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A tale of two populations: thermal comfort in air-conditioned and naturally ventilated offices in Thailand

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Abstract

A field study of thermal comfort was conducted in Bangkok, Thailand, in which over 1100 office workers responded to a questionnaire while simultaneous physical measurements were taken. In this study we explore whether there is justification for adopting a comfort standard that differs from those developed for office workers accustomed to more temperate climates. Both air-conditioned and naturally ventilated offices were surveyed. Participants cast votes on standard subjective thermal rating scales and these were correlated with temperature indices that variously account for the thermal impacts of humidity, radiant temperature, air velocity, and clothing levels. Following the criteria used in developing a widely adopted thermal comfort standard, it was found that the upper temperature bound for a Thai comfort standard, instead of being the currently accepted level of 26.1 °C, should be as high as 31 °C for office workers accustomed to naturally ventilated spaces, and as high as 28 °C for those accustomed to air-conditioning. Comparing the responses from the naturally ventilated buildings with both those from the air-conditioned buildings and from studies conducted in the temperate regions provides convincing evidence of acclimatization. These and other findings of this study suggest that interior spaces in Thailand can be cooled to a far lesser degree without sacrificing comfort.

Introduction

As the Third World traverses the path of modernization, it appears almost inevitable that buildings will increasingly be air-conditioned to meet the higher standards of amenity that "modernity" implies. One need only travel to the burgeoning cities of the tropics to witness the transformation from the vernacular, open designs utilizing natural techniques for cooling, to closed-box, conditioned architecture. Accepting for the moment that this particular expression of the development process will continue, and recognizing that furnishing air-conditioning to buildings requires significant private and public investment, ongoing costs, and environmental externalities, it behooves us to consider ways to minimize the financial burden.

At the root of air-conditioning use is the yearning for a higher degree of comfort. Air-conditioning design and operation are based upon guidelines developed through thermal comfort research conducted on subjects from temperate climates. These guidelines are closely followed the world over, from climates temperate to tropical.

In this study we explore the question of whether or not there is justification for a different standard of thermal comfort for people accustomed to a climate that is radically different from the temperate bases of comfort guidelines. We do this by assessing the thermal comfort responses of two populations in hot and humid Bangkok, Thailand: those who work in air-conditioned offices and those who work in non-conditioned or naturally ventilated buildings. These two populations give us a wide range of thermal experience in the Thai office, and provide a basis for comparison that can shed light on energy conservation opportunities.

Methods

In this Section we describe the buildings and how we chose them, followed by our methods for conducting the field survey and carrying out the analysis.

Building selection

The criteria for selecting buildings for the field study were as follows:

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- located in Bangkok, the capital city of Thailand, where the majority of commercial buildings are;
- modern buildings not more than ten years old;
- both air-conditioned (AC) and naturally ventilated (NV) buildings;
- regular office desk work the primary activity of the building occupants;
- a range of ages and both sexes represented in office workers.

The two air-conditioned buildings are of modern high-rise design, one a head office for a bank, the other a multiple-client building. The two naturally ventilated buildings are contemporary medium-rise government buildings housing ministerial and departmental offices. All buildings are located within ten kilometers of one another in downtown Bangkok.

Data collection

Thailand experiences three distinct seasons in a year. The studies reported in this paper were carried out in each of two seasons: during the hot season (in April) and the wet season (in July) of 1988. (The third season is the cool season, which was not as relevant to a study of cooling.) Each of the four study buildings was visited in both seasons. Data were typically collected at each building over one work-week per season.

The questionnaire consisted of a section of subjective ratings on a variety of thermal scales, followed by a section on recent food and beverage consumption, separate clothing lists for men and women, and concluded with a section on demographic factors. Subjective ratings employed the seven-point ASHRAE Thermal Sensation Scale shown in Fig. 1. Respondents were asked to mark the scale at any one of the seven points or the mid-points in between them (i.e., at any "tick mark"). The respondents were also asked the question, "I would like to be ..... warmer (1), no change (0), cooler(−1)", otherwise known as the three-point McIntyre Thermal Preference Scale. Two further seven-point scales specifically addressing perceptions of airflow and humidity conditions were also used. The questionnaire was translated into the Thai language from English and scrutinized for accuracy and cultural appropriateness by Thai social scientists with facility in both languages and experience in human subject surveys*.

