Review of fan-use rates in field studies and their effects on thermal comfort, energy conservation, and human productivity

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Abstract: This paper is a literature review of field studies on fan-use rates and their effects on thermal comfort, energy conservation, and human productivity. In the assessed literature, fans are more popular in Asia, and more used in mixed-mode (MM) and naturally ventilated (NV) buildings than in air-conditioned (AC) buildings. On the basis of collected fan-use models, probit regression models of fan-use rates and ambient environments were obtained and indicate that the essential trigger of fan-use is a warm environment rather than building types. This result helps us to understand the control behaviors and comfort requirements of occupants. Also, fans could provide benefits in three aspects: widening neutral temperatures, saving energy, and improving occupants' productivity. First, using fans in buildings elevates the *neutral* temperature and the *upper limit* of neutral zone (0.5 thermal sensation scale) averages by about 3 K in ranges from 25.7°C to 28.7°C and 27.5°C to 30.7°C, respectively. Second, fan-use reduces AC-use rates in MM buildings in summer. The regression models based on the collected AC-use rate models illustrate that, on average, AC-use is expected to be reduced by about 15% in summer when fans are used. Third, providing occupants access to fans could improve occupants' productivity. Based on the limited data available, a 3-K temperature extension is achieved by fans ensuring productivity not decreasing. This review could shed some light on the extension of the neutral temperature range, predictions of MM buildings' energy consumptions, and methods to enhance productivity. Additionally, this review suggests some valuable directions for future research on fans.

Keywords: Fans; Thermal comfort; Energy conservation; Productivity; Review of field studies.

Nomenclature

AC	air-conditioned
AC-use	air-conditioning-use
CEP	corrective-efficiency-to-power (W/K)
CP	corrective power (K)
MM	mixed-mode
NV	naturally-ventilated
p_{AC}	AC-use rate (%)
p_{fan}	fan-use rate (%)

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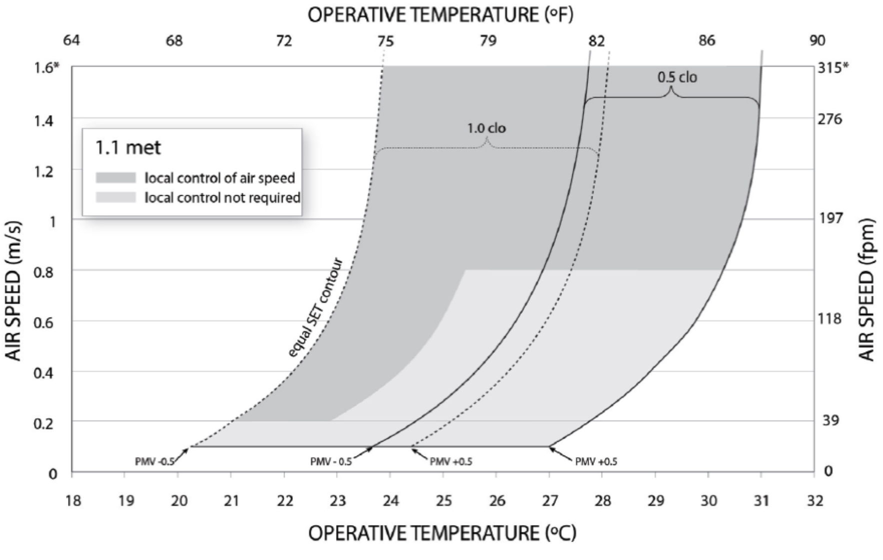
https://escholarship.org/uc/item/7hx9338z

PCS	personal comfort system
PMV	predicted mean vote
T_{in}	indoor temperature (°C)
T_{out}	outdoor temperature (°C)
TSV	thermal sensation vote

1. Introduction

1.1 Background

A comfortable environment in buildings is essential for occupants' health, well-being, and work. In 1970s, Fanger established the predicted mean vote (PMV) model to predict human thermal sensations [1]. On the basis of this model, two comfort zones of indoor environments were shown in ASHRAE Standard 55 for winter and summer, respectively [2]. These zones are for occupants exposed to uniform environments with still air. Later on, ASHRAE Standard 55 [2] provided new information (see Fig. 1) on elevated air movement for comfort in warm ambient temperatures.



*There is no upper limit to air speed when occupants have local control.

Fig. 1. Acceptable ranges of operative temperatures and average airspeeds for the 1.0 and 0.5 clo comfort zones [2].

Using fans is an easy and practical way to produce high airspeeds and improve the thermal comfort of occupants in warm environments [3]. There are various types of fans, such as desk fans [4, 5], ceiling fans [6], floor fans [7], seat fans [8, 9], and even, clothing fans [10].

Many laboratory studies have evaluated the comfort performance of fans in warm environments. He et al. [4] used desk fans as supplementary cooling for radiant cooled ceilings and found that desk fans made subjects feel neutral at warm ambient temperatures up to 30°C. Similar results were found in Zhai et al.'s lab tests with 16 subjects [7] and Huang et al.'s lab study with 30 subjects [11]. Zhai et al. [7] confirmed that thermal comfort could be maintained up to 30°C with personally controlled air movement. Huang et al. [11] found that the comfortable temperature range could be relaxed to 28°C-32°C with frontal desk fans. Yang et al.'s lab tests [12] with 32 subjects found that individually-controlled ceiling fans could improve both the perceived thermal comfort and air quality in environments at 26°C. Similarly, Atthajariyakul and Lertsatittanakorn's tests [13] found that comfortable temperatures could be relaxed to 28°C with small frontal desk fans, leading to an estimated air-conditioning energy-saving potential of as much as

1,959.51 GWh/year in Thailand. Additionally, when subjects were able to control both the fans and thermostats of air conditioners, they still used fans and set warm indoor temperatures [5]. To sum up, fans are clearly effective for ameliorating occupants' discomfort in warm environments and make it possible for occupants to elevate set-point temperatures of air-conditioning systems in summer, and therefore reduce the energy consumption of buildings [14].

Some researchers have proposed ways to evaluate the effects of fans on thermal comfort and energy saving. Yang et al. [15] used the cooling fan efficiency (CFE) index to evaluate the ratio between the fan-generated whole-body cooling effect (as measured with a thermal manikin) and fan power consumption. Zhang et al. [3] proposed corrective power (CP) index to quantify the extent to which a fan can "correct" a warm ambient temperature toward neutral. The CP index can be used to evaluate both the equivalent change in ambient temperatures caused by fans as well as the changes in subjective responses, such as thermal sensations and comfort. Based on the CP, He et al. [16] proposed the corrective-efficiency-to-power (CEP) index, which describes how much energy is consumed when 1-K CP value of personal comfort systems (PCSs) is achieved. The CEP index provides a detailed but simple calculation method for evaluating the energy-efficiency of PCSs, including fans.

Due to the advantages of thermal comfort and energy conservation, fans have become the most successful commercial PCS. Nowadays, fans are used in offices [17, 18], classrooms [19, 20], houses [21, 22], and numerous other indoor environments. However, a lack of critical information obstructs the wider use of fans.

(1) The first question is: why do people and to what extent do they use fans in real buildings? Fan-use rates in different buildings in real-world settings may answer this question because the occupants themselves actively choose to use fans (rather than being "asked" to use fans as in lab studies). However, no studies have presented a comprehensive review of fan-use and its influential factors in practice.

(2) Secondly, although many lab studies show that building occupants with fans can be thermally comfortable in warmer environments (up to 30°C or higher), no review to examine the comfortable ambient temperatures using fans in actual buildings, i.e., the neutral-zone temperatures of occupants with fans in actual buildings are not clear.

(3) Thirdly, energy conservation achieved by fans in buildings is usually estimated by simulations with increased indoor set-point temperatures [3, 13, 14]. Nonetheless, actual energy savings due to fan use have not been fully validated.

(4) Lastly, the productivity of humans is related to their thermal conditions [23, 24]. Since fans effectively reduce warm sensations, they may improve human productivity in warm environments. However, this point has not been fully explored in field studies.

1.2 Objectives

The main objectives are to explore:

(1) Fan-use rates (including fan-use rate models) in different types of buildings and the triggers for using fans.

(2) Effects of fans on thermal comfort, energy consumption, and work productivity in field studies, including the elevation of neutral temperatures with fans, energy saving potentials by using fans, and the extension of temperatures ensuring high-productivity.

1.3 Framework of this review

As shown in Fig. 2, this review includes two major parts: *fan-use rates* and the *effects of fans*. Section 3.1 on fan-use rates mentions 54 studies on the prevalence of fans and the triggers of their uses. Section 3.2 on the effects of fans consists of three sections: thermal comfort, energy conservation, and human productivity. Lastly, a discussion section provides useful information for relevant standards and future studies. Detailed methods for presenting fan-use rates and its effects are presented in Sections 2.2 and 2.3.

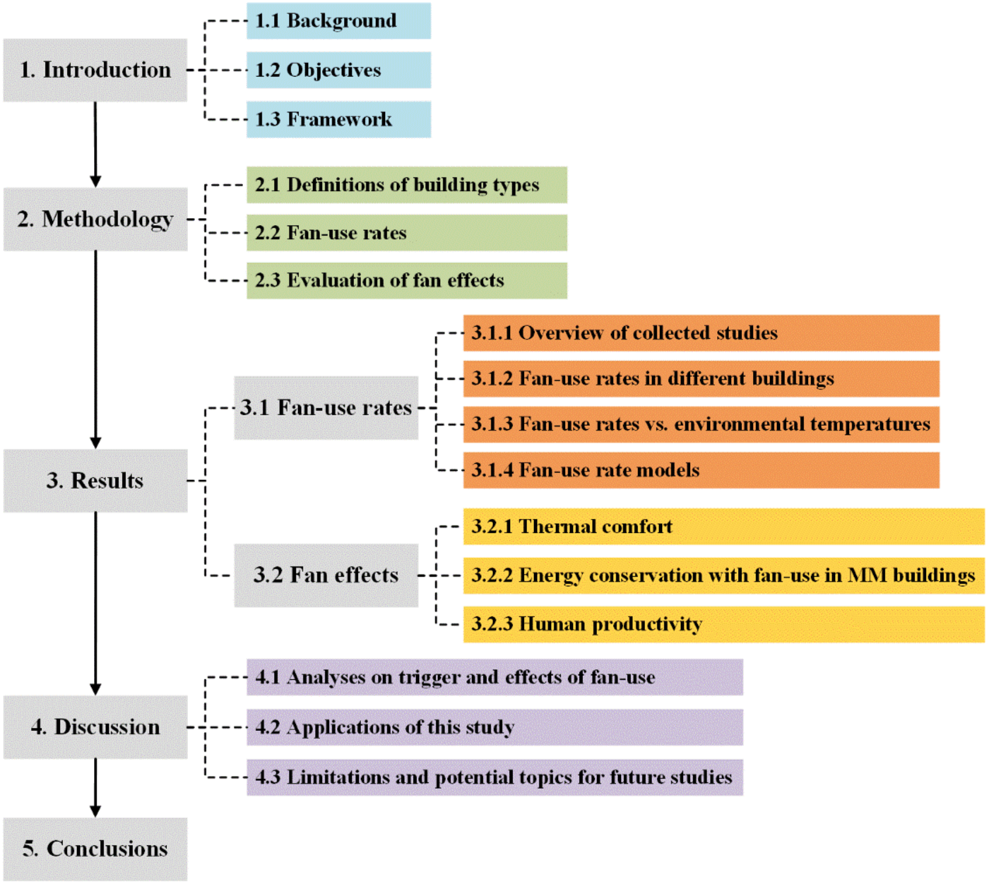


Fig. 2. Framework of this review.

2. Methodology

The studies mentioned in the collected literature were mainly conducted during warm seasons.

2.1 Definitions of building types

Based on HVAC system operation conditions, the buildings' cooling strategies in the collected literature are divided into three types: air-conditioned (AC), mixed-mode (MM) and naturally-ventilated (NV). In AC buildings, all the air-conditioning systems are running. For example, in study [25], all the occupants in AC buildings were using air conditioners. In MM buildings, mechanical cooling and operable windows are both available, and only a fraction of the air-conditioning systems are running all the time or all the air-conditioning systems run for only part of the time. For instance, in [26], the air-conditioning systems were not always running, so the buildings were regarded as MM ones. In NV buildings, there are no air-conditioning systems or the air-conditioning systems are turned off (as in [27]), and there are operable windows.

Also, in this review, the buildings are also divided according to their functions: residential buildings (including houses, apartments, dormitories and so on), office buildings, teaching buildings (classrooms, school computer rooms and so on), hybrid buildings (the original studies involved several types of buildings but did not separate them), etc. The detailed building types are listed in Appendix tables.

2.2 Fan-use rate, maximum fan-use rate, and fan-use rate models

Fan-use rate. The fan-use rate is defined as the percentage of the occupants who are using fans corresponding to an ambient temperature. In a study, the fan-use rate was usually calculated in each bin of the ambient temperatures. For example, in [18] which was conducted in two office buildings, all records of fan-use rates were assigned to outdoor air temperature bins with 1°C interval, e.g., the temperature bin of 25°C contains the fan-use data (use fans or not) in the range of outdoor air temperatures from 24.5°C to 25.4°C.

Maximum fan-use rate. In general, the fan-use rate increases as indoor or outdoor temperature increases. Usually, as the temperature increases to a certain level, the fan-use rate reaches its maximum (often it is not 100%) and does not increase further as ambient temperature increases further. In this case, we use the first ambient temperature when the maximum fan-use rate was recorded as the corresponding temperature of the maximum fan-use rate. This temperature defines threshold for maximum fan-use rates. For example, if the maximum fan-use rate is 80% which appears at the environmental temperatures of 30°C, 32°C, and 34°C in a study, then 30°C is selected as the corresponding temperature of the 80% fan-use rate. For some studies, if only the average fan-use rate and its average ambient temperature are reported, then these are used as the maximum fan-use rate and its corresponding temperature, respectively.

Fan-use rate model. Many collected studies also provided fan-use rate models, and those models were also collected. These models represent correlations between fan-use rates and environmental temperatures. Most of the models in the original studies were obtained by logistic regressions (see Appendix Table 1). These models can be divided into two groups according to whether they are correlated with indoor or outdoor temperatures. Indoor temperatures could be indoor air, globe, or effective temperatures, depending on what is available in the original papers, while outdoor temperatures are raw or calculated dry-bulb outdoor temperatures, which could be actual, binned, average monthly, or average daily outdoor dry-bulb temperatures. Detailed temperatures are explained in appendix tables.

This review developed general models based on these collected models. Since most papers that provide models do not provide original data, the general models of this study were established by using the calculated values of the collected models rather than the original data. To quantify the correlations between temperatures and fan-use rates, probit regressions were used to obtain general models of fan-use rates. First, the use rate of each model in each 0.1°C bin was calculated. The 0.1°C bin corresponds to the resolution of temperature sensors used in field studies which is usually 0.1°C. Then, the average use rate of each model in each 0.1°C bin was calculated. Subsequently, probit regressions were used to obtain the general models. Logistic regressions use original data in the discrete form which are lacked. Probit regressions allow the use of calculated values (such as average values in temperature bins which are continuous), and can generate very similar results as those by using logistic regressions. The main difference between logistic and probit regressions only lies in the link function. Thus, probit regressions are adopted in this study. Probit regressions were also used in some of previous studies on occupant behaviors (including using fans) and thermal comfort, such as [1, 28]. The form of regression models is shown as follows:

$$p_{fan} = \frac{1}{1 + \exp(aT + b)} \qquad (1)$$

where p_{fan} is the fan-use rate, T is the environmental temperature (indoor or outdoor temperature), a and b are the coefficients which are obtained through probit regressions.

2.3 Evaluation of fan effects

2.3.1 Thermal comfort

The goal of this analysis is to isolate the effects of fans on thermal comfort in field studies. The approach entails a comparison of two groups of field studies: one group with fans and the other without. For the group with fans, studies were conducted in buildings in which at least 70% of the total occupants used fans in warm seasons. Their neutral temperatures (thermal sensation vote (TSV) equals to 0) and upper limits of neutral-zone temperatures (TSV=+0.5) were analyzed. Choosing TSV=+0.5 as the upper limit of the neutral zone was based on the suggestions of ASHRAE Standard 55 [2]. For the group without fans, studies were selected from buildings in which none of the occupants used fans. The thermal comfort of occupants in AC buildings without fans was not included in the analysis because people in AC buildings are less adaptive to warm environments [25] and the comparison would not be influenced by adaptation. Therefore, the comfort comparison mainly consists of the results obtained in MM and NV buildings without fans, and AC, MM, and NV buildings with fans.

