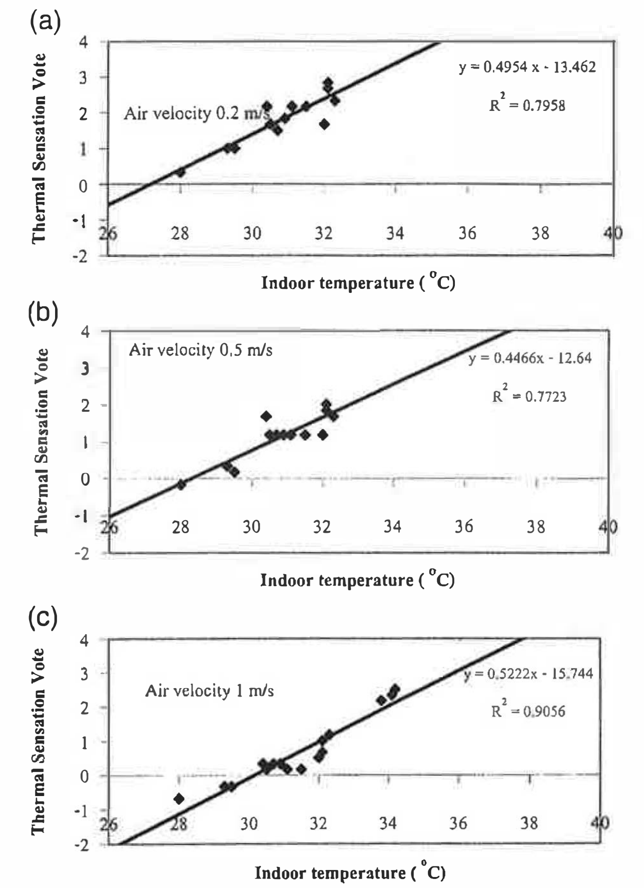

Fig. 4. Thermal sensation vote vs. indoor temperature for 60% < RH ≤ 70%.

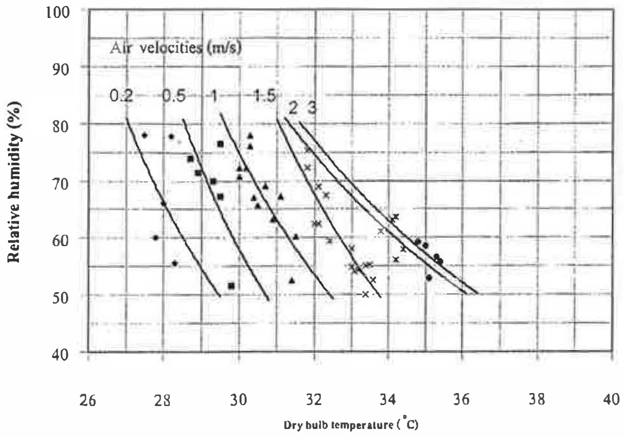

Fig. 5. Thailand ventilation comfort chart.

3.2. The effect of air velocity on neutral temperature

Some examples of the relationship between mean thermal sensation vote of subjects and indoor temperature at a given relative humidity and air velocity are shown in Fig. 4. The points on the graphs represent the mean of thermal sensation vote of one group of six subjects under the room temperature at that time. The graphs could be represented by simple correlationships using a simple linear regression technique. The corresponding neutral temperature is then the temperature at which the regression line crosses the x-axis.

Fig. 4a shows that at air velocity of 0.2 m/s, the mean neutral temperature would be 27.17°C. When air velocity increased, Fig. 4b, the neutral temperature increased to 28.30°C and so on. In fact, as expected, it was found that the higher the air velocity, the higher the neutral temperature.