The measured physical quantities were dry-bulb temperature, relative humidity, globe temperature, and air velocity. The globe thermometer was fashioned from a thermister and a 38-mm-diameter ping-pong ball painted flat grey. The dry-bulb thermister was shielded by a cylinder of reflective foil. Air velocity was measured with a hot-film anemometer. All readings were gathered using a datalogger that

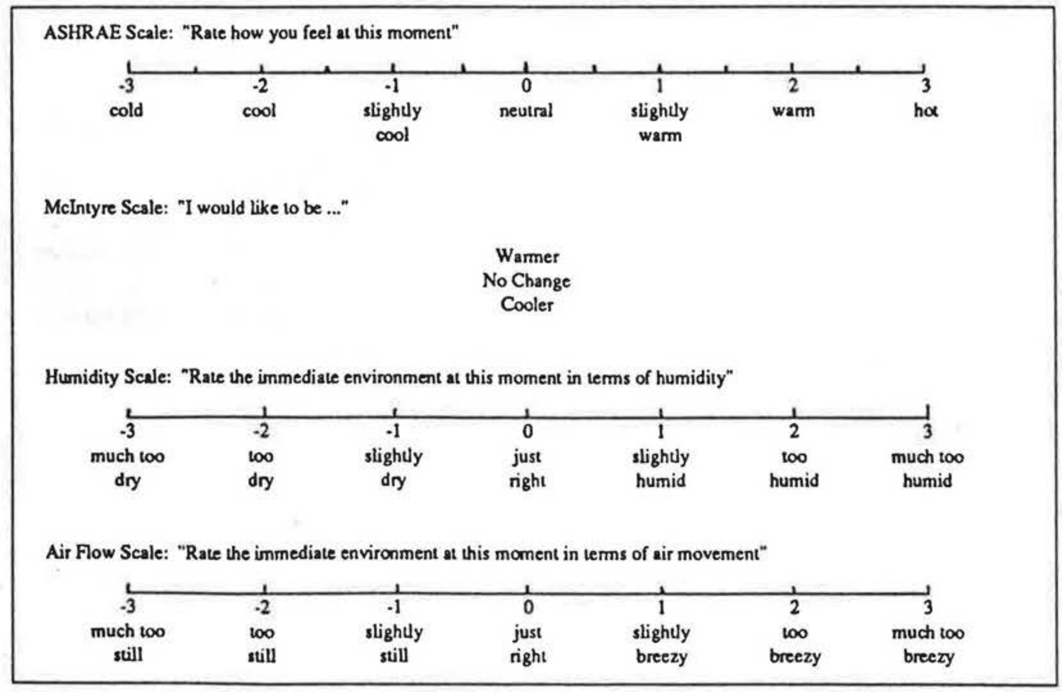

Fig. 1. Subjective rating scales.

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*While the translations were, by all accounts, accurately rendered, there was no rigorous validation of the rating scales in Thai nor is the author aware of any previous attempts to cross-culturally verify them. The use of the translated scales in this analysis is predicated on a common interpretation across cultures.

stored ten-second readings on magnetic tape. The datalogger, tape recorder, and battery (for the hot-film anemometer) were all contained within, and the temperature and humidity sensors were attached to, a wooden box with a handle similar in size and shape to a standard tool box (see Fig. 2). The hot-film anemometer was detached from the wooden box but connected by a two-meter cord. As is evident from Fig. 2, the sensors were attached vertically to maximize exposure to room air and far enough apart to minimize interference with each other. Data for outdoor weather conditions were gathered from measurements made in the city center by the Royal Thai Meteorological Department.

Conduct of the survey

Teams of two or three typically carried out the survey, with one member taking the physical measurements and one or two handing out and collecting the questionnaires. The latter would approach prospective respondents and ask if they had been seated at that spot for at least 15 minutes; those who replied affirmatively received the questionnaire, the others did not. The questionnaire came with a cover letter explaining the project and the auspices under which it was being carried out, along with general directions for answering the questions. Confidentiality was confirmed and disclosure of respondent's name was optional. Participation by any individual was solicited only once per season, but there was no corresponding effort to exclude people from participating in both seasons. Survey teams sought the participation from a roughly equal proportion of men and women in a range of age and job positions and, to the extent possible, those from different zones and floors of each building.