2.3.2 Energy conservation

There is only one field study that directly elevated set-point temperatures of air-conditioning systems with fans and measured the energy saved by this set-up [29]. Elevating the set-point temperature from 23°C without fans to 26°C with fans was estimated to achieve annual energy savings of 44 kWh/m^2.

MM buildings provide a unique opportunity to compare the energy use of air-conditioning by comparing the temperature at which air-conditioning was turned on with or without fans. The higher the temperature, the higher were the energy savings. In this review, 50% of the air-conditioning-use (AC-use) rate was taken as the threshold to find the corresponding ambient temperatures. The 50% AC-use rate means that half of occupants are using air-conditioning systems. When AC-use rate reaches 50% or higher, it indicates more occupants are using AC than those who are not. If the corresponding ambient temperature of 50% AC-use rate is higher, it means that occupants rely less on AC in warm environments, thus saving both energy and money. The 50% AC-use rate was also used in some collected literature (such as references [18] and [22]) to study AC-use behaviors of occupants in buildings. Moreover, AC-use rate models were also collected for analyzing whether AC-use rates could be reduced with fans. Similar to what was mentioned in Section 2.2, general AC-use rate models correlated with environmental temperatures were obtained by probit regressions.

2.3.3 Human productivity

Human productivity includes actual work productivity, psychological productivity, and productivity-related symptoms. The actual work productivity mainly refers to the score achievable by a person who is working (in activities such as learning, typing, calculation, and thinking). The self-estimated productivity is the psychological perception of how effective an individual perceives himself or herself to be while working. The work-related symptoms refer to factors such as fatigue and tiredness that directly influence a person’s work.

Different studies used different scales to evaluate productivity. We converted the scales to percentages to quantify the productivity. For example, in [29], using a scale ranging from “not productive” to “very productive”, occupants reported their self-estimated productivity at temperatures of 23°C (no fans), 26°C (with fans), and 27°C (with fans). We represented 0% as “not productive” and 100% as “very productive”. Then, we converted the self-estimated votes averaging 0.849, 0.836, and 0.765 to 84.9%, 83.6%, and 76.5%, respectively. Thus, the productivity changes are -1.30% and -8.40% at temperatures of 26°C and 27°C with fans as compared to the reference condition at 23°C without fans. The corresponding ambient temperature deviations are 3°C and 4°C, respectively. This method interpolates the original data to the corresponding full scale. For this review, we calculated only the temperature deviations of conditions with fans that had ambient temperatures equal to or higher than those without fans. Additionally, for studies with fatigue proportions, the increase and decrease in productivity were equivalent to the decrease and increase in fatigue proportions.

3. Results

3.1 Fan-use rate in field studies

3.1.1. Overview of collected studies

In total, 54 studies of fan-use rates were collected. Of these studies, 42 were conducted in Asia, 4 in Europe, and 3 each in Americas and Australia. 2 studies were conducted in both Asia and Europe. It is probably due to both climatic and cultural reasons that fans are more popular in Asia. The main building types in the collected literature were residential and office buildings (30 and 16 studies for residential and office buildings, respectively, and one study for both types), with several teaching and hybrid buildings (2 and 5 studies, respectively). Of the studies, 4, 13, and 29 were undertaken in AC, NV, and MM buildings, respectively, and 8 involve two or three of these building operation types.

Among these 54 studies, 30 studies provide 60 models that present the relationship between fan-use rates and environment temperatures, whereas 38 models are with indoor and 22 with outdoor temperatures. All details of the field studies on fan-use rates are presented in Table 1 in the Appendix.

3.1.2 Fan-use rates in different regions, in buildings with different cooling strategies and functions

Difference with regions. Fig. 3 illustrates the maximum fan-use rates (means and distributions) in different buildings. The blue dots are the actual data of maximum fan-use rates of the collected studies. The grey curve represents the distribution trend of data which form the box on the curve's left. The more the curve bends to right, the more data on the rate range (Y axis) which the bend corresponds with. For example, in Fig. 3a, the data of fan-use rates in Asia mainly vary between 50% and 100%, and thus the curve forms its bend (to right) mainly corresponding to this range. Asia and Europe are the main regions surveyed in the collected studies. As shown in Fig. 3a, fan-use rates are higher in Asia (usually higher than 60% and the mean rate is more than 75%) than in Europe (use rate is more evenly distributed and the mean rate is about 60%), whereas no significant statistical difference was found between Asia and Europe (t-test, $p>0.05$).

Difference with cooling strategies. As for buildings with different cooling strategies, in general, the use rate in NV buildings is the highest (usually higher than 80%; average use rate is 82%), followed by MM buildings with the average fan-use rate reaching about 70%, then by AC buildings (usually lower than 60%; average lower than 50%), Fig. 3b. No significant difference between the fan-use rates of MM and NV buildings (t-test, $p>0.05$) was found, but the fan-use rates are significantly higher in MM and NV buildings than in AC buildings (t-test, $p<0.05$).

Difference with building functions. Moreover, fan-use rates are different among buildings with different functions. In office buildings, fan-uses rates are relatively uniformly distributed between 0% and 100%, whereas it primarily varies between 60% and 100% in residential buildings (Fig. 3c). However, the difference is not significant between office and residential buildings. In teaching and hybrid buildings (those having multiple functions, such as living and recreation spaces in one building), the fan-use rate appears high but there are little supporting data. The data on America and Australia, as well as on teaching and hybrid buildings, are not included in Fig. 3 due to the very limited quantity of data.

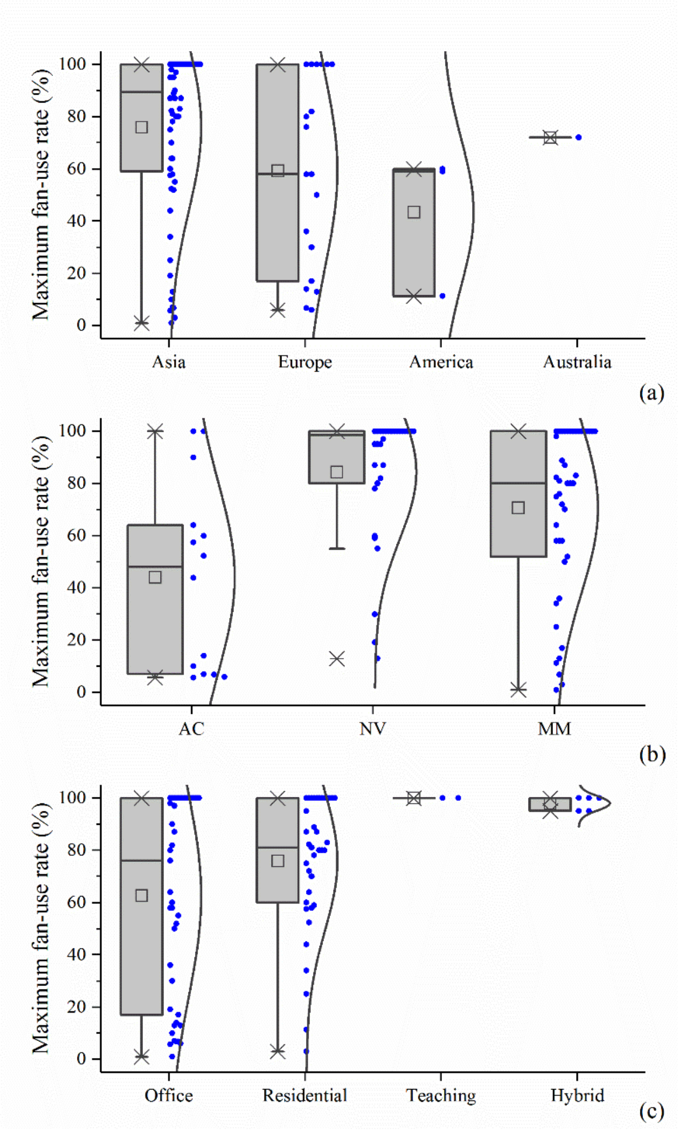


Fig. 3. Maximum fan-use rates with (a) different regions, (b) cooling strategies, and (c) building functions.

3.1.3 Maximum fan-use rates vs. environmental temperatures

Fig. 4 shows the maximum fan-use rates in different studies and their corresponding indoor and outdoor temperatures. It is clear that maximum fan-use rates occur in indoor ambient temperature ranges of 24°C–34°C and outdoor temperatures of 18°C–34°C. Also, the maximum fan-use rate increases as the indoor or outdoor environment becomes warmer (see the trends shown by the circles with gray dashed lines). Moreover, between the ranges (23°C-28°C indoors) when AC building data are available, the fan-use rate in AC buildings is close to those in NV and MM buildings under the same temperatures (statistical indifferent, $p>0.05$ for indoors), indicating that the driving force of fan-use is indoor temperatures, regardless cooling strategies such as AC, MM, or NV. This point is further discussed in Section 4.1. There are too few data corresponding to outdoor temperature, so no statistical analysis was performed,

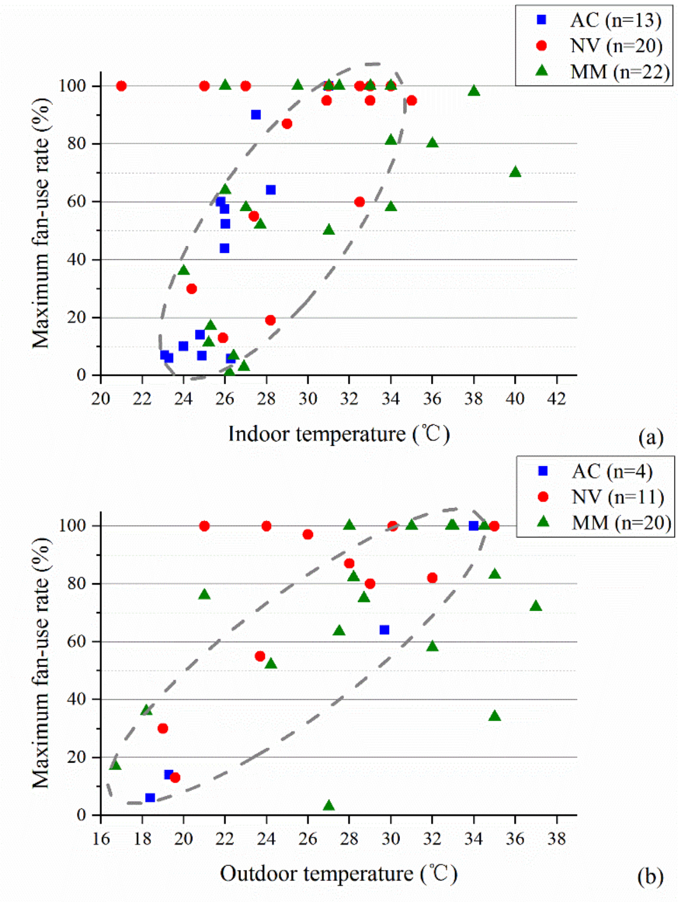


Fig. 4. Maximum fan-use rates against (a) indoor and (b) outdoor temperatures.

3.1.4 Fan-use rate models

AC, MM, and NV cooling strategy buildings. 60 models (from 30 studies) correlating fan-use rates with indoor and outdoor temperatures were collected, which are presented in Fig. 5 and listed in Appendix Table 1. Fig. 5a shows the original models corresponding to the indoor temperature and Fig. 5d shows outdoor temperature models. The ranges of the original models were obtained from the original papers. Fan-use rates tend to increase as the indoor or outdoor environments become hotter. Also, the models of fan-use rates in AC, MM, and NV buildings are similar (as the lines of the original models usually overlap each other) when correlating to indoor or outdoor temperatures. Despite of limited data of fan-use rates in AC buildings, the trend is similar to the trends of MM and NV buildings.

To develop general models based on those individual models, we extended the indoor and outdoor temperature ranges to 12°C-40°C and 0°C-40°C, respectively, which are the largest ranges provided by those models in their original papers (see Fig. 5(b, d)). Based on these extended indoor and outdoor temperature ranges, we calculated the average fan-use rates of AC, MM, and NV buildings. They are also close to each other (Fig. 5(c, f)). The differences between MM and NV buildings are very small (green and orange lines are very close with each other), maximum difference less than 5% for indoors and less than 10% for outdoors. The differences between AC and MM or NV are bigger, but still lower than 10% at the same indoor temperature, and lower than 20% at the same outdoor temperature.

The results indicate that the indoor temperature, not the cooling strategy, mainly drives the fan-use rate.

The probit regression models based on average fan-use rates (p_{fan}) against the indoor (T_{in}) and outdoor (T_{out}) temperatures (Fig. 5(c, f)) were obtained as described by several equations below:

correlated with indoor temperatures:

For AC buildings: $$p_{fan} = \frac{1}{1 + \exp(-0.247 \times T_{in} + 7.036)} \tag{2}$$

For NV buildings: $$p_{fan} = \frac{1}{1 + \exp(-0.424 \times T_{in} + 11.967)} \tag{3}$$

For MM buildings: $$p_{fan} = \frac{1}{1 + \exp(-0.383 \times T_{in} + 11.418)} \tag{4}$$

For All buildings: $$p_{fan} = \frac{1}{1 + \exp(-0.360 \times T_{in} + 10.394)} \tag{5}$$

correlated with outdoor temperatures:

For AC buildings: $$p_{fan} = \frac{1}{1 + \exp(-0.142 \times T_{out} + 4.150)} \tag{6}$$

For NV buildings: $$p_{fan} = \frac{1}{1 + \exp(-0.215 \times T_{out} + 5.686)} \tag{7}$$

For MM buildings: $$p_{fan} = \frac{1}{1 + \exp\left(-0.231 \times T_{out} + 6.599\right)} \tag{8}$$

For All buildings: $$p_{fan} = \frac{1}{1 + \exp(-0.224 \times T_{out} + 6.161)} \tag{9}$$

Again, it should be noted that only 6 and 2 original fan-use rate models of AC buildings are correlated with indoor and outdoor temperatures, respectively, therefore, their regression models of fan-use rate models may not be very solid.

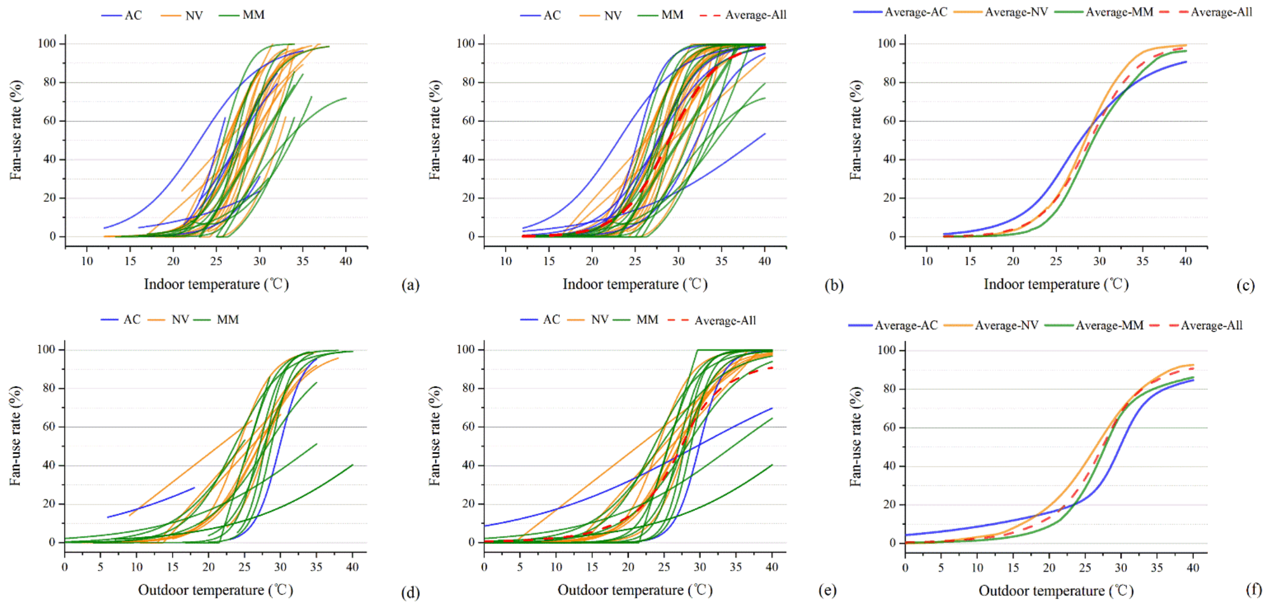


Fig. 5. AC, NV, and MM buildings' fan-use models with (a) original indoor, (b) extended indoor, (c) extended indoor (average fan-use rates), (d) original outdoor, (e) extended outdoor, and (f) extended outdoor (average fan-use rates) temperature ranges.