When compared to results from previous research in Thailand [7,8] with relatively similar indoor conditions, the results are in fairly good agreement. Results from Refs. [7] and [8] showed that the neutral temperature of the whole sample was in the range of 27–31°C, with air velocities varying between 0.1 and 1.68 m/s. That indicates good

Table 4
Predicted Mean Vote equations and neutral temperature
PMV = Predicted Mean Vote
Ti = Indoor temperature, °C

Relative humidity	Air velocity (m/s)	PMV equation	Neutral temperature (°C)
50% ≤ RH ≤ 60%	0.2	PMV = 0.4576 Ti–12.817	28.01
	0.5	PMV = 0.4121 Ti–11.873	28.81
	1	PMV = 0.4016 Ti–12.412	30.56
	1.5	PMV = 0.4114 Ti–13.363	32.48
60% < RH ≤ 70%	0.2	PMV = 0.4954 Ti–13.462	27.17
	0.5	PMV = 0.4466 Ti–12.640	28.30
	1	PMV = 0.5222 Ti–15.744	30.15
	1.5	PMV = 0.3991 Ti–12.555	31.46
70% < RH ≤ 80%	0.2	PMV = 0.5753 Ti–15.651	27.20
	0.5	PMV = 0.4793 Ti–13.560	28.29
	1	PMV = 0.3596 Ti–10.885	30.27
	1.5	PMV = 0.3587 Ti–11.207	31.24
50% < RH ≤ 80%	2	PMV = 0.5308 Ti–17.767	33.47
	3	PMV = 0.2031 Ti–7.2158	35.53

Table 5
Number of subjects which voted "Neutral"

Air velocity (m/s)	Number of all subjects	Number of subjects which vote neutral
0.2	30	26
0.5	36	27
1	72	53
1.5	90	71
2	30	23
3	30	26
Total	288	226
Percentage	100	78.47

accuracy of the methodology used here. It should be recognized that the two studies were undertaken to satisfy different objectives and, therefore, the comparison is not exact; however, comparison was made "qualitatively". A complete analysis yields 14 PMV equations with 14 neutral temperatures as shown in Table 4.

3.3. Ventilation comfort chart

Based on above results, a ventilation comfort chart was plotted as shown in Fig. 5. The percentage of subjects who voted neutrally is about 78.4% (Table 5), indicating, therefore, good acceptability. This chart is valid under the conditions that were used here: air velocity from 0.2 to 3 m/s, relative humidity of 50–80% and maximum air temperature of about 36.3°C.

It can be seen that the thermal acceptability is a few degrees celsius beyond the common comfort zone defined by ASHRAE and ISO 7730 for the warm boundary of summer comfort. This demonstrates, therefore, that Thai people have a tolerance to higher temperature. For example, at about 28°C, a low air velocity (> 0.2 m/s) is sufficient to provide acceptable comfort. In addition, as the air flows from the rear side of volunteers, air motion would not disturb the subject. Above 34°C, higher air velocity (above 3 m/s) is required that might limit the benefit of ventilation as the noise caused by fans becomes important and would probably disturb mental work. However, such indoor conditions would only occur during summer vacation. Therefore, tropical classroom comfort could be satisfied during the whole scholar year by air ventilation.

4. Conclusions

Based on common studies of thermal comfort, a field survey was conducted for "controlled air velocity of a classroom building". Analysis of the data of thermal sensation votes based on the Predicted Mean Vote method permits us to develop a ventilation comfort chart under Bangkok ambient condition. Its main advantage might be summarized as follows: though developed for non-air-conditioned building, this chart can be used for designing air ventilation system for both non- and air-conditioned buildings within the limit of air velocity not over 3 m/s, and indoor conditions used here, namely, maximum air temperature of about 36.3°C and relative humidity of 50–80%. In the case of air-conditioned building, increasing indoor air velocity — not over 1 m/s — would allow to increase the indoor temperature (the relative humidity being relatively constant at around 50%). This would decrease the electricity consumption of the air-condition unit. When no air-condition unit is used, the electricity consumption of fans — even with a big number of units, depending on room size — is still small compared to that of air-conditioned buildings, leading to a considerable energy saving while providing reasonable indoor conditions.

Finally, this chart could also be used by surrounding countries of Thailand which not only have similar ambient conditions but also have similar social and traditional norms.

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