Field Survey of Air Conditioner Temperature Settings in Hot, Humid Climates, Part 1: Questionnaire Results on Use of Air Conditioners in Houses During Sleep

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Abstract

This paper presents the results of a questionnaire survey on the use of air conditioners in houses in Surabaya, Indonesia, and Kuala Lumpur, Malaysia. The objective of the survey was to clarify what temperature and humidity levels people in these regions prefer in order to feel comfortable, with special focus on their sleeping environment. This was determined through survey responses and by measuring the thermal environments in their bedrooms. The questionnaire file was distributed to 64 university students in Surabaya and 65 in Kuala Lumpur. The students interviewed their family members and described their own experiences in their daily lives at home. The survey results show that the respondents set their air conditioners at very low temperatures. They also show that more than half of the respondents reported a cold or cool thermal sensation while using the air conditioner. Many respondents also reported various health problems and feeling cold while they were sleeping.

Keywords: field survey; thermal environment; hot, humid climate; sleeping environment

1. Introduction

In conventional air conditioning design, the comfortable range of temperatures is 25–27°C, with relative humidity (RH) levels of 40–60%; these numbers change only slightly based on a person's race and country. However, the authors have frequently experienced conference halls and hotels in Indonesia and Singapore that are maintained at very low temperatures, which seems inconsistent with these research results. Fanger proposed the predicted mean vote (PMV), based on the comfort equation and predicted percentage of dissatisfaction (PPD), on which the international thermal comfort standard ISO7730 is based. Although the comfort equation is based on experiments using North Americans as subjects, the application of the equation to other groups has been discussed. Several studies on thermal comfort in tropical climates have been conducted, and their findings show that the observed thermal comfort requirement in hot climates is not in good agreement with that obtained from the thermal comfort equation. However, there is no reasonable and consistent rationale that explains why the comfort equation does not adequately describe comfortable conditions in a hot climate. On the other hand, de Dear et al. conducted an experiment in Singapore in which climate chamber subjects adjusted the temperature according to their wishes. At the observed preferred temperature, the mean thermal sensation was significantly lower than neutral, which indicates that subjects prefer to select cool conditions. International thermal comfort standards define the neutral temperature obtained from physical measurement and the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) thermal sensation scale as a measure of comfort. However, as these field studies show, more surveys on thermal comfort might be needed in different climatic regions such as the tropics.

In Asia, which is a hot and humid climate region, people are somewhat used to controlling their indoor thermal environment by using external air flow, and most researchers have focused on the cooling effect of natural ventilation. However, there has recently been a rapid and widespread diffusion of air conditioners. Thus, people seem to prefer a cool indoor environment.
Therefore, the goal of the present research was to clarify what temperature and humidity level people in these regions prefer in order to feel comfortable, using a questionnaire survey and measurements of indoor thermal environments. In this research, the authors particularly emphasized the thermal conditions during sleep. In this paper (Part 1), they report on the climate and living conditions in the surveyed cities. In the following paper (Part 2), they will describe air conditioner usage in the surveyed cities, focusing on the temperature settings and thermal sensations respondents reported feeling while sleeping.

2. Field survey on Air Conditioner Usage

2.1. Outline of survey

2.1.1 Studied area

Surabaya, Indonesia, and Kuala Lumpur, Malaysia, which are characterized by the humid, tropical climate of Southeast Asia, were chosen as the surveyed areas. Surabaya, located at latitude 7° south and longitude 112° east in the eastern part of Java Island, is the second largest city in Indonesia. Kuala Lumpur, located at latitude 3° north and longitude 102° east in the southern part of Malay Island, is the capital city of Malaysia. Meteorological data from Surabaya, Kuala Lumpur, and Tokyo show that the temperatures and RH levels throughout the year in the surveyed cities are almost the same as those in Tokyo during midsummer.

2.1.2 Respondents and period of survey

Residential buildings were chosen for the survey instead of non-residential buildings because the occupants have a greater chance of being able to choose their preferred temperature setting for the air conditioner. Conference halls and hotel lobbies are designed for public use, so some of the occupants may have to endure conditions that are set to accommodate the comfort level of the average person. Therefore, in order to achieve the authors' objectives, measurements in residential buildings and responses from their residents were used in this research.

The questionnaire survey was given to 64 students in the Architectural Department of the Sepuluh Nopember Institute of Technology in Surabaya and 65 students in the Architectural Department of the International Islamic University, Malaysia. These surveys were handed out during class, and the students were directed to fill them out at home. They were then collected in a later class. Because the families of university students usually belong to the wealthier class, the results of the questionnaire might be biased against an average Malaysian or Indonesian sample.

2.1.3 Questionnaire items

In order to comprehensively understand the circumstances surrounding the use of air conditioning in these countries, the questionnaire items included not only the use of an air conditioner but also information about living conditions. For example, the questions regarding living conditions asked about the number of family members, house layout, house construction, surrounding environment, income, and electrical appliances owned by the household. Questions concerning the use of air conditioners asked about the duration of air conditioner use and the air conditioner temperature setting. The first questionnaire results revealed that most respondents used an air conditioner for a long time while sleeping. Therefore, to determine how the respondents felt about their indoor thermal environment while using an air conditioner, the authors also asked about the thermal sensations that they experienced while using the air conditioner, the clothing worn while sleeping, and any health problems reported while using the air conditioner. Further details are given in the appendix.