Office and residential buildings. Further, Fig. 6 represents the models of residential (orange lines) and office (green lines) buildings which are the two major building functions of the collected studies regarding fan-use rates. There are 23 models of residential buildings (15 and 8 models correlated with indoor and outdoor temperatures, respectively), and 33 models of office buildings (20 and 13 models correlated with indoor and outdoor temperatures, respectively).

For the models correlating with indoor ambient temperatures (Fig. 6a), the ones for office buildings (represented by green lines) are located at the lower ambient temperature ranges (curves towards the left) than the models for residential buildings (represented by orange lines, curves towards the right). It indicates that the ambient temperatures in office buildings are cooler than the residential buildings. This tendency also appears in models based on outdoor temperatures (Fig. 6d), and with the extended temperature ranges (Fig. 6(b, e)).

The probit regression models of residential and office buildings based on average fan-use rates (p_{fan}) against the indoor (T_{in}) and outdoor (T_{out}) temperatures were obtained (Fig. 6(c, f)). The corresponding indoor and outdoor temperature ranges are 12°C-40°C and 0°C-40°C, respectively. The models are listed as below:

correlated with indoor temperatures:

For Residential buildings:
$$p_{fan} = \frac{1}{1 + \exp(-0.425 \times T_{in} + 12.891)} \qquad (10)$$

For Office buildings:
$$p_{fan} = \frac{1}{1 + \exp(-0.342 \times T_{in} + 9.576)} \qquad (11)$$

correlated with outdoor temperatures:

For Residential buildings:
$$p_{fan} = \frac{1}{1 + \exp(-0.200 \times T_{out} + 6.065)} \tag{12}$$

For Office buildings:
$$p_{fan} = \frac{1}{1 + \exp(-0.221 \times T_{out} + 5.783)} \tag{13}$$

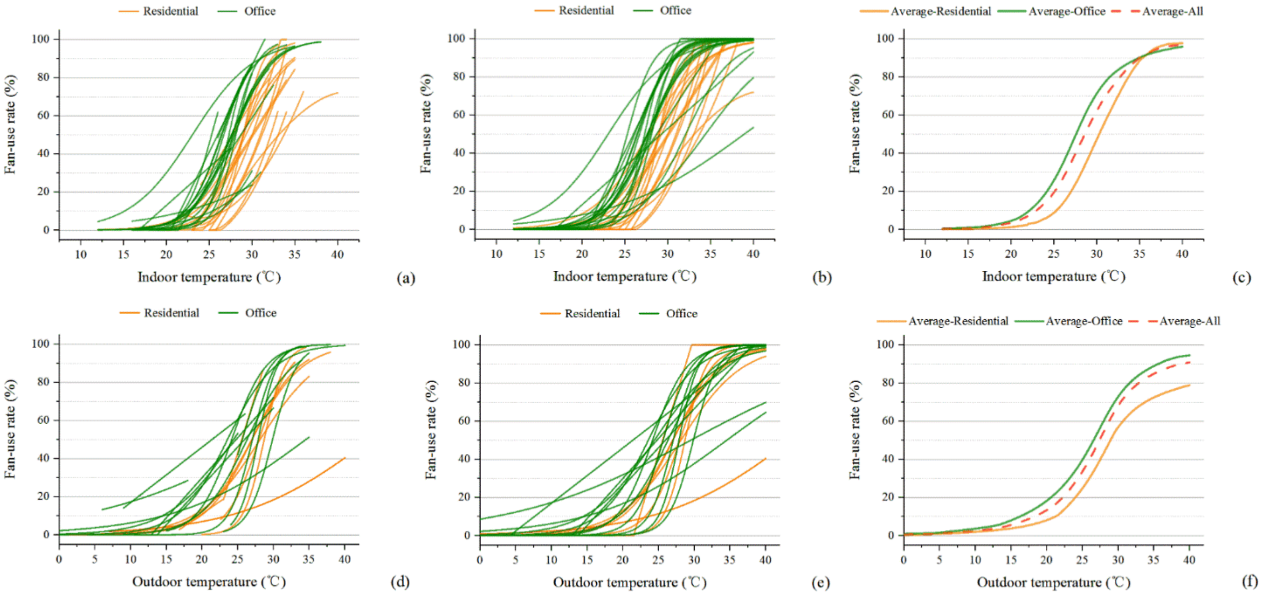


Fig. 6. Residential and office buildings' fan-use models with (a) original indoor, (b) extended indoor, (c) extended indoor (average fan-use rates), (d) original outdoor, (e) extended outdoor, and (f) extended outdoor (average fan-use rates) temperature ranges.

3.2. Effects of Fans

3.2.1 Thermal comfort

AC, MM, and NV cooling strategy buildings. As described in Section 2.3.1, to study the effects of fans on comfort, those with a fan-use rate of 70% or more were compared to those without fans. By excluding the data from AC buildings without fans, the comfort results are more comparable assuming adaptation opportunities are available for the MM and NV buildings without fans, and AC, MM, and NV buildings with fans. A total of 30 studies (2, 3, and 25 were conducted in AC, MM and NV buildings, respectively) with fans and 20 studies (9 in MM and 11 in NV buildings) without fans were collected. The details of these studies are listed in Table 2 in the Appendix.

The neutral temperatures (TSV=0) and the upper limit of the neutral-zone temperatures (TSV=+0.5) in these studies are presented in Fig. 7(a, b). All results of the neutral temperatures and upper limits were calculated based on the original models in the collected literature.

Without fans (represented by red and orange squares), neutral temperatures are 24°C-28°C and the average value is

25.7°C. The TSV=0.5 mainly range from 26°C to 29°C with only two sets of data being higher than 29°C, and the average value of the upper limits is 27.5°C. No data appears above 30°C for TSV=0 and +0.5, indicating it impossible to achieve comfort when the indoor temperature is above 30°C.

When there are fans (green, blue, and dark blue), both the neutral temperatures and upper limits of neutral-zone temperatures are shifted to higher levels. Neutral temperatures with fans fall in the range 27°C-31°C with the average value being 28.7°C, which is about 3°C higher than that without fans. The upper limits are within the range 29°C-32°C with the average value being 30.7°C, which is also about 3°C higher than that without fans. It should be noted that occupants with fans in MM (blue circles) and NV (green circles) buildings have similar neutral temperatures and close upper limits. Occupants without fans (red and orange squares) also have similar neutral temperatures and close upper limits but those values are usually lower than when they have fans. It indicates that MM and NV buildings have similar ambient temperatures for TSV=0 and +0.5. This point is further discussed in Section 4.1.

Moreover, the data in Fig. 7a show that neutral temperatures increase as fans are used while the relative humidity remains same between 50% and 70%. This indicates that fans are effective at raising neutral temperatures with the same relative humidity. Nonetheless, statistical analysis shows no robust correlations between neutral temperatures and relative humidity (absolute value of Pearson's r is lower than 0.04). This result implies that the increase of neutral temperatures is mainly produced by using fans rather than by decreasing of relative humidity.

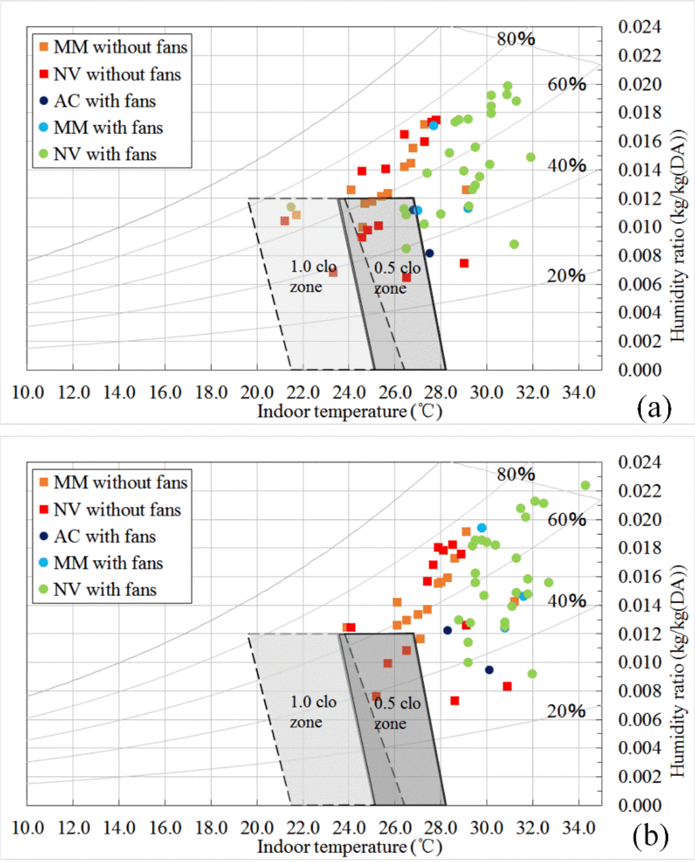


Fig. 7. (a) Neutral temperatures (TSV=0) and (b) upper limit of neutral-zone temperatures (TSV=0.5) with and without fans (MM, NV and AC buildings).

Office, residential, and teaching buildings. The collected studies mainly include three building function types: office, residential and teaching buildings. Fig. 8 presents their neutral temperatures (TSV=0, Fig. 8a) and the upper limits of neutral-zone temperatures (TSV=+0.5, Fig. 8b). For residential buildings (cross marks), without fans, neutral temperatures are 24°C-29°C and the average value is 26.4°C; the temperatures for TSV=0.5 mainly range from 26°C to 30°C with only two sets of data being higher than 30°C, and the average value of the upper limits is 28.3°C. With fans, neutral temperatures in residential buildings increase to 27°C-31°C and the average value is 29.3°C (increased by 2.9°C as compared to those without fans, 26.4°C); and the upper limits are mainly 30°C-32°C (only one set of data is lower than 30°C), and the average value is 31.0°C (increased by 2.7°C as compared to those without fans 28.3°C). For office buildings (triangle marks), using fans increases the average neutral temperature and the average upper limit by 0.9°C (from 26.2°C to 27.1°C) and 1.2°C (from 28.0°C to 29.2°C). The small increase is because that in office buildings, even with fans, the ambient temperature didn't increase as much as in residential buildings. For teaching buildings (circle marks), using fans increases the average neutral temperature and the average upper limit by 4.8°C (from 23.7°C to

28.5°C) and 5.0°C (from 25.7°C to 30.7°C). These results indicate that fans are more useful to extend neutral-zone temperatures in teaching and residential buildings than in office buildings. Besides, although different-function buildings may have different neutral temperatures, the results of Fig. 8b indicate that occupants without fans are hard to be comfortable when the ambient temperature is higher than 30°C (only two sets of residential data without fans are higher than 30°C when TSV=+0.5).

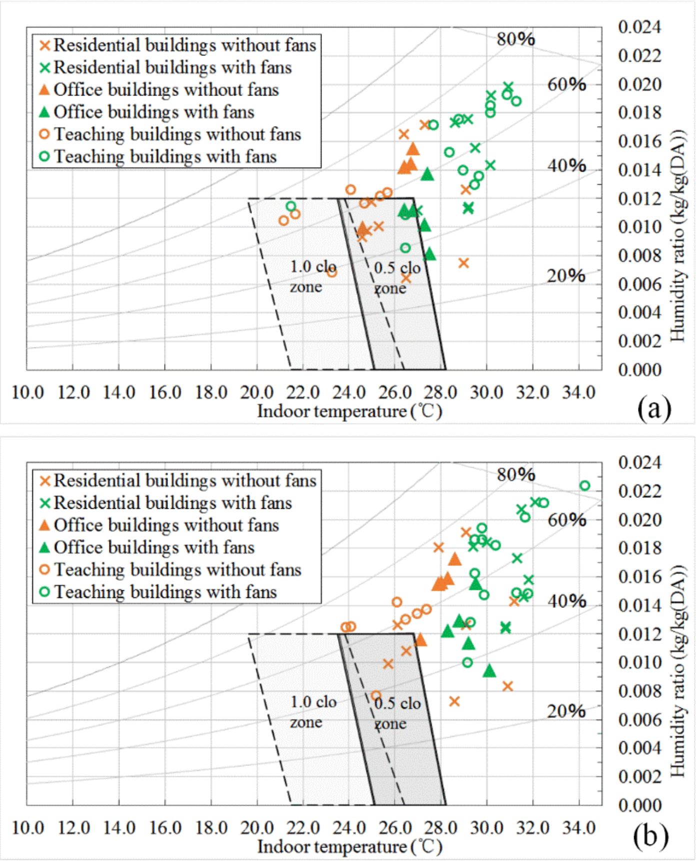


Fig. 8. (a) Neutral temperatures (TSV=0) and (b) upper limits (TSV=0.5) of neutral temperatures with and without fans (residential, office and teaching buildings).

3.2.2 Energy conservation with fan-use in MM buildings

As described in Section 2.3.2, we used AC-use rates in MM buildings with and without fans to indicate energy savings. A total of 24 studies about air-conditioning energy use in MM buildings have been collected. Among these studies, 16 and 5 are with or without fans, respectively. The remaining three studies include both data with and without fans. Each of the three studies had a same group of occupants, AC-use rates with and without fans. The details of these studies are listed in Table 3 in the Appendix.

Fig. 9 shows the results for indoor and outdoor temperatures when the AC-use rate is 50% in MM buildings. Without fans, the mean values of indoor and outdoor temperatures (corresponding to 50% AC-use rate) are 29.7°C and

27.3°C, respectively. When occupants have fans, the indoor and outdoor temperatures (corresponding to 50% AC-use rate) are higher. The fans increase indoor temperatures by 2.7°C on average (mean value 32.4°C, mainly varying from 32°C to 33°C, blue boxes in Fig. 9) and outdoor temperatures by 4.1°C (mean value 31.4°C, mainly varying from 28°C to 35°C, orange boxes in Fig. 9) as compared to the temperatures without fans. A significant difference was found between outdoor temperature groups with and without fans (t-test, $p<0.05$) but not among indoor temperature groups due to the small number of data available for without-fan condition. Increases of the indoor and outdoor temperatures with 50% AC-use rate indicate that AC-use would be reduced. For example, at 27.3°C outdoors, AC-use rate in buildings without fans reaches 50%, whereas AC-use rate is much less than 50% in buildings with fans because its threshold of 50% AC-use is 32.4°C. A quantified reduction of the AC-use rate by using fans is presented in Fig. 13.

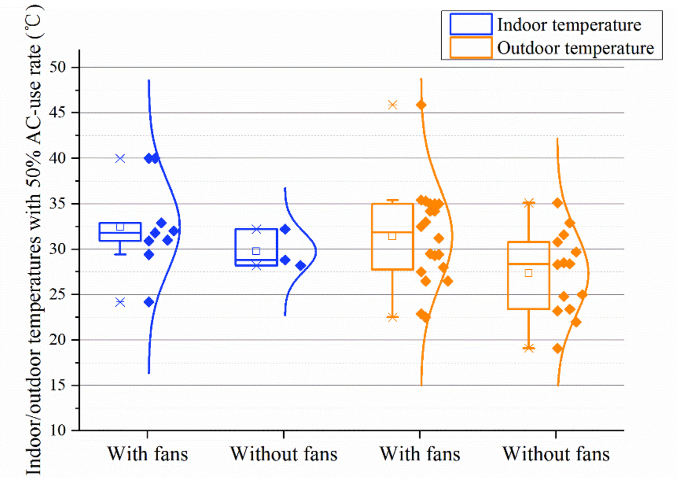


Fig. 9. Indoor/outdoor temperatures when AC-use rate is 50% in buildings.

Fig. 10 shows indoor (Fig. 10a) and outdoor (Fig. 10b) temperatures (Y-axis) and the corresponding fan-use rate (X-axis) when 50% AC-use rate happens. The orange dots illustrate the data without fans while the green dots show data with fans. The two fitted regression lines (Fig. 8a and 8b) show the trend as the fan-use rate increases from 0% to 100%. The indoor and outdoor temperatures (with 50% AC-use rate) increase by about 5 and 8 K, respectively, indicating that a higher fan-use rate can reduce the AC-use rate.