Measurements of the thermal environment were taken at each workstation following, or in some cases during, the completion of the questionnaire, but usually within five minutes of one another. The wooden box was placed on or very near the desk where the respondent was seated for at least one minute prior to starting a data sweep. A unique code number for each response was entered into the datalogger and also written on the questionnaire, along with the starting time of the data sweep to assure proper matching of data sets later. The hot-film anemometer wand was held at the subject's torso level, as close to the respondent as decorum allowed (i.e., 0.5 m at a minimum) on the side that intercepted the strongest discernible airflow impinging on the subject. A tell-tale made of thread was used to determine airflow direction. After four minutes of data collection, the wooden box was shifted to the next workstation. Care was taken to allow the equipment to equilibrate when moving to zones with different temperatures.

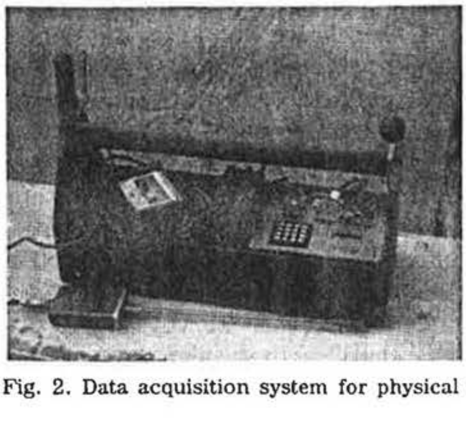

Fig. 2. Data acquisition system for physical measurements.

Assumptions and calculations

Questionnaire data were numerically coded to facilitate statistical analysis. Individual clothing articles indicated in the survey responses were converted into their respective thermal insulation values (I_{comp}) in units of clo (1 clo = 0.155 m$^{2\circ}$C/W) as tabulated by McIntyre [1]. The overall clo value for each subject's entire clothing ensemble was then determined using the following empirical formulae, also from McIntyre [1],

$$I_{\text{clo, men}} = 0.113 + 0.727\Sigma I_{\text{comp}}$$
$$I_{\text{clo, women}} = 0.05 + 0.77\Sigma I_{\text{comp}} \qquad (1)$$

Metabolic heat production was not directly measured, but since respondents were carefully prescreened to have been seated for at least 15 minutes, their metabolic rate was assumed to be 1.1 met (1 met = 58 W/m^2), which is the typical level given for light office activities [2]. Later computation of various comfort indices required determining the body surface area (A_{Du}) of each subject in square meters based on their reported weight (W) and height (H) (in kilograms and meters, respectively) using the Dubois formula [1],

$$A_{\text{Du}} = 0.202W^{0.425}\text{H}^{0.725} \qquad (2)$$

Mean radiant temperature (MRT) was calculated as prescribed in the 1984 ASHRAE Systems [3]. A program adapted from the Gagge two-node model [4] was used for calculating two environmental indices that are based on analysis [5] of the thermoregulatory response of the body to thermal stress (described in the next Section).

Results

Profile of the sample

The total sample of responses numbered 1146 drawn from office workers in four buildings[*] during each of two seasons. Of these, 669 were women and 476 were men. Six hundred responses were obtained in the hot season and 546 in the wet season. Nobody was surveyed more than once per season, but some portion of the respondents participated in the survey in both seasons[†]. Two-thirds of the sample were from the air-conditioned buildings (770) while the rest (376) were taken from naturally ventilated buildings. The age of the sample ranges from 18 to 75 years and has a mean of 32. Respondents from the AC and NV buildings show a similar age distribution though the former tend towards a slightly younger age.