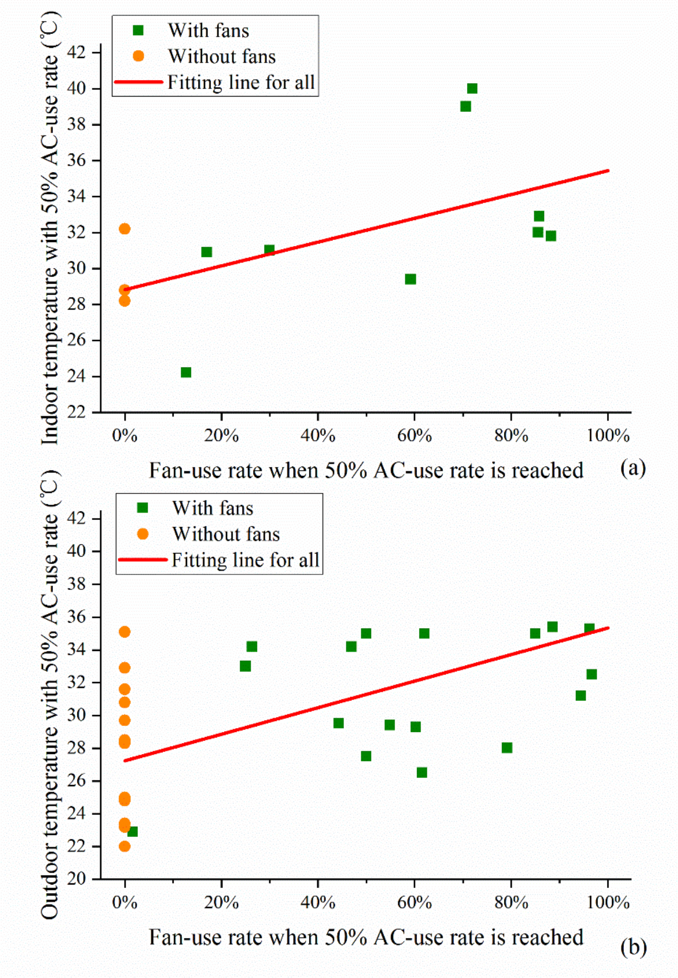


Fig. 10. Relationships between fan-use rate and indoor/outdoor temperatures when 50% AC-use rate is reached.

Among the 24 collected studies, 18 studies provide models of AC-use rates vs. outdoor temperatures. Some of the models are with fans and others are without fans. Fig. 11 presents all the models of these studies (with original temperature ranges). The details are also listed in Table 3 in the Appendix. The orange-solid lines represent the conditions without fans and the green-solid lines represent the conditions with fans. At a certain level of AC-use rate, fan-use (presented by the green lines) slightly shifted the outdoor temperatures toward warmer temperatures (comparing to the orange lines without fans). In other words, occupants with fans use less air-conditioning when the outdoor climate is the same. However, there is an overlap between the areas with and without fans, which may lead to some doubt whether using fans truly reduces AC-use. To answer this question, three studies provide both models with and without fans, which are presented in Fig. 12 (original models with original temperature ranges). From these studies, it is clear that the use of fans postpones extensive AC-use because the solid lines (with fans) all located at the warmer side comparing to the dashed lines (without fans).

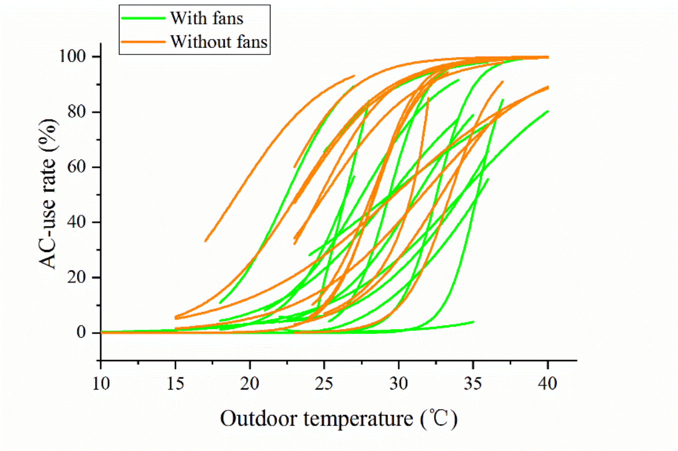


Fig. 11. AC-use models against outdoor temperatures.

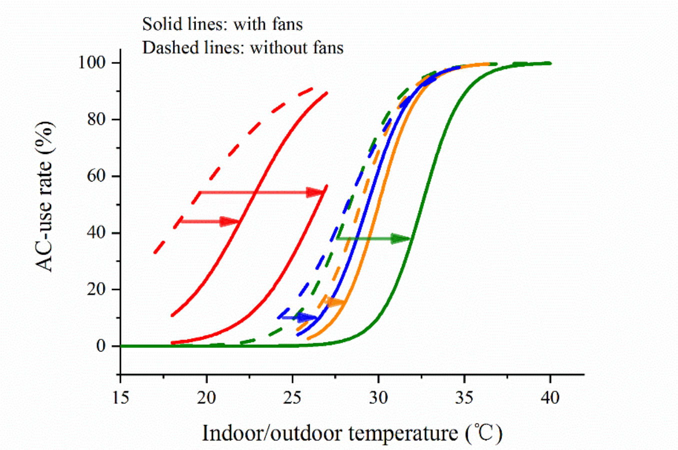


Fig. 12. Three studies that provide four models with and without fans (green lines [18], red lines [30], and blue and orange lines [31]).

The average AC-use rates of the collected models (Table 3 in the Appendix) with and without fans and their differences against outdoor temperatures (temperature ranges of all models were extended to 10°C-40°C) are illustrated in Fig. 13. Clearly, the reduction in AC-use rate peaks at the outdoor temperature of 32.5°C. When outdoors is 25°C-35°C (which is also the main range of outdoor temperatures in summer), the reduction is higher than 15%, which indicates that at least 15% of the energy used for air-conditioning is saved by the use of fans. The reduction in AC-use rate is lower than 10% when the outdoor temperature is higher than 37.5°C or lower than 22°C, indicating that fan-use does not reduce AC-use rates significantly when outdoors is lower than 22°C (when fans are unlikely to be needed) or above 36.5°C (when AC is needed regardless of the availability of fans). On the basis of the average values, two non-linear models correlating AC-use rates (p_{AC}) with outdoor temperatures (T_{out}) were established:

With fans:
$$p_{AC} = \frac{1}{1 + \exp(-0.252 \times T_{out} + 7.671)} \tag{14}$$

Without fans: $$p_{AC} = \frac{1}{1 + \exp(-0.276 \times T_{out} + 7.493)} \tag{15}$$

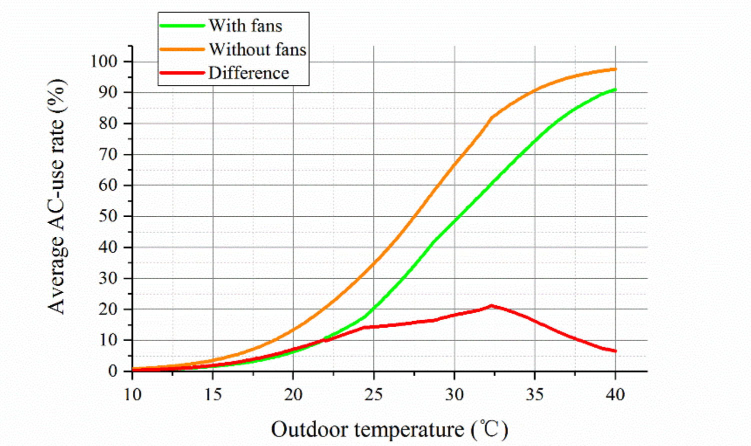


Fig. 13. Average AC-use rates with and without fans in MM buildings.

3.2.3 Human productivity

Seven studies were found to evaluate people's work productivity with fans (see Table 4 in the Appendix) and all of them directly compared human productivity with fans at higher ambient temperatures to the productivity without fans at the same or lower ambient temperatures (these are called comparison temperatures). Of these 7 studies, 1 compared the actual work productivity (learning, scores obtained through examinations), 2 compared the self-estimated productivity, and 4 compared the work-related symptoms, respectively. The results of productivity changes with fans vs. temperature deviations from the comparison temperatures were calculated according to the data presented in the 7 papers, shown in Fig. 14. These studies provide 43 samples of productivity data (43 dots in Fig. 14). The positive value means that the human productivity is better with fans than without at the comparison temperatures, whereas the negative value means that the human productivity is worse with fans. A zero value means that there is no change in productivity with or without fans. The positive temperature deviations mean that the ambient temperature with fans was higher than the comparison temperature while a zero-temperature deviation means that the comparison had been made under the same ambient temperature both with and without fans. The comparison temperatures are the tested ambient temperatures used in the original studies to calculate the temperature derivatives. For example, when a study investigated the productivity at 26°C, 28°C, and 31°C, then used 26°C and 28°C as comparison temperatures, the deviation temperatures would be 0 K (26°C-26°C, 28°C-28°C, and 31°C-31°C), 2 K (28°C-26°C), 3 K (31°C-28°C), and 5 K (31°C-26°C).

It can be seen from the comparison temperatures (0 K-no temperature increase, or within 1 K) that when the ambient temperature increases within 1 K, the fans improve the human productivity for most studies (data when deviation<1 K, Fig. 14). When the ambient temperature increases further, i.e., between 1 and 5 K from the comparison temperatures, with fans, some studies show that the human productivity could be maintained at the same levels as the comparison temperatures (the dots along the 0% productivity change line). There are more data showing that the productivity has been reduced compared with the no-fan under comparison temperatures (negative values in Fig. 14), but most of the reductions are within 5%. There are only three instances where the reduction is between 8%-10%. There are seven examples when productivity increases with fans as compared to the productivity at comparison temperatures without fans. Among these examples, 3 are within a 5% increase, whereas 4 are much higher than 10% increase and almost reached 20%.

As shown by the red line in Fig. 14, a linear regression had been made for the data when the deviation temperature was larger, i.e., between 1 and 5 K (Pearson's $r = -0.245$, R^2=0.037, ANOVA: p=0.113, F value=2.612). Although the fitting line is not perfect, it indicates a trend that fans could improve occupant productivity (positive productivity change) within a certain range of temperature deviations from the comparison temperatures, and the threshold is 3 K. When the ambient temperature is warmer than 3 K from the comparison temperatures, fans cannot make up for the productivity loss (productivity increase becomes negative; Fig. 14). In the seven studies, there are more data with comparison temperatures between 26°C-29°C (Table 4 in the Appendix), so the 3 K threshold indicates that fans could enhance productivity at 29°C-32°C comparing to the productivity at 26°C-29°C ambient temperatures.

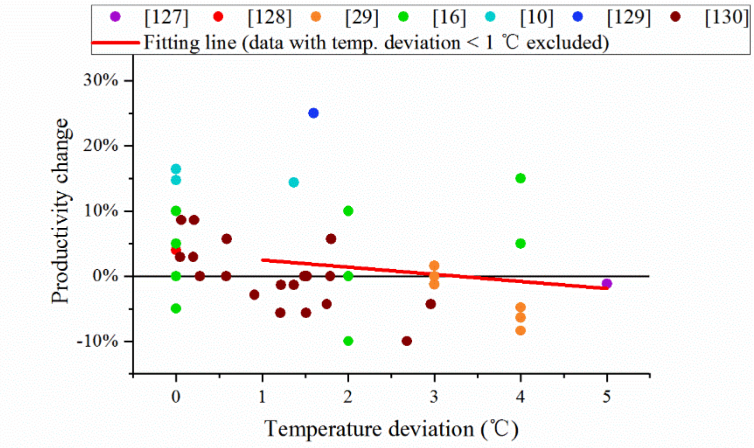


Fig. 14. Results of productivity changes with fans vs. temperature deviations (N=7): fitting without data of temperature deviation <1°C. Legend and the color of the dots refer to different studies.

4. Discussion

4.1 Analyses of trigger and effects of fan-use

Trigger of fan use. Fig. 5a shows that fan-use is more prevalent in MM and NV buildings because AC buildings usually have cooler indoor environments than MM and NV buildings, and so, fewer occupants need fans. When extending the temperature range, fan-use models of AC buildings do not show large deviations from those of MM and NV buildings (Fig. 5(b, e)). Therefore, it is reasonable to believe that if indoor temperatures in AC buildings become higher, more occupants will use fans to remain comfortable. In a similar way, the climate in Europe is less extreme than in Asia in the summer, so people in Asia make more use of fans. Similarly, as shown in Fig. 6a, office buildings have lower fan-use rates because their indoor environments are cooler than those of residential buildings. Whereas with extended temperature ranges, offices buildings can have the same or even higher fan-use rates (Fig. 6b). These findings indicate that the main trigger of using fans is a warm indoor environment, whereas building types do not noticeably influence the fan-use mode.

Fan, an important adaptive strategy for thermal comfort. The ASHRAE adaptive model [32] is for NV buildings, and it shows that occupants are still comfortable when their ambient temperatures are up to more than 30°C (33°C at most). According to the results in Fig. 6, a high neutral-zone temperature (30°C or higher) is only achieved when occupants have fans. Although occupants in NV or MM buildings may have various approaches to adapting to warm environments, such as opening windows and doors, adjusting clothing, and drinking cool beverages, they could hardly become comfortable with ambient temperatures higher than 30°C (red and orange dots; no fans) unless they have fans (green and blue dots; with fans). This result also indicates that using fans is an important factor for adapting to warm environments in summer.

Energy saving potential. The study [3] implies that using fans could save more than 40% of energy, which is much higher than the energy-saving estimation shown in Fig. 13 (20% at most). The difference is caused by the method to predict energy savings: the energy-saving estimation of [3] is based on energy simulations with the changed set-point temperatures, whereas that of this study is based on the change of AC-use rates of MM buildings rather than the real or the simulated energy consumptions. Nonetheless, the field studies listed in Table 3 in the Appendix offer no details of how the occupants set the indoor temperatures with or without fans. Therefore, it is difficult to define the extended set-point temperatures generated by using fans and the resulting energy savings.

3-K ambient temperature extension with fans for productivity. Fig. 14 shows a trend that fans can extend the productivity by 3 K more than the comparison temperatures. This extension is coincident with the extensions of neutral temperatures and the upper limit of neutral-zone temperatures mentioned in Section 4.1 (both are about 3°C; Fig. 7). One hypothesis states that human productivity is related to the body's thermal conditions [23, 24]. Fans effectively cool the bodies and maintain neutral body temperatures in warmer environments but can only bring warm environments to neutral within a certain range (3 K increase; Fig. 7). Thus, when the temperature deviation is too large, individuals using fans still feel too warm, so their productivity may decline.

4.2 Applications of this study

This study summarized numerous studies related to fan-use in field studies. The applications of the findings in this study are as follows:

(1) According to the fan-use rate models (Equations (2)~(13)), fan-use rates can be predicted in a certain building.

Also, fan-use rates help researchers and designers understand the control behaviors and comfort requirements of building occupants [5, 17].

(2) According to the results mentioned in Fig. 7, fans can averagely extend neutral temperatures by 3 K in the real world. This finding can be used to define the different comfortable ranges for people with and without fans, as well as specifically help define the neutral-zone temperatures for MM buildings, which are missing in the current standards regarding indoor environments.

(3) AC-use rate models (Equations (14) and (15)) contribute to the energy estimations of MM buildings with and without fans. Along with the neutral-zone temperatures (Figs. 7 and 8) being set as indoor set-point temperatures, AC-use rate models may be used as algorithms for running AC systems in the energy simulations of MM buildings. These algorithms are different from the conventional ones of building energy simulations with fixed set-point temperatures (usually lower than 26°C) and always-on air-conditioning systems.

(4) The findings of human productivity presented in Fig. 14 offer guidance for building designers and employers to offer fans to improve or maintain productivity when ambient temperature fluctuations do not exceed 3 K.

4.3 Limitations and potential topics for future studies

First, it should be noted that a large proportion of the collected studies had been conducted in Asia. Although the obtained results (fan-use rates and effects) provide critical information, they will potentially be more suitable for Asian regions. Second, as mentioned in Section 3.2.2, the energy savings achieved by fans were estimated by using AC-use rate differences in MM buildings but were not based on real set-point temperatures with and without fans, which would have given a direct energy saving estimation. Therefore, more studies are needed to prove the final energy savings using fans. Third, the trend in Fig. 14 is not universal or fully validated because of the limited number of collected studies. The validation of the trend could be a future work when there are more relevant studies. Moreover, air speed is not analyzed in this review because only a small group of collected studies provide data of air speed and no robust correlations between air speed and neutral temperature were found. One reason for no robust correlations could be that literature do not give detailed data of air speed of fans, natural wind or AC. Airflow of fans is usually local and intense (mostly on upper body parts of occupants), while natural wind and AC are less intense and could cover bigger area of a body. It is questionable whether merely a measured air speed is able to fully represent the air movement of a person experiences. Another reason is that measurement locations are often limited in real buildings which might not precisely represent ambient air velocities of occupants. Lastly, many factors (such as fan type, fan size and location) may influence the results in this study, whereas they are not provided in most of the collected literature, and thus it's impossible to analyze them.

As for future studies, several potential topics, mostly related to fan-use in AC buildings, are worth further exploration. First, control behaviors over AC thermostats and fans should be studied. Using fans can make occupants comfortable at elevated AC set-point temperatures [5]. Nonetheless, current literature provides little detailed information regarding how occupants use AC thermostats and fans simultaneously. For example, it is still unknown whether occupants use fans when AC is available, and if they do, especially in dynamic conditions (such as moving from outdoors to indoors), how they choose certain fan-speed levels and AC set-point temperatures is another piece of missing information. This work is useful for estimating the energy consumption of AC buildings where occupants have fans and thermostats. This work could be done through lab experiments and validated by field investigations. Second, practical control strategies of integrating AC and fans should be studied. As described in Section 3.2.2, using fans postpones the use of AC. This postponement is helpful for proposing the "fan-first" control strategy for air-conditioning systems. In future, the delay times and indoor temperature thresholds for turning on air-conditioning should be explored. Last, the cooling effects of fans may also improve people's comfort and productivity in outdoor or semi-outdoor environments where air-conditioning systems are usually not available. Fans may create wider comfort zones in outdoor environments and increase the work productivity of people working outdoors. Since outdoor environments involve more variables, such as strong winds and solar radiation, the effects will likely differ from those of fans indoors.

5. Conclusions

This study reviewed fan-use rates in field studies and their effects on thermal comfort, energy conservation, and human productivity. The major findings are listed as follows:

(1) Currently, fans are more prevalent in MM and NV buildings but not in AC buildings. Despite of some fan-use rate differences caused by different cooling strategies (AC, MM and NV) and building functions (residential and office), fan-use rate models in different buildings have similar tendencies and they are mainly decided by environmental temperatures. This result indicates that the main trigger of using fans is the indoor or outdoor temperatures, not building types or functions. Several models were established to present fan-use rates in different buildings correlating with indoor and outdoor temperatures, respectively.

(2) Using fans increases the average neutral temperatures and upper limit of neutral-zone temperatures (using TSV=+0.5) in buildings by about 3 K from 25.7°C to 28.7°C and from 27.5°C to 30.7°C, respectively.

(3) Fan-use reduces AC-use in MM buildings. According to the AC-use rate models in this review, the peak reduction of AC-use rate is about 20% when the outdoor temperature is 32.5°C. When the outdoor temperature is 25°C-35°C, the AC-use rate is reduced by more than 15%, which indicates that at least 15% of cooling energy can be saved in MM buildings.

(4) When the temperature rises within 1 K from its comparison temperatures, offering fans to occupants can improve their productivity better than it under the comparison temperatures without fans. As temperature increases more, by 1-3 K from the comparison temperatures, a trend shows that fans can still maintain occupants' productivity at

the levels under comparison temperature. This 3 K is coincident with the extensions of neutral temperatures and the upper limits of neutral-zone temperatures. As temperature further increases beyond 3K from the comparison temperature, fan cannot maintain the productivity level from decreasing.

Acknowledgments

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Appendix

Table 1. Summary of fan-use rates and models.

Studies	Region	Sample size	Building function	Building type	Fan type^1	Max. fan-use rate (%)	Temp. type^2	Corresponding temp. (°C)	Fan-use models
[27]	Chongqing, China	573	Residential	NV	Ceiling	87	Out-Raw	28	logit(p)=$0.45\times T_{out}$ -12.59 R^2=0.82
	Chongqing, China	428	Residential	MM	Ceiling	75	Out-Raw	28.7	-
[33]	Chongqing, China	1471	Residential	NV	N.A.	60	In-Air	32.5	$0.9960\times T_{in}^2$ $-49.9940\times T_{in}$ $+627.33$ R^2=0.9853
	Wuhan, China	1281	Residential	NV	N.A.	100	In-Air	34	$0.8189\times T_{in}^2$ $-38.22\times T_{in}$ $+448.30$ R^2=0.9591
	Nanjing, China	1332	Residential	NV	N.A.	100	In-Air	32.5	$0.7103\times T_{in}^2-29.9070\times T_{in}$ $+307.53$ R^2=0.9463
[34]	Guangzhou, China	1395	Hybrid	MM	N.A.	100	In-ET	29.5	$100\times\Phi(0.41528\times T_{in}$ $-10.71057)$
[35]	Guangzhou, China	921	Hybrid	NV	N.A.	100	In-ET	31	$100\times\Phi(0.331\times T_{in}$ $-9.539)$
[36]	Haikou, China	1944	Residential	MM	N.A.	82.3	Out-Monthly	28.2	T_{out} <22.9°C: $2.603\times T_{out}$ -41.004 T_{out} >22.9°C: $12.296\times T_{out}$ -264.28
[37]	Huanggang, China	85	Residential	MM	N.A.	100	-	-	-
[38]	Guangzhou, China	1092	Residential	NV	Ceiling	95	In-ET	33	logit(p)=$0.66\times T_{in}$ -19.12 R^2=0.48
[39]	Xi'an China	1605	Residential	NV	N.A.	100	In-Air	33	logit(p)=$0.372\times T_{in}$ -10.89 R^2=0.837
	Xi'an China	1605	Residential	NV	N.A.	100	Out-Raw	35	logit(p)=$0.283\times T_{out}$ -7.63 R^2=0.87
[18]	Changsha, China	2159	Office	MM	Ceiling and Wall	100	Out-Raw	33	logit(p)=$0.621\times T_{out}$ -16.792 R^2=0.683
[40]	Tianjin, China	4743	Residential	MM	N.A.	34	Out-Raw	33	-
[25]	Changsha, China	240	Residential	AC	N.A.	57.5	In-Air	25.99	-
	Changsha, China	132	Residential	AC	N.A.	43.9	In-Air	25.99	-
	Changsha, China	107	Residential	AC	N.A.	52.3	In-Air	26.03	-

[41]	Changsha, China	101	Residential	MM	N.A.	100	Out-Raw	32.91	-
	Yueyang, China	131	Residential	NV	N.A.	100	Out-Raw	30.1	-
[42]	Hanzhong, China	99	Residential	MM	N.A.	64	In-Air	26	-
[43]	Chongqing, China	732	Residential	MM	N.A.	81	In-Operative	34	$0.4053\times T_{in}^2-13.834\times T_{in}+87.547$ $R^2=0.9759$
	Chongqing, China	732	Residential	MM	N.A.	58	In-Operative	34	$0.6439\times T_{in}^2-30.786\times T_{in}+364.2$ $R^2=0.9709$
[44]	Nanyang, China	1320	Residential	MM	N.A.	100	In-Air	33	$7.1416\times T_{in}$ -164.18 $R^2=0.7415$
[17]	Oxford, UK	2441	Office	NV	N.A.	100	In-Air	21	$0.0912\times T_{in}$ -1.87 $R^2=0.369$
	Oxford, UK	2441	Office	NV	N.A.	100	Out-Raw	21	$0.042\times T_{out}$ -0.54 $R^2=0.375$
	Oxford, UK	1132	Office	NV	N.A.	100	In-Air	21	$0.040\times T_{in}$ -0.67 $R^2=0.066$
	Oxford, UK	1132	Office	NV	N.A.	100	Out-Raw	24	$0.029\times T_{out}$ -0.12 $R^2=0.24$
[45]	Karachi, Multan, Peshawar, Quetta & Saidu Sharif, Pakistan	4927	Office	MM	N.A.	100	In-Globe	31	-
		4927	Office	MM	N.A.	100	Out-Raw	28	-
[46]	Singapore	257	Residential	MM	N.A.	88.8	Out-Daily	-	-
[26]	UK	5000	Office	MM	N.A.	76	Out-Raw	21	$\text{logit}(p)=0.220\times T_{out}$ -5.37
	Europe	4655	Office	MM	N.A.	58	Out-Raw	32	$\text{logit}(p)=0.110\times T_{out}$ -3.80
	Pakistan	7000	Office	MM	N.A.	100	Out-Raw	33	$\text{logit}(p)=0.301\times T_{out}$ -7.09
	UK	5000	Office	MM	N.A.	58	In-Globe	27	$\text{logit}(p)=0.817\times T_{in}$ -22.33
	Europe	4655	Office	MM	N.A.	50	In-Globe	31	$\text{logit}(p)=0.243\times T_{in}$ -8.36
	Pakistan	7000	Office	MM	N.A.	98	In-Globe	38	$\text{logit}(p)=0.431\times T_{in}$ -12.01
[47]	Tokyo, Japan	2402	Office	AC	Desk and Floor	64	In-Air	28.2	-

	Tokyo, Japan	2402	Office	AC	Desk and Floor	64	Out-Raw	29.7	-
[48]	Philadelphia, USA	5548	Office	AC	N.A.	60	In-Operative	25.8	logit(p)=$0.66\times T_{in}$ -16.68 R^2=0.13
	Philadelphia, USA	5548	Office	AC	N.A.	-	Out-Raw	-	logit(p)=$0.08\times T_{out}$ -2.36 R^2=0.17
[49]	Fukuoka, Japan	81	Office	NV	Floor	19.1	In-Air	28.2	-
	Fukuoka, Japan	222	Office	AC	Floor	5.7	In-Air	26.3	-
[50]	Lumpur, Malaysia	115	Office	AC	Floor	10	In-Air	24	-
	Bandung, Indonesia	300	Office	MM	Floor	1	In-Air	26.2	-
	Singapore	56	Office	AC	Floor	7	In-Air	23.1	-
	Yokohama & Tokyo, Japan	455	Office	MM	Floor	6.8	In-Air	26.4	-
[22]	Sydney, Australia	1185	Residential	MM	Ceiling and Desk	72	Out-Raw	37	logit(p)=$0.11\times T_{out}$ -4.79 R^2=0.15
[51]	Chennai & Hyderabad, India	559	Office	NV	Ceiling and Floor	100	In-Globe	31	logit(p)=$0.448\times T_{in}$ -11.706 R^2=0.17
	Chennai & Hyderabad, India	2053	Office	AC	Ceiling and Floor	100	In-Globe	31	logit(p)=$0.338\times T_{in}$ -10.698 R^2=0.12
[52]	Chennai, India	1389	Office	AC	N.A.	100	Out-Daily	34	logit(p)=$0.59\times T_{out}$ -17.62 R^2=0.264
	Chennai, India	672	Office	MM	N.A.	100	Out-Daily	31	logit(p)=$0.75\times T_{out}$ -20.89 R^2=0.300
	Hyderabad, India	1356	Office	MM	N.A.	100	Out-Daily	31	logit(p)=$0.51\times T_{out}$ -13.07 R^2=0.143
[53]	Hyderabad, India	3962	Residential	MM	Ceiling	70	In-Globe	40	$-0.007\times T_{in}^3+0.572\times T_{in}^2-7.099\times T_{in}$ -57.5 R^2=1
[54]	Jaipur, India	1220	Hybrid	NV	N.A.	95	In-Air	30.9	-
[55]	Jaipur, India	1418	Hybrid	MM	N.A.	100	In-Air	26	-
[56]	Pakistan	6802	Office	NV	Ceiling	100	In-Globe	27	logit(p)=$0.426\times T_{in}$ 11.78 R^2=0.48
[57]	Detroit, USA	15598	Residential	MM	N.A.	11.3	In-Air	25.2	-

[21]	Harbin, China	423	Residential	MM	N.A.	3	In-Air	26.9	-
	Harbin, China	423	Residential	MM	N.A.	3	Out-Raw	27	-
[58]	Jogjakarta, Indonesia	274	Residential	NV	N.A.	78.1	-	-	-
[20]	Kharagpur, India	67	Teaching	NV	Ceiling and Wall	100	In-Operative	27	-
[59]	Shanghai, China	67	Residential	MM	N.A.	87	-	-	-
[60]	Singapore	538	Residential	MM	N.A.	80	-	-	-
[61]	Cuba	101	Residential	NV	N.A.	59	-	-	-
[62]	Taiwan, China	968	Office	MM	N.A.	13	-	-	-
	Taiwan, China	707	Residential	MM	N.A.	25	-	-	-
[63]	Oxford & Aberdeen, UK	1311	Office	NV	N.A.	100	In-Air	25	$0.0683\times T_{in}$ -1.4395 $R^2=0.3514$
	Oxford & Aberdeen, UK	1311	Office	NV	N.A.	80	Out-Raw	29	$0.0408\times T_{out}$ -0.5585 $R^2=0.3276$
[64]	Johor Bahru, Malaysia	345	Residential	MM	Ceiling	80	-	-	-
[31]	Hyogo & Osaka, Japan	70	Residential	MM	N.A.	100	In-Operative	33	$\mathrm{logit}(p)=0.88\times T_{in}$ -25.5 $R^2=0.8$
	Hyogo & Osaka, Japan	70	Residential	MM	N.A.	100	Out-Raw	34.5	$\mathrm{logit}(p)=0.69\times T_{out}$ -19.8 $R^2=0.83$
[65]	Chandigarh & Roorkee, India	984	Residential	MM	N.A.	100	In-Globe	31.5	-
[66]	Lausanne, Switzerland	3538	Office	NV	N.A.	100	In-Air	34	$\mathrm{logit}(p)=0.696\times T_{in}$ -19.32 $R^2=0.39$
	Lausanne, Switzerland	3538	Office	NV	N.A.	82	Out-Raw	32	$\mathrm{logit}(p)=0.311\times T_{out}$ -8.18 $R^2=0.39$
[67]	Taiwan, China	1480	Teaching	MM	Ceiling	100	Out-Raw	33	$\mathrm{logit}(p)=0.88\times T_{out}$ -25.6 $R^2=0.88$
[68]	Chongqing, China	452	Residential	MM	N.A.	80	Out-Raw	36	$0.0045\times T_{in}^2 - 0.2176\times T_{in} + 2.6696$ $R^2=0.7753$
[69]	Chongqing, Chengdu & Changsha, China	1477	Hybrid	NV	N.A.	95	In-Air	35	$-0.01\times T_{in}^2 + 5.411\times T_{in}$ -85.34 $R^2=0.898$
[70]	Portugal	1300	Office	AC	N.A.	6.8	In-Air	24.9	-

[71]	Greece and UK	581	Office	AC	N.A.	14	In-Globe	24.8	$\mathrm{logit}(p)=0.377\times T_{in}-12.1$
	Greece and UK	581	Office	AC	N.A.	14	Out-Raw	19.3	-
	Greece and UK	373	Office	MM	N.A.	17	In-Globe	25.3	-
	Greece and UK	373	Office	MM	N.A.	17	Out-Raw	25.3	-
	Greece and UK	619	Office	NV	N.A.	13	In-Globe	25.9	$\mathrm{logit}(p)=0.804\times T_{in}-22.6$
	Greece and UK	619	Office	NV	N.A.	13	Out-Raw	19.6	-
	Greece and UK	2049	Office	AC	N.A.	6	In-Globe	23.3	$\mathrm{logit}(p)=0.131\times T_{in}-5.1$
	Greece and UK	2049	Office	AC	N.A.	6	Out-Raw	18.4	-
	Greece and UK	1963	Office	MM	N.A.	36	In-Globe	24	$\mathrm{logit}(p)=0.577\times T_{in}-15.4$
	Greece and UK	1963	Office	MM	N.A.	36	Out-Raw	18.2	-
	Greece and UK	3023	Office	NV	N.A.	30	In-Globe	24.4	$\mathrm{logit}(p)=0.519\times T_{in}-13.7$
	Greece and UK	3023	Office	NV	N.A.	30	Out-Raw	19	-
	Pakistan	1562	Office	MM	N.A.	52	In-Globe	27.7	$\mathrm{logit}(p)=0.532\times T_{in}-14.9$
	Pakistan	1562	Office	MM	N.A.	52	Out-Raw	24.2	-
	Pakistan	3697	Office	NV	N.A.	55	In-Globe	27.4	$\mathrm{logit}(p)=0.506\times T_{in}-13.4$
	Pakistan	3697	Office	NV	N.A.	55	Out-Raw	23.7	-
[72]	Xi'an China	1320	Residential	MM	N.A.	100	In-Air	34	$7.1314\times T_{in}-165.21$ $R^2=0.7411$
[73]	Sydney, Australia	4876	Residential	MM	Ceiling and Desk	-	Out-Raw	-	$\mathrm{logit}(p)=0.11\times T_{out}-4.79$
[74]	Darwin, Australia	2535	Residential	MM	Portable and Ceiling	-	Out-Raw	-	$\mathrm{logit}(p)=0.232\times T_{out}-6.523$
	Darwin, Australia	2535	Residential	MM	Portable and Ceiling	-	In-Air	-	$\mathrm{logit}(p)=0.36\times T_{in}-10.355$

[75]	Tokyo, Japan	2504	Residential	NV	N.A.	-	Out-Raw	-	$\mathrm{logit}(p)=0.305\times T_{out}$ -8.232 $R^2=0.28$
	Tokyo, Japan	2505	Residential	NV	N.A.	-	In-Air	-	$\mathrm{logit}(p)=0.508\times T_{in}$ -14.737 $R^2=0.31$
	Tokyo, Japan	423	Residential	AC	N.A.	-	In-Air	-	$\mathrm{logit}(p)=0.312\times T_{in}$ -8.642 $R^2=0.11$
[76]	Hyderabad, India	3962	Residential	MM	Ceiling	83	Out-Raw	-	
[77]	Tokyo, Japan	320	Office	NV	Floor, Wall and Desk	87	In-Air	29	$\mathrm{logit}(p)=0.441\times T_{in}$ -12.18 $R^2=0.101$
	Tokyo, Japan	1689	Office	AC	Floor, Wall and Desk	90	In-Air	27.5	$\mathrm{logit}(p)=0.277\times T_{in}$ -6.38 $R^2=0.021$
	Tokyo, Japan	423	Office	NV	Floor, Wall and Desk	97	Out-Daily	-	$\mathrm{logit}(p)=0.422\times T_{out}$ -10.19 $R^2=0.179$

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[1]: *None* for no fans, *Ceiling* for ceiling fans, *Wall* for fans installed on the wall, *Desk* for desk fans, *Chair* for chairs with fans, *Clothing* for clothing with fans, *Portable* for Portable fans, *Floor* for floor fans or pedestal fans, N.A (not available) for studies having fans but not providing information of fan types.