The distribution of measured physical data by building type is shown in Table 1. Clo values from the AC buildings average 0.56 clo whereas from the NV buildings the average was 0.49 clo. The average Dubois body surface area (not shown in Table 1) for the entire Thai sample was 1.56 m^2 with a standard deviation of 0.17 m^2. Air temperatures ranged from a low of 19.5 °C in an air-conditioned building to a high of 34.2 °C in a naturally ventilated building, averaging around 26 °C for the sample with little difference between the hot and wet seasons. Figure 3 shows the distributions of dry bulb temperatures measured in the two buildings types. Vapor pressures averaged 16.9 Torr, again with little seasonality. Air-conditioned buildings had an average air velocity of 0.13 m/s while naturally ventilated buildings experienced higher airflows of 0.33 m/s on average. Because the latter buildings also utilized local fans, air velocities at the workstation were recorded as high as 2.25 m/s.

From these data we calculated the ASHRAE effective temperature (ET*), defined as that temperature at 50% relative humidity, and with mean radiant temperature equal to air temperature, that would produce the same thermal sensation as the actual environment. In other words, ET* normalizes temperatures for humidity and radiation thereby facilitating comparisons of various parameters with a single index. The resultant ET* averaged 27.5 °C for the entire sample. Figure 4 is a relative frequency distribution of ET* disaggregated by building type. The bi-modal separation of the data between air-conditioned and naturally ventilated buildings is clearly evident.

TABLE 1. Distribution of physical data

	Air-conditioned	Naturally ventilated
Sample size	770	376
Clothing (clo)		
average	0.56	0.49
standard deviation	0.12	0.10
minimum	0.24	0.24
maximum	1.19	0.72
Air temperature (°C)		
average	23.7	30.8
standard deviation	1.6	1.8
minimum	19.5	23.5
maximum	31.3	34.2
Vapor pressure (Torr)		
average	13.2	24.3
standard deviation	2.7	1.6
minimum	6.9	7.6
maximum	26.1	28.4
Air velocity (m/s)		
average	0.13	0.33
standard deviation	0.04	0.27
minimum	0.09	0.09
maximum	0.88	2.25
ET* (°C)		
average	24.7	33.0
standard deviation	1.8	1.6
minimum	20.5	24.0
maximum	34.0	36.0
SET* (°C)		
average	24.3	31.5
standard deviation	2.0	2.1
minimum	18.1	24.4
maximum	34.3	35.4

The standard effective temperature (SET*) is an extension of ET* in that it normalizes for air velocity as well as the two personal variables, clothing insulation and metabolic rate. Standard clothing insulation values are based on metabolic rate. Thus, SET* is defined as the value of an isothermal enclosure with radiant temperature equal to the air temperature, at 50% relative humidity, and air velocity of 0.1 m/s, in which a person with standard clothing for the actual activity level would have the same heat loss at the same mean skin temperature and the same skin wettedness as he or she does in the actual environment with the actual clothing insulation after one hour of exposure. Figure 5 depicts the relative frequency distribution of SET* by building type.

Since respondents in this survey were prescreened for "standard" activity levels (seated for at least 15 minutes at a desk), SET* differs from

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[*] One additional building served in a single-day pilot study in the hot season and the 25 responses from that building are included in the analysis.

[†] For reasons of confidentiality, participant names were not tracked and therefore an exact figure of multiple-season respondents cannot be calculated.