[2]: *Out* means outdoor, *Raw* for actual or binned actual temperatures (binned indicates temperatures are assigned to several temperature points, e.g. 24.1°C is assigned to the temperature point of 24°C while 26.8°C is assigned to the temperature point of 27°C), *Monthly* for average monthly temperatures, Daily for average daily temperatures; *In* means indoor, *Operative* for operative temperatures, *Air* for air temperatures, *ET** for new effective temperatures, Globe for globe temperatures.

Table 2. Summary of neutral temperatures and upper limits of neutral-zone temperatures with and without fans.

Studies	Region	Sample size	Building function	Building type	Fan type[1]	Relative humidity (%)	Neutral temp. (°C)	Upper limit[2] (°C)
[78]	Makassar, Indonesia	1111	Teaching	NV	N.A.	68	30.2	32.5
[79]	Ho Chi Minh City, Vietnam	3395	Teaching	NV	Ceiling	65	31.3	34.3
[80]	Chennai, India	50	Residential	NV	N.A.	60	29.5	31.3
[19]	Singapore	506	Teaching	NV	Ceiling	70	28.8	29.8
[81]	Changsha, China	1273	Teaching	NV	Ceiling	71.2	21.5	29.5
[82]	Hyderabad, India	100	Residential	NV	Ceiling	45	29.23	30.8
[20]	Kharagpur, India	67	Teaching	NV	Ceiling and Wall	50	29.5	31.8
[83]	Kharagpur, India	121	Teaching	NV	Ceiling	50	26.5	29.3
[84]	Lumpur, Malaysia	208	Residential	NV	Ceiling	70	30.93	32.1
	Lumpur, Malaysia	208	Residential	NV	Ceiling	70	28.63	29.4
[85]	La Réunion	594	Teaching	MM	Ceiling	73	27.7	29.8
[86]	Kajang, Malaysia	375	Teaching	NV	Ceiling	62.4	28.4	29.5
[87]	Calcutta, India	100	Teaching	NV	Ceiling	68	30.9	31.7
[88]	Bangkok, Thailand	376	Office	NV	N.A.	60	27.4	29.5
[89]	Jaipur, India	900	Teaching	NV	Ceiling	39.4	26.5	29.2
[90]	Chennai & Hyderabad, India	1352	Office	NV	Ceiling and Wall	45	27.3	29.2
[51]	Chennai & Hyderabad, India	152	Office	NV	Ceiling and Floor	52.2	26.4	28.8
[91]	Jaipur, India	855	Hybrid	NV	N.A.	49.12	29.4	31.1
[54]	Jaipur, India	1220	Hybrid	NV	N.A.	46	28.0	30.8
[92]	Jaipur, India	1020	Office	AC	Wall	35.7	27.5	30.1
[93]	Maiduguri, Nigeria	100	Temple	NV	Wall and Floor	31	31.2	32.0
[94]	Siliguri & Sonada, Bengal	346	Teaching	NV	Ceiling	51.7	29.7	31.3
[95]	Dhaka, Bengal	100	Teaching	NV	Ceiling	66.25	30.2	30.4

[77]	Tokyo, Japan	1979	Office	AC	Floor, Wall and Desk	50.9	26.8	28.3
[96]	Jaipur, India	429	Residential	NV	Ceiling	53.4	30.15	31.8
[97]	Hyderabad, India	113	Residential	MM	Ceiling	44.5	29.2	30.8
[58]	Jogjakarta, Indonesia	525	Residential	NV	N.A.	68.6	29.2	30.0
[98]	Kota Kinabalu, Malaysia	890	Residential	NV	N.A.	70.71	30.2	31.5
[99]	Chennai, India	402	Railway station	NV	Ceiling and Wall	50	31.93	32.7
[100]	Xi'an, China	80	Residential	MM	N.A.	50	27.0	31.6
[101]	Tiruchirappalli, India	176	Teaching	NV	Ceiling	55.34	29.0	29.9
[102]	Nkongsamba, Douala & Bafang, Cameroon	1200	Residential	NV	None	48.2	24.58	25.7
[103]	Shiraz, Iran	1605	Teaching	NV	None	38.3	23.3	25.2
[104]	Jakarta, Indonesia	70	Cathedral	NV	None	74.3	27.6	28.1
	Jakarta, Indonesia	77	Museum	NV	None	74.1	27.8	28.5
	Jakarta, Indonesia	72	Market	NV	None	70	27.3	28.9
[105]	Guangzhou, China	460	Office	MM	None	70	26.8	28.6
[106]	Jos, Nigeria	200	Hybrid	NV	None	71.9	24.57	27.68
[107]	Nanyang, China	149	Residential	MM	None	75	27.3	29.1
[108]	Seville, Spain	34	Office	MM	None	51.8	24.6	27.1
[109]	Jakarta, Indonesia	596	Office	MM	None	65.7	26.7	28.3
	Jakarta, Indonesia	596	Office	MM	None	65.7	26.4	28.0
[110]	Jakarta, Indonesia	90	Teaching	MM	None	66.9	24.1	26.1
	Jakarta, Indonesia	90	Teaching	MM	None	66.9	21.7	23.9
[111]	Guangdong, China	448	Residential	NV	None	76	26.4	27.9
[112]	Jiangsu & Zhejiang, China	1814	Not-given	NV	None	68.3	25.6	27.4
[94]	Siliguri & Sonada, Bengal	382	Teaching	NV	None	66.3	21.2	24.1

[113]	Nigeria	40	Residential	MM	None	50	29.1	31.2
[114]	Jakarta, Indonesia	596	Office	MM	None	65.7	26.4	27.9
[115]	Mexicali, Hermosillo, La Paz, Culiacán, Colima & Mérida, Mexico	150	Residential	NV	None	50	24.8	26.5
[116]	Bandung, Indonesia	20	Teaching	MM	None	59.8	24.7	26.5
	Bandung, Indonesia	20	Teaching	MM	None	59.8	25.7	27.4
	Bandung, Indonesia	20	Teaching	MM	None	59.8	25.4	27.0
[117]	Jordan, Syria	160	Residential	NV	None	30	26.5	28.6
[118]	Ilam, Iran	513	Residential	NV	None	30	29.0	30.9
[119]	Hermosillo, Mexicali, Merida & Colima, Mexico	663	Residential	NV	None	50	25.3	29.1
[120]	Seoul, Korea	24	Residential	MM	None	59.5	25.0	26.1

[1]: *None* for no fans, *Ceiling* for ceiling fans, *Wall* for fans installed on the wall, *Desk* for desk fans, *Chair* for chairs with fans, *Clothing* for clothing with fans, *Portable* for Portable fans, *Floor* for floor fans or pedestal fans, N.A (not available) for studies having fans but not providing information of fan types.

[2]: 90% acceptable limit, i.e., thermal sensation vote is no higher than +0.5.

Table 3. Summary of AC-use with and without fans.

Studies	Region	Sample size	Building function	Fan type^1	Temp. type^2	Temp. with 50% AC-use rate (°C)	Fan-use rates with 50% AC-use rate	AC-use rate models
[27]	Chongqing, China	428	Residential	Ceiling	Out-Raw	27.5	50.0%	logit(p)=0.37×T_{out} -10.19 R^2=0.72
[36]	Haikou, China	1944	Residential	N.A.	Out-Monthly	26.5	61.6%	T_{out} <24.4°C: 0.4177×T_{out} -5.1268 R^2=0.1285 T_{out} >24.4°C: 21.859×T_{out} -527.89 R^2=0.942
[18]	Changsha, China	2159	Office	Ceiling and Wall	Out-Raw	32.5	96.7%	logit(p)=0.852×T_{out} -27.721 R^2=0.75
	Changsha, China	2159	Office	None	Out-Raw	28.3	0	logit(p)=0.683×T_{out} -19.35 R^2=0.783
[40]	Tianjin, China	4743	Residential	N.A.	Out-Raw	33.0	25.0%	
[44]	Nanyang, China	1320	Residential	N.A.	Out-Raw	35.4	88.6%	0.3679×T_{out}^2 -17.475×T_{out} +207.96 R^2=0.6612
[72]	Xi'an, China	1320	Residential	N.A.	Out-Raw	34.2	47.0%	0.3769×T_{out}^2 -17.575×T_{out} +210.11 R^2=0.6552
[121]	Chengdu, China	400	Residential	N.A.	Out-Raw	29.5	44.3%	logit(p)=0.172×T_{out} -5.063 R^2=0.089
[122]	China	114	Office	None	Out-Raw	28.5	0	logit(p)=0.635×T_{out} -18.035 R^2=0.324
[123]	Hangzhou, China	2512	Office	None	Out-Raw	30.8	0	1/(exp(-0.279×T_{out} +9.705)-1)
[22]	Sydney, Australia	1185	Residential	Ceiling and Desk	Out-Raw	34.2	26.3%	logit(p)=0.24×T_{out} -8.2 R^2=0.4
[52]	Chennai, India	723	Office	N.A.	Out-Daily	22.9	1.6%	logit(p)=0.30×T_{out} -6.86 R^2=0.134
	Hyderabad, India	1489	Office	N.A.	Out-Daily	31.2	94.5%	logit(p)=0.35×T_{out} -10.93 R^2=0.394
[53]	Hyderabad, India	3962	Residential	Ceiling	In-Globe	40.0	70.6%	0.464×T_{in}^2 -26.98×T_{in} +385.8 R^2=0.966
	Jaipur, India	3962	Residential	Ceiling	In-Globe	>40.0	>72.0%	-0.113×T_{in}^2 +8.783×T_{in} -146.7 R^2=0.751
[31]	Hyogo & Osaka, Japan	80	Residential	N.A.	In-Operative	29.4	59.20%	logit(p)=0.87×T_{in} -26.1 R^2=0.78
	Hyogo & Osaka, Japan	42	Residential	None	In-Operative	28.8	0	logit(p)=0.76×T_{in} -22 R^2=0.76

	Hyogo & Osaka, Japan	80	Residential	N.A.	Out-Raw	29.3	60.3%	logit(p)=0.78×T_{out} -22.9 R^2=0.79
	Hyogo & Osaka, Japan	42	Residential	None	Out-Raw	28.4	0	logit(p)=0.55×T_{out} -15.5 R^2=0.79
[67]	Taiwan, China	1480	School	Ceiling	Out-Raw	35.3	96.3%	logit(p)=0.97×T_{out} -34.2 R^2=0.86
[68]	Chongqing, China	452	Residential	N.A.	Out-Raw	35.0	62.1%	
[71]	Greece and UK	373	Office	N.A.	In-Globe	30.9	17.0%	logit(p)=0.498×T_{in} -15.4
	Greece and UK	2049	Office	N.A.	In-Globe	24.2	12.7%	logit(p)=0.281×T_{in} -6.8
	Pakistan	1562	Office	N.A.	In-Globe	31.8	88.3%	logit(p)=0.220×T_{in} -7.0
[124]	Fukuoka, Japan	36	Residential	None	Out-Raw	31.6	0	$1/(1+1.285^{-(T_{out}-31.6)})$
	Fukuoka, Japan	36	Residential	None	Out-Raw	23.2	0	$1/(1+1.405^{-(T_{out}-23.2)})$
	Fukuoka, Japan	36	Residential	None	In-Globe	32.2	0	$1/(1+1.850^{-(T_{in}-32.2)})$
	Fukuoka, Japan	36	Residential	None	In-Globe	28.2	0	$1/(1+3.425^{-(T_{in}-28.2)})$
[74]	Darwin, Australia	2535	Residential	Portable and Ceiling	Out-Raw	45.9	98.4%	logit(p)=0.293×T_{out} -13.459
[75]	Tokyo, Japan	3121	Residential	N.A.	Out-Raw	29.4	54.9%	logit(p)=0.271×T_{out} -7.979 R^2=0.22
	Tokyo, Japan	3122	Residential	N.A.	In-Air	32.9	85.8%	logit(p)=0.214×T_{in} -7.044 R^2=0.12
[125]	China	474	Residential	None	Out-Raw	29.7	0	logit(p)=0.199×T_{out} -5.915
[26]	Europe	4655	Office	N.A.	In-Globe	>31.0	>30.0%	
	Pakistan	7000	Office	N.A.	In-Globe	32.0	85.6%	
	Europe	4655	Office	N.A.	Out-Raw	>35.0	>50%	
	Pakistan	7000	Office	N.A.	Out-Raw	28.0	79.2%	
[76]	Hyderabad, India	3962	Residential	Ceiling	Out-Raw	>35.0	>85.0%	
[30]	Tokyo, Japan	39	Residential	None	Out-Raw	19.1	0	$1/(1+55.1\times\exp(-0.33\times T_{out}))$

	Tokyo, Japan	39	Residential	N.A.	Out-Raw	26.5	-	$1/(1+9.56\times10^{5}\times\exp(-0.52\times T_{out}))$
	Tokyo, Japan	39	Residential	N.A.	Out-Raw	22.5	-	$1/(1+3.86*10^{4}\times\exp(-0.47\times T_{out}))$
[126]	Chongqing, China	-	Residential	None	Out-Daily	24.8	0	$\text{logit}(p)=0.42\times T_{out}-10.4$
	Chongqing, China	-	Residential	None	Out-Daily	32.9	0	$\text{logit}(p)=0.35\times T_{out}-11.5$
	Chongqing, China	-	Residential	None	Out-Daily	25	0	$\text{logit}(p)=0.32\times T_{out}-8.01$
	Chongqing, China	-	Residential	None	Out-Daily	23.4	0	$\text{logit}(p)=0.33\times T_{out}-7.71$
	Chongqing, China	-	Residential	None	Out-Daily	22	0	$\text{logit}(p)=0.42\times T_{out}-9.25$
	Chongqing, China	-	Residential	None	Out-Daily	35.1	0	$\text{logit}(p)=0.65\times T_{out}-21.74$

[1]: *None* for no fans, *Ceiling* for ceiling fans, *Wall* for fans installed on the wall, *Desk* for desk fans, *Chair* for chairs with fans, *Clothing* for clothing with fans, *Portable* for Portable fans, *Floor* for floor fans or pedestal fans, N.A (not available) for studies having fans but not providing information of fan types.

[2]: *Out* means outdoor, *Raw* for actual or binned actual temperatures (binned indicates temperatures are assigned to several temperature points, e.g. 24.1°C is assigned to the temperature point of 24°C while 26.8°C is assigned to the temperature point of 27°C), *Monthly* for average monthly temperatures, Daily for average daily temperatures; *In* means indoor, *Operative* for operative temperatures, *Air* for air temperatures, *ET** for new effective temperatures, Globe for globe temperatures.

Table 4. Summary of human productivity with and without fans.

Studies	Region	Sample size	Temp. (°C)	Fan type[1]	Productivity type	Productivity evaluation scale	Original productivity	Converted productivity	Temp. deviation (°C)	Productivity change
[127]	India	50	24	None	Learning	0-100	61.2	61.2%	-	-
	India	50	29	Ceiling	Learning	0-100	60.0	60.0%	5	-1.2%
[128]	Tokyo, Japan	119	26	Chair	Self-estimated	-50%-+50%	-	4%	0	+4%
[29]	Singapore	15	23	None	Self-estimated	Alert-Sleep	88.1%[2]	88.1%	-	-
	Singapore	15	26	Ceiling	Self-estimated	Alert-Sleep	88.1%[2]	88.1%	3	0
	Singapore	15	27	Ceiling	Self-estimated	Alert-Sleep	81.7%[2]	81.7%	4	-6.40%
	Singapore	15	23	None	Self-estimated	Easy-Difficult to concentrate	83.9%[2]	83.9%	-	-
	Singapore	15	26	Ceiling	Self-estimated	Easy-Difficult to concentrate	85.5%[2]	85.5%	3	+1.60%
	Singapore	15	27	Ceiling	Self-estimated	Easy-Difficult to concentrate	79.1%[2]	79.1%	4	-4.80%
	Singapore	15	23	None	Self-estimated	Productive-Less productive	84.9%[2]	84.9%	-	-
	Singapore	15	26	Ceiling	Self-estimated	Productive-Less productive	83.6%[2]	83.6%	3	-1.30%
	Singapore	15	27	Ceiling	Self-estimated	Productive-Less productive	76.5%[2]	76.5%	4	-8.40%
[16]	Changsha, China	20	28	None	Fatigue	0-100%	15%	85%	-	-
	Changsha, China	20	28	Desk	Fatigue	0-100%	15%	85%	0	0
	Changsha, China	20	28	Desk	Fatigue	0-100%	10%	90%	0	+5%
	Changsha, China	20	30	None	Fatigue	0-100%	0%	100%	-	-

	Changsha, China	20	30	Desk	Fatigue	0-100%	5%	95%	0/2	-5%/+10%
	Changsha, China	20	30	Desk	Fatigue	0-100%	5%	95%	0/2	-5%/+10%
	Changsha, China	20	32	None	Fatigue	0-100%	10%	90%	-	-
	Changsha, China	20	32	Desk	Fatigue	0-100%	10%	90%	0/2/4	0/-10%/+5%
	Changsha, China	20	32	Desk	Fatigue	0-100%	0%	100%	0/2/4	+10%/0/+15%
[10]	Hong Kong, China	140	29.84	None	Fatigue	1-7	3.75[2]	45.8%	-	-
	Hong Kong, China	140	29.84	Clothing	Fatigue	1-7	4.63[2]	60.5%	0	+14.7%
	Hong Kong, China	140	31.21	None	Fatigue	1-7	3.63[2]	43.8%	-	-
	Hong Kong, China	140	31.21	Clothing	Fatigue	1-7	4.61[2]	60.2%	0/1.37	+16.4%/+14.4%
[129]	Guangzhou, China	20	26.8	None	Fatigue	0-100%	40%	60%	-	-
	Guangzhou, China	20	28.4	Ceiling	Fatigue	0-100%	15%	85%	1.6	+25%
[130]	Malaysia	151	30.82	None	Fatigue	0-100%	10.0%	90.0%	-	-
	Malaysia	151	29.35	None	Fatigue	0-100%	5.7%	94.3%	-	-
	Malaysia	151	30.52	None	Fatigue	0-100%	10.0%	90.0%	-	-
	Malaysia	151	30.51	None	Fatigue	0-100%	15.7%	84.3%	-	-
	Malaysia	151	32.31	Ceiling	Fatigue	0-100%	10.0%	90.0%	1.49/1.79/1.8/2.96	0/0/+5.7%/-4.3%
	Malaysia	151	30.57	Ceiling	Fatigue	0-100%	7.1%	92.9%	0.05/0.06/1.22	+2.9%/+8.6%/-1.4%
	Malaysia	151	30.72	Ceiling	Fatigue	0-100%	7.1%	92.9%	0.2/0.21/1.37	+2.9%/+8.6%/-1.4%
	Malaysia	151	31.1	Ceiling	Fatigue	0-100%	10.0%	90.0%	0.28/0.58/0.59/1.75	0/0/+5.7%/-1.4%

Malaysia	151	30.26	Ceiling	Fatigue	0-100%	8.6%	91.4%	0.91	-2.9%
Malaysia	151	32.03	Ceiling	Fatigue	0-100%	15.7%	84.3%	1.21/1.51/1.52/2.68	-5.7%/-5.7%/0/-10.0%

[1]: *None* for no fans, *Ceiling* for ceiling fans, *Wall* for fans installed on the wall, *Desk* for desk fans, *Chair* for chairs with fans, *Clothing* for clothing with fans, *Portable* for Portable fans, *Floor* for floor fans or pedestal fans, N.A (not available) for studies having fans but not providing information of fan types.

[2]: lower values mean worse productivity.

References

[1] P.O. Fanger, Thermal comfort—Analysis and applications in environmental engineering, Copenhagen, Danish Technical Press (1970).
[2] ANSI/ASHRAE, Standard 55-2013: Thermal environmental conditions for human occupancy, American Society of Heating, Refrigerating and Air-Conditioning Engineering, Atlanta, GA, (2013).
[3] H. Zhang, E. Arens, Y. Zhai, A review of the corrective power of personal comfort systems in non-neutral ambient environments, Building & Environment, 91 (2015) 15–41.
[4] Y. He, X. Wang, N. Li, M. He, D. He, K. Wang, Cooling ceiling assisted by desk fans for comfort in hot-humid environment, Building and Environment, 122 (2017) 23-34.
[5] Y. He, N. Li, N. Li, J. Li, J. Yan, C. Tan, Control behaviors and thermal comfort in a shared room with desk fans and adjustable thermostat, Building and Environment, 136 (2018) 213-226.
[6] Y. Zhai, Y. Zhang, H. Zhang, W. Pasut, E. Arens, Q. Meng, Human comfort and perceived air quality in warm and humid environments with ceiling fans, Building and Environment, 90 (2015) 178-185.
[7] Y. Zhai, H. Zhang, Y. Zhang, W. Pasut, E. Arens, Q. Meng, Comfort under personally controlled air movement in warm and humid environments, Building and Environment, 65 (2013) 109-117.
[8] S. Watanabe, T. Shimomura, H. Miyazaki, Thermal evaluation of a chair with fans as an individually controlled system, Building and Environment, 44 (7) (2009) 1392-1398.
[9] W. Pasut, H. Zhang, E. Arens, Y. Zhai, Energy-efficient comfort with a heated/cooled chair: Results from human subject tests, Building and Environment, 84 (2015) 10-21.
[10] A.P. Chan, Y. Zhang, F. Wang, F.F. Wong, D.W. Chan, A field study of the effectiveness and practicality of a novel hybrid personal cooling vest worn during rest in Hong Kong construction industry, Journal of Thermal Biology, 70 (2017) 21-27.
[11] L. Huang, Q. Ouyang, Y. Zhu, L. Jiang, A study about the demand for air movement in warm environment, Building and Environment, 61 (2013) 27-33.
[12] B. Yang, S. Sekhar, A.K. Melikov, Ceiling−mounted personalized ventilation system integrated with a secondary air distribution system–a human response study in hot and humid climate, Indoor air, 20 (4) (2010) 309-319.
[13] S. Atthajariyakul, C. Lertsatittanakorn, Small fan assisted air conditioner for thermal comfort and energy saving in Thailand, Energy Conversion and Management, 49 (10) (2008) 2499-2504.
[14] T. Hoyt, E. Arens, H. Zhang, Extending air temperature setpoints: Simulated energy savings and design considerations for new and retrofit buildings, Building & Environment, 88 (2015) 89-96.
[15] B. Yang, S. Schiavon, C. Sekhar, D. Cheong, K.W. Tham, W.W. Nazaroff, Cooling efficiency of a brushless direct current stand fan, Building and Environment, 85 (2015) 196-204.
[16] Y. He, N. Li, X. Wang, M. He, D. He, Comfort, Energy Efficiency and Adoption of Personal Cooling Systems in Warm Environments: A Field Experimental Study, International journal of environmental research and public health, 14 (11) (2017) 1408.
[17] I.A. Raja, J.F. Nicol, K.J. McCartney, M.A. Humphreys, Thermal comfort: use of controls in naturally ventilated buildings, Energy and Buildings, 33 (3) (2001) 235-244.
[18] W. Liu, Y. Zheng, Q. Deng, L. Yang, Human thermal adaptive behaviour in naturally ventilated offices for different outdoor air temperatures: A case study in Changsha China, Building and Environment, 50 (2012) 76-89.
[19] N.H. Wong, S.S. Khoo, Thermal comfort in classrooms in the tropics, Energy and Buildings, 35 (4) (2003) 337-351.
[20] A.K. Mishra, M. Ramgopal, A thermal comfort field study of naturally ventilated classrooms in Kharagpur, India, Building & Environment, 92 (2015) 396-406.
[21] Z. Wang, L. Zhang, J. Zhao, Y. He, Thermal comfort for naturally ventilated residential buildings in Harbin, Energy and Buildings, 42 (12) (2010) 2406-2415.
[22] J. Kim, R. de Dear, T. Parkinson, C. Candido, Understanding patterns of adaptive comfort behaviour in the Sydney mixed-mode residential context, Energy and Buildings, 141 (2017) 274-283.
[23] R. Kosonen, F. Tan, Assessment of productivity loss in air-conditioned buildings using PMV index, Energy and Buildings, 36 (10) (2004) 987-993.
[24] T. Akimoto, S.-i. Tanabe, T. Yanai, M. Sasaki, Thermal comfort and productivity-Evaluation of workplace environment in a task conditioned office, Building and Environment, 45 (1) (2010) 45-50.
[25] Y. He, N. Li, J. Peng, W. Zhang, Y. Li, Field study on adaptive comfort in air conditioned dormitories of university with hot-humid climate in summer, Energy and Buildings, 119 (2016) 1-12.
[26] J.F. Nicol, M.A. Humphreys, A Stochastic Approach to Thermal Comfort--Occupant Behavior and Energy Use in Buildings, ASHRAE Transactions, 110 (2) (2004).
[27] Z. Wang, W. Zhang, Y. Xiao, Y. Wu, H. Liu, Occupants' Adaptation of Thermal Environment before and after Air-conditioner Installation in Dormitory, Building Energy & Environment, 36 (8) (2017) 14-17.
[28] J.F. Nicol, Characterising occupant behaviour in buildings: towards a stochastic model of occupant use of windows, lights, blinds, heaters and fans, in: Proceedings of the seventh international IBPSA conference, Rio, 2001, pp. 1073-1078.

[29] A. Lipczynska, S. Schiavon, L.T. Graham, Thermal comfort and self-reported productivity in an office with ceiling fans in the tropics, Building and Environment, 135 (2018) 202-212.
[30] M. Schweiker, M. Shukuya, Investigation on the relationship between occupants' individual difference and air-conditioning usage during nighttime in summer, Journal of Environmental Engineering (Transactions of AIJ), 73 (633) (2008) 1275-1282.
[31] T. Nakaya, N. Matsubara, Y. Kurazumi, Use of occupant behaviour to control the indoor climate in Japanese residences, in: Proceedings of conference: Air Conditioning and the Low Carbon Cooling Challenge, Windsor, UK, 2008, pp. 27-29.
[32] R. De Dear, G.S. Brager, The adaptive model of thermal comfort and energy conservation in the built environment, International Journal of Biometeorology, 45 (2) (2001) 100-108.
[33] H. Liu, W. Zheng, B. Li, M. Tan, Y. Gao, Z. Jin, Behavioral adaptation of indoor thermal environment in hot-summer and cold-winter zone, Journal of Central South University (Science and Technology), 42 (6) (2011) 1805-1812 (in Chinese).
[34] Y. Zhang, H. Chen, Q. Meng, Field study on thermal comfort and adaptation in buildings with split air conditioners in hot-humid area of China (2): Adaptive behaviors, HV&AC, 44 (1) (2014) 15-23 (in Chinese).
[35] Y. Zhang, J. Wang, H. Chen, J. Zhang, Q. Meng, Thermal comfort in naturally ventilated buildings in hot-humid area of China, Building and Environment, 45 (11) (2010) 2562-2570.
[36] Y. Qi, Research on thermal comfort and thermal adaptation of residents in tropical island, M.S. Thesis, Tianjin University, 2014 (in Chinese).
[37] Y. Xiong, L. Zhang, Thermal Environment and Thermal Comfort Investigation in the Countryside Housing in Hubei Province, Building Energy Efficiency, 44 (309) (2016) 52-56 (in Chinese).
[38] Y. Zhang, Q. Liu, Q. Meng, Airflow utilization in buildings in hot and humid areas of China, Building and Environment, 87 (2015) 207-214.
[39] L. Si, Research on human thermal comfort and human thermal adaptive behaviour of university dormitories in Xi'an, M.S. Thesis, Xi'an University of Architecture and Technology, 2017 (in Chinese).
[40] Y. Song, Y. Sun, S. Luo, J. Hou, J. Kim, T. Parkinson, R. de Dear, Indoor environment and adaptive thermal comfort models in residential buildings in Tianjin, China, Procedia Engineering, 205 (2017) 1627-1634.
[41] J. Han, Thermal Comfort Model of Natural Ventilation Environment and Its Application in the Yangtze Climate Zone, Ph.D Thesis, Hunan University, 2008 (in Chinese).
[42] M. Zhou, L. Yang, H. Yan, 汉中村镇住宅夏季热舒适调查, Sichuan Building Science, 39 (2) (2013) 341-345 (in Chinese).
[43] H. Zhang, Thermal Comfort of Elderly People During Summer in Residential Buildings, M.S. Thesis, Chongqing University, 2013 (in Chinese).
[44] J. Li, An adaptive thermal comfort model for hot summer and cold winter context, M.S. Thesis, Xi'an University of Architecture and Technology, 2006 (in Chinese).
[45] J.F. Nicol, I.A. Raja, A. Allaudin, G.N. Jamy, Climatic variations in comfortable temperatures: the Pakistan projects, Energy and Buildings, 30 (3) (1999) 261-279.
[46] N. Wong, H. Feriadi, P. Lim, K. Tham, C. Sekhar, K. Cheong, Thermal comfort evaluation of naturally ventilated public housing in Singapore, Building and Environment, 37 (12) (2002) 1267-1277.
[47] M. Indraganti, R. Ooka, H.B. Rijal, Thermal comfort in offices in summer: Findings from a field study under the ‘setsuden’ conditions in Tokyo, Japan, Building and Environment, 61 (Supplement C) (2013) 114-132.
[48] J. Langevin, P.L. Gurian, J. Wen, Tracking the human-building interaction: a longitudinal field study of occupant behavior in air-conditioned offices, Journal of Environmental Psychology, 42 (2015) 94-115.
[49] M.S. Mustapa, S.A. Zaki, H.B. Rijal, A. Hagishima, M.S.M. Ali, Thermal comfort and occupant adaptive behaviour in Japanese university buildings with free running and cooling mode offices during summer, Building and Environment, 105 (2016) 332-342.
[50] S.A. Damiati, S.A. Zaki, H.B. Rijal, S. Wonorahardjo, Field study on adaptive thermal comfort in office buildings in Malaysia, Indonesia, Singapore, and Japan during hot and humid season, Building and Environment, 109 (Supplement C) (2016) 208-223.
[51] M. Indraganti, R. Ooka, H.B. Rijal, Field investigation of comfort temperature in Indian office buildings: a case of Chennai and Hyderabad, Building and Environment, 65 (2013) 195-214.
[52] M. Indraganti, R. Ooka, H.B. Rijal, Thermal comfort in offices in India: Behavioral adaptation and the effect of age and gender, Energy and Buildings, 103 (2015) 284-295.
[53] M. Indraganti, Thermal comfort in apartments in India: Adaptive use of environmental controls and hindrances, Renewable Energy, 36 (4) (2011) 1182-1189.
[54] S. Kumar, M.K. Singh, V. Loftness, J. Mathur, S. Mathur, Thermal comfort assessment and characteristics of occupant's behaviour in naturally ventilated buildings in composite climate of India, Energy for Sustainable Development, 33 (2016) 108-121.
[55] A. Honnekeri, G. Brager, S. Dhaka, J. Mathur, Comfort and adaptation in mixed-mode buildings in a hot-dry climate, in: 8th Windsor Conference: Counting the Cost of Comfort in a Changing World, London, UK, 2014.
[56] H.B. Rijal, P. Tuohy, M.A. Humphreys, J.F. Nicol, A. Samuel, I.A. Raja, J. Clarke, Development of adaptive algorithms for the operation of windows, fans, and doors to predict thermal comfort and energy use in Pakistani

buildings, American Society of Heating Refrigerating and Air Conditioning Engineers (ASHRAE) Transactions, 114 (2) (2008) 555-573.