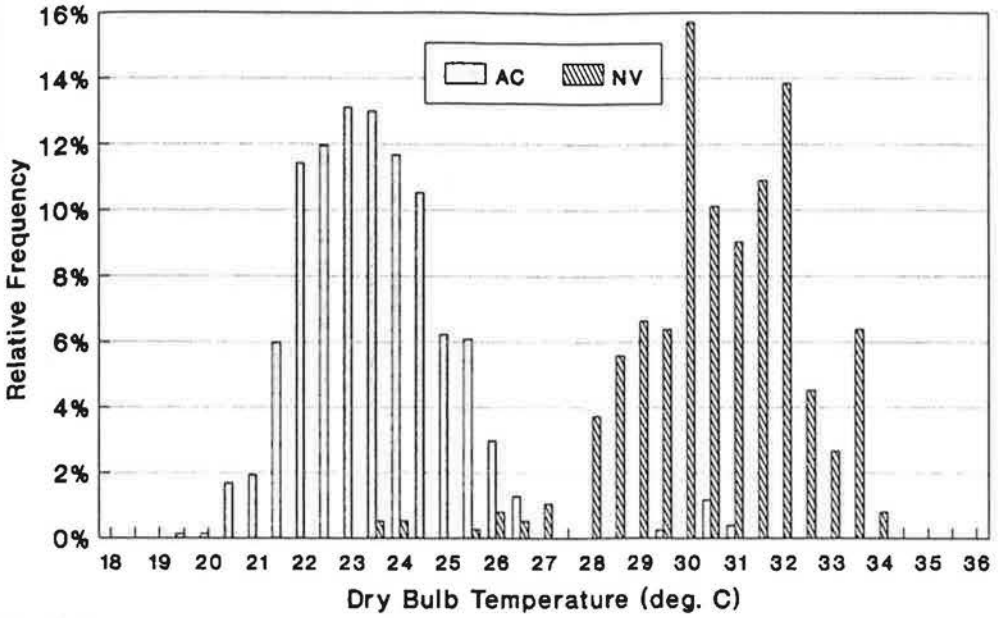

Fig. 3. Temperature.

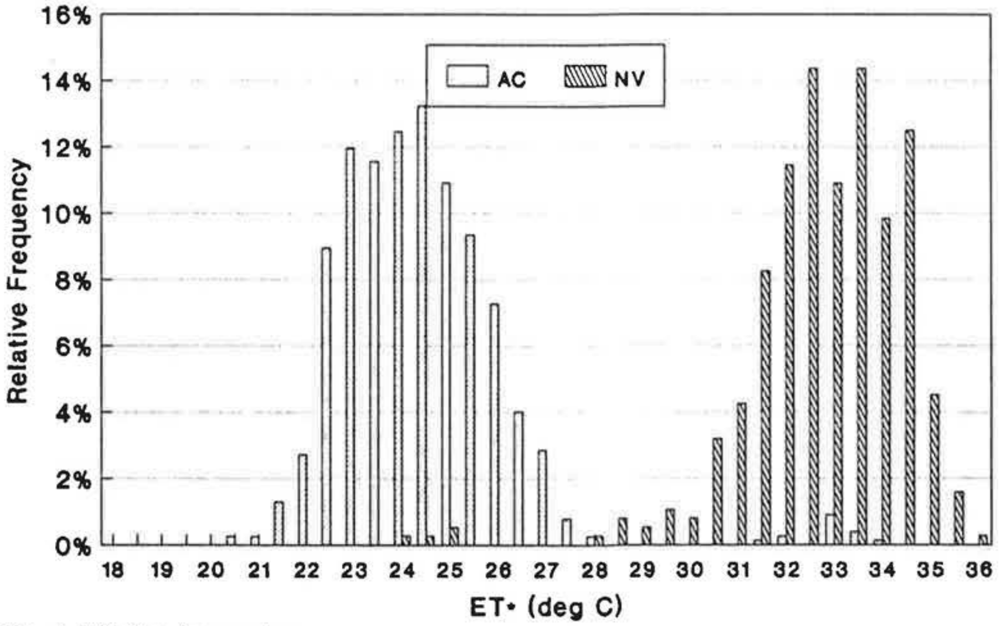

Fig. 4. Effective temperature.

ET* due to air velocities and non-standard clo levels only. Figure 6 depicts the distribution of clo values found in the two building types. Clothing insulation levels were generally lower in the NV buildings by an average 0.07 clo units (see Table 1). This result also confirms our qualitative observation of differing standards for office attire between the building types, in which the NV buildings were occupied solely by government civil servants, and the AC buildings by private sector workers. In Thailand, the business sector has adopted Western formal dress in conforming to international norms, while civil servants tend to wear more traditional Thai clothing ensembles or dress that would be considered more informal than that of the private sector.

Air speed, the other factor contributing to the difference in the sample's calculated SET* and ET* indices, was likewise different between the two building types. Figure 7 shows a relative frequency plot of air movement at different velocities. While the overwhelming majority (i.e., greater than 90%) of measurements in the AC buildings registered air velocities around 0.1 m/s, in the NV buildings air velocities were much more widely distributed and