[57] J.L. White-Newsome, B.N. Sánchez, E.A. Parker, J.T. Dvonch, Z. Zhang, M.S. O'Neill, Assessing heat-adaptive behaviors among older, urban-dwelling adults, Maturitas, 70 (1) (2011) 85-91.

[58] H. Feriadi, N.H. Wong, Thermal comfort for naturally ventilated houses in Indonesia, Energy and Buildings, 36 (7) (2004) 614-626.

[59] K. Zhong, H. Fu, Y. Kang, X. Peng, Indoor thermal conditions and the potential of energy conservation of naturally ventilated rooms in summer, China, Energy and Buildings, 55 (2012) 183-188.

[60] H. Feriadi, N.H. Wong, S. Chandra, K.W. Cheong, Adaptive behaviour and thermal comfort in Singapore's naturally ventilated housing, Building Research & Information, 31 (1) (2003) 13-23.

[61] A. Tablada, A. De la Peña, F. De Troyer, Thermal comfort of naturally ventilated buildings in warm-humid climates: field survey, Proceedings of Passive Low Energy Architecture (PLEA), Beirut, (2005) 191-196.

[62] R.-L. Hwang, M.-J. Cheng, T.-P. Lin, M.-C. Ho, Thermal perceptions, general adaptation methods and occupant's idea about the trade-off between thermal comfort and energy saving in hot–humid regions, Building and Environment, 44 (6) (2009) 1128-1134.

[63] I.A. Raja, J.F. Nicol, K.J. McCartney, Natural ventilated buildings: use of controls for changing indoor climate, Renewable Energy, 15 (1-4) (1998) 391-394.

[64] T. Kubota, S. Ahmad, Questionnaire survey on behavior for natural ventilation and electricity consumption in terraced houses: A case study of Johor Bahru City, in: Asian Planning Schools Association (APSA) Conference, 2005, pp. 11-14.

[65] S. Singh, Seasonal evaluation of adaptive use of controls in multi-storied apartments: A field study in composite climate of north India, International Journal of Sustainable Built Environment, 5 (1) (2016) 83-98.

[66] F. Haldi, D. Robinson, On the behaviour and adaptation of office occupants, Building and Environment, 43 (12) (2008) 2163-2177.

[67] C.-P. Chen, R.-L. Hwang, W.-M. Shih, Effect of fee-for-service air-conditioning management in balancing thermal comfort and energy usage, International Journal of Biometeorology, 58 (9) (2014) 1941-1950.

[68] H. Liao, H. Liu, Z. Zang, A field study on the elderly's adaptive behavior and strategies of indoor thermal environment in the summer of Chongqing, in: The 7th International Conference of SuDBE, UK, 2015.

[69] C. Diao, Y. Gao, H. Liu, The analysis of indoor human thermal adaptive behaviors in hot-summer and cold-winter zone, in: The 7th International Conference of SuDBE, UK, 2015.

[70] A. Freire, J.L. Alexandre, F. Nicol, Adaptive comfort opportunities under mechanically conditioned environment, in: The 8th Windsor Conference: Counting the Cost of Comfort in a changing world, London, UK, 2014.

[71] H. Rijal, M. Humphreys, J. Nicol, How do the occupants control the temperature in mixed-mode buildings? Predicting the use of passive and active controls, in: Proceeding of conference: Air Conditioning and the Low Carbon Cooling Challenge, Windsor, UK, 2008.

[72] B. Xiao, Study on adaptive thermal comfort model for northwest arid--case study of Xi'an, M.S. Thesis, Xi'an University of Architecture and Technology, 2014 (in Chinese).

[73] J. Kim, R. De Dear, T. Parkinson, C. Candido, P. Cooper, Z. Ma, W. Saman, Field study of air conditioning and thermal comfort in residential buildings, in: The 9th windsor conference: Making comfort relevant, London, UK, 2016.

[74] L. Daniel, 'We like to live in the weather': Cooling practices in naturally ventilated dwellings in Darwin, Australia, Energy and Buildings, 158 (2018) 549-557.

[75] H. Imagawa, H.B. Rijal, M. Shukuya, Field survey on the comfort temperature and occupant behaviour in bedrooms, Journal of Environmental Engineering (Transactions of AIJ), 81 (728) (2016) 875-883.

[76] M. Indraganti, Behavioural adaptation and the use of environmental controls in summer for thermal comfort in apartments in India, Energy and Buildings, 42 (7) (2010) 1019-1025.

[77] R. Ooka, M. Indraganti, H.B. Rijal, Comfort temperature and the adaptive use of environmental controls in offices in Japan, in: Proceedings of 8th Windsor Conference: Counting the Cost of Comfort in a Changing World Cumberland Lodge, Windsor, UK, 2014, pp. 10-13.

[78] B. Hamzah, R. Mulyadi, S. Amin, Thermal comfort analyses of elementary school students in the tropical region, in: The 51st International Conference of the Architectural Science Association, Victoria University of Wellington, New Zealand, 2017.

[79] T.H.V. Le, M.C. Gillott, L.T. Rodrigues, An analysis of thermal comfort in primary schools in Vietnam, in: The 16th International Conference on Sustainable Energy Technologies, Bologna, Italy, 2017.

[80] E. Rajasekar, A. Ramachandraiah, A study on thermal parameters in residential buildings associated with hot humid environments, Architectural Science Review, 54 (1) (2011) 23-38.

[81] G. Zhang, C. Zheng, W. Yang, Q. Zhang, D.J. Moschandreas, Thermal comfort investigation of naturally ventilated classrooms in a subtropical region, Indoor and Built Environment, 16 (2) (2007) 148-158.

[82] M. Indraganti, Thermal comfort in naturally ventilated apartments in summer: findings from a field study in Hyderabad, India, Applied Energy, 87 (3) (2010) 866-883.

[83] A.K. Mishra, M. Ramgopal, Thermal comfort in undergraduate laboratories—A field study in Kharagpur, India, Building and Environment, 71 (2014) 223-232.

[84] N.D. Dahlan, P.J. Jones, D.K. Alexander, E. Salleh, D. Dixon, Field measurement and subjects' votes assessment

on thermal comfort in high-rise hostels in Malaysia, Indoor and Built Environment, 17 (4) (2008) 334-345.

[85] A. Lenoir, P. Françoise Thellier Phd, P. François Garde Phd, Towards net zero energy buildings in hot climate, Part 2: Experimental feedback, ASHRAE Transactions, 117 (2011) 458.

[86] I. Hussein, M.H.A. Rahman, T. Maria, Field studies on thermal comfort of air-conditioned and non air-conditioned buildings in Malaysia, in: Energy and Environment, 2009. ICEE 2009. 3rd International Conference on, IEEE, 2009, pp. 360-368.

[87] M. Pellegrino, M. Simonetti, L. Fournier, A field survey in Calcutta. Architectural issues, thermal comfort and adaptive mechanisms in hot humid climates, in: Proceedings of 7th Windsor Conference: the changing context of comfort in an unpredictable world. Windsor, UK: NCEUB, 2012.

[88] J.F. Busch, A tale of two populations: thermal comfort in air-conditioned and naturally ventilated offices in Thailand, Energy and Buildings, 18 (3-4) (1992) 235-249.

[89] M.K. Singh, S. Kumar, R. Ooka, H.B. Rijal, G. Gupta, A. Kumar, Status of thermal comfort in naturally ventilated classrooms during the summer season in the composite climate of India, Building and Environment, 128 (2018) 287-304.

[90] M. Indraganti, R. Ooka, H.B. Rijal, G.S. Brager, Adaptive model of thermal comfort for offices in hot and humid climates of India, Building and Environment, 74 (2014) 39-53.

[91] S. Dhaka, J. Mathur, G. Brager, A. Honnekeri, Assessment of thermal environmental conditions and quantification of thermal adaptation in naturally ventilated buildings in composite climate of India, Building and Environment, 86 (2015) 17-28.

[92] S. Dhaka, J. Mathur, Quantification of thermal adaptation in air-conditioned buildings of composite climate, India, Building and Environment, 112 (2017) 296-307.

[93] S. Shodiya, M. Oumarou, G. Ngala, A. Muhammad, M. Yusuf, Field Studies of Thermal Comfort in a Naturally Ventilated Large Space Building in Maiduguri, Borno State, ATBU Journal of Science, Technology and Education, 4 (1) (2016) 16-24.

[94] S. Thapa, A.K. Bansal, G.K. Panda, Adaptive thermal comfort in the two college campuses of Salesian College, Darjeeling–Effect of difference in altitude, Building and Environment, 109 (2016) 25-41.

[95] T. Tariq, Z.N. Ahmed, Perception of indoor temperature of naturally ventilated Classroom environments during warm periods in a tropical city, in: Proceedings of 30th International PLEA conference. Ahmedabad: CEPT University, 2014.

[96] S. Dhaka, J. Mathur, A. Wagner, G.D. Agarwal, V. Garg, Evaluation of thermal environmental conditions and thermal perception at naturally ventilated hostels of undergraduate students in composite climate, Building and Environment, 66 (2013) 42-53.

[97] M. Indraganti, K.D. Rao, Effect of age, gender, economic group and tenure on thermal comfort: A field study in residential buildings in hot and dry climate with seasonal variations, Energy and Buildings, 42 (3) (2010) 273-281.

[98] H. Djamila, C.-M. Chu, S. Kumaresan, Field study of thermal comfort in residential buildings in the equatorial hot-humid climate of Malaysia, Building and Environment, 62 (2013) 133-142.

[99] C. Deb, A. Ramachandraiah, Evaluation of thermal comfort in a rail terminal location in India, Building and Environment, 45 (11) (2010) 2571-2580.

[100] Q. Yang, L. Yang, J. Liu, Field Study on Thermal Comfort in Summer of Xi'an Urban Residence Buildings [J], Refrigeration & Air Conditioning, 25 (1) (2011) 49-52.

[101] R. Vittal, S. Gnanasambandam, Perceived Thermal Environment of Naturally-Ventilated Classrooms in India, Creative Space, 3 (2) (2016) 149-165.

[102] M.K. Nematchoua, R. Tchinda, P. Ricciardi, N. Djongyang, A field study on thermal comfort in naturally-ventilated buildings located in the equatorial climatic region of Cameroon, Renewable & Sustainable Energy Reviews, 39 (2014) 381-393.

[103] S. Haddad, P. Osmond, S. King, Revisiting thermal comfort models in Iranian classrooms during the warm season, Building Research & Information, 45 (4) (2017) 457-473.

[104] T.H. Karyono, E. Sri, J.G. Sulistiawan, Y. Triswanti, Thermal comfort studies in naturally ventilated buildings in Jakarta, Indonesia, Buildings, 5 (3) (2015) 917-932.

[105] T. Wu, M. Li, B. Cao, Y. Zhu, A Field Study of Thermal Comfort in Public Buildings in Guangzhou, in: The 9th International Conference on Indoor Air Quality Ventilation & Energy Conservation In Buildings, Soul, South Korea, 2016.

[106] A.C. Ogbonna, D.J. Harris, Thermal comfort in sub-Saharan Africa: Field study report in Jos-Nigeria, Applied Energy, 85 (1) (2008) 1-11.

[107] J. Li, L. Yang, J. Liu, A thermal comfort field survey in residential buildings in hot-summer and cold-winter area, Sichuan Building Science, 34 (4) (2008) 200-205 (in Chinese).

[108] E. Barbadilla-Martín, J.M.S. Lissén, J.G. Martín, P. Aparicio-Ruiz, L. Brotas, Field study on adaptive thermal comfort in mixed mode office buildings in southwestern area of Spain, Building and Environment, 123 (2017) 163-175.

[109] T.H. Karyono, Thermal comfort for the Indonesian workers in Jakarta: Adopting the current Ashrae standard for Jakarta would create cool discomfort and in addition waste energy—a greater understanding of true comfort range is called for, Building research and information, 23 (6) (1995) 317-323.

[110] T.H. Karyono, S. Heryanto, I. Faridah, Air conditioning and the neutral temperature of the Indonesian university students, Architectural Science Review, 58 (2) (2015) 174-183.

[111] L. Jin, Q. Meng, L. Zhao, Y. Zhang, L. Chen, Indoor environment and thermal comfort in rural houses in east Guangdong of China, J Civ Archit Environ Eng, 35 (2) (2013) 105-112.

[112] X. Ji, B. Wang, S. Liu, Z. Dai, Study on Thermal Comfort in Non-Air-Conditioned Buildings in Jiangsu and Zhejiang Provinces, Journal of Beijing Institute of Technology, 24 (12) (2004) 1100-1103 (in Chinese).

[113] M. Adebamowo, O. Olusanya, Energy savings in housing through enlightened occupants behaviour and by breaking barriers to comfort: a case study of a hostel design in Nigeria, in: Proceedings of 7th Windsor Conference: The changing context of comfort in an unpredictable world Cumberland Lodge, Windsor, UK, 2012, pp. 12-14.

[114] T.H. Karyono, Report on thermal comfort and building energy studies in Jakarta—Indonesia, Building and Environment, 35 (1) (2000) 77-90.

[115] G. Gomez-Azpeitia, G. Bojorquez, P. Ruiz, R. Romero, J. Ochoa, M. Pérez, O. Reséndiz, A. Llamas, Comfort Temperatures Inside Low-Cost Housing, in: 26th Conference on Passive and Low Energy Architecture PLEA, 2009, pp. 498-503.

[116] T.H. Karyono, Bandung thermal comfort Study: Assessing the applicability of an adaptive model in Indonesia, Architectural Science Review, 51 (1) (2008) 60-65.

[117] D. Albadra, M. Vellei, D. Coley, J. Hart, Thermal comfort in desert refugee camps: An interdisciplinary approach, Building and Environment, 124 (2017) 460-477.

[118] S. Heidari, S. Sharples, A comparative analysis of short-term and long-term thermal comfort surveys in Iran, Energy and Buildings, 34 (6) (2002) 607-614.

[119] L.G. Gomez-Azpeitia, G. Bojórquez-Morales, R.P. Ruiz, I. Marincic, E. González, A. Tejeda, Extreme adaptation to extreme environments in hot dry, hot sub-humid and hot humid climates in Mexico, Journal of Civil Engineering and Architecture, 8 (8) (2014).

[120] C. Bae, C. Chun, Research on seasonal indoor thermal environment and residents' control behavior of cooling and heating systems in Korea, Building and Environment, 44 (11) (2009) 2300-2307.

[121] S. Zang, Chengdu Area Residents Behavior Study of Energy Saving, M.S. Thesis, Southwest Jiaotong University, 2011 (in Chinese).

[122] C. Zhang, Decay Rate Prediction of Energy Efficiency of Domestic Air Conditioners Based on BP Neural Network, M.S. Thesis, South China University of Technology, 2015 (in Chinese).

[123] Y. Yu, Y. Yang, Research on energy behavior testing on office building occupants in summer, Environmental Engineering, 33 (5) (2015) 153-156 (in Chinese).

[124] J. Tanimoto, A. Hagishima, State transition probability for the Markov Model dealing with on/off cooling schedule in dwellings, Energy and Buildings, 37 (3) (2005) 181-187.

[125] S. Chen, Y. Zhuang, J. Zhang, Y. Fu, H. Zhang, Statistical Characteristics of Usage Behavior of Air Conditioners in The University Students' Dormitories, Procedia Engineering, 205 (2017) 3593-3598.

[126] Y. Zhang, M. Liu, L. Luo, D. Mmereki, Indoor thermal conditions and air conditioner usage in high-rise residential buildings in summer, Chongqing, Southwest China, International Society of Indoor Air Quality and Climate (ISIAQ), https://www.isiaq.org/docs/Papers/Paper720.pdf.

[127] A.K. Mishra, M. Ramgopal, A comparison of student performance between conditioned and naturally ventilated classrooms, Building and Environment, 84 (2015) 181-188.

[128] T. Imanari, S. Ogawa, T. Nobe, S.-i. Tanabe, Renovation of "Earth Port" for Net-Zero Energy Building, in: International High Performance Buildings, Purdue University, 2012, pp. 68.

[129] Y. Zhang, J. Mai, M. Zhang, F. Wang, Y. Zhai, Adaptation-based indoor environment control in a hot-humid area, Building and Environment, 117 (2017) 238-247.

[130] N.M. Salleh, N.A.A. Salim, S.N. Kamaruzzaman, N. Mahyuddin, F.M. Darus, The Prevelence of SBS and Absenteeism among Children in Urban Refurbished Private Preshools, in: MATEC Web of Conferences, EDP Sciences, 2016, pp. 00119.