2.2 Results of survey

2.2.1 Results of living conditions

2.2.1.1 Family members

In Surabaya, the number of family members ranged from 1 to 11 persons, whereas in Kuala Lumpur, it ranged from 2 to 9 persons. The average household size among the Surabaya respondents was 4.7 persons and 5.1 persons among the Kuala Lumpur respondents. The results also revealed large families with up to 11 persons; this was because employees (e.g., servants, housekeepers) were included in the count.

2.2.1.2 Monthly household income

Fig. 2. shows the monthly household incomes of the respondents' families. In the Kuala Lumpur survey, the relevant question asked about the respondents' annual income, which was then divided by 12 to find the monthly income. Among the Surabaya respondents, about 60% of families had a monthly income of Rp 3,000,000 – 6,000,000. In contrast, among the Kuala Lumpur respondents, many families had incomes of RM 1,667 or less, whereas many others had incomes of RM 8,333 or more. When calculating the average value, the intermediate value of each interval was used to represent that interval. The average monthly income of the Surabaya respondents was Rp 5,458,000 (approximately $604; $1 = Rp 9,040, as of June 2010), while that of the Kuala Lumpur respondents was RM...
4,515 (approximately $1,398; $1 = RM 3.23, as of June 2010).

2.2.1.3 Number of major electrical appliances
Fig. 3 shows the average number of major electrical appliances owned by the respondents. For most of these appliances, larger numbers are owned by people in Indonesia and Malaysia than in Japan[16], which might be the result of larger family sizes. However, in terms of air conditioners, the Indonesian homes, on average, owned fewer air conditioners (2.1) than the Japanese (2.3) and Malaysian (3.0) homes. This might be a result of the high cost of air conditioners. However, although the number is lower in Indonesia than in Malaysia and Japan, the ownership of air conditioners in Indonesia has increased rapidly each year since 2003[17]. According to the survey, 73% of the respondents introduced air conditioners into their homes between 2005 and 2009. The number of air conditioners is growing quickly and widely, which will have a significant influence on the amount of energy being used and on the global environment in the near future.

2.2.1.4 Electricity charges
Fig. 4 shows the monthly electricity charges for the respondents. In the Surabaya survey, although more than half of the families had electricity charges of less than Rp 500,000 (approximately $55), 39% had higher charges than that. In the Kuala Lumpur survey, although 53% of the families spent between RM 100 and 200 (approximately $31–62), 27% still spent between RM 200 and 400 (approximately $62–124). In both cities, the electricity charges are high in proportion to household income.
2.2.2 Results for use of air conditioners

2.2.2.1 Operating time of air conditioners

Fig. 6 shows the room where the air conditioner was installed. In both cities, air conditioners were placed almost exclusively in the bedrooms or living room. In particular, the installation rate in bedrooms is very high, which means great value is placed on the thermal environment during sleep. Fig. 7 shows the daily operating times of air conditioners. The longest period of use was 24 h in both cities; the average use was 10 h in Surabaya and 9.1 h in Kuala Lumpur. These are very long periods compared to use in Japan: 1.3 and 1.5 times longer than the periods reported in Kyoto and Tokyo, respectively.

![Fig. 6. Room where Air Conditioner was Installed](image)

Fig. 6. Room where Air Conditioner was Installed

![Fig. 7. Daily Operating Time of Air Conditioner](image)

Fig. 7. Daily Operating Time of Air Conditioner

2.2.2.2 Temperature settings of air conditioners and thermal sensations while sleeping

Fig. 8 shows the temperature settings of the respondents’ air conditioners, and Fig. 9 shows the thermal sensations they reported while sleeping. Surveys on thermal sensations usually use thermal sensation votes based on the ASHRAE-seven-point scale. However, in this survey, the respondents were asked to rate the thermal sensation based on a five-point scale ranging from cold (1) to hot (5) with neutral (3) in the middle for ease of response.

The temperature settings varied widely, from 16 to 28°C in Surabaya, and 15 to 39°C in Kuala Lumpur. Several people reported setting their air conditioner at a temperature above 36°C, but this may have been the result of a misunderstanding. Although there was a slight difference between the two cities, there were two peaks at about 18°C and 25°C in both cities. The average temperature settings were 21.6°C in Surabaya and 22.0°C in Kuala Lumpur. These values are rather low for environmental temperature settings for sleeping, compared to the average setting in Japan, which is 25.8°C.

Regarding the thermal sensations reported while sleeping (Fig. 9), there was a clear difference between the respondents in Surabaya and Kuala Lumpur. More than half of the respondents in Surabaya reported a thermal sensation of 1 (cold; 5 = hot), and the votes for 1 and 2 (cool) accounted for more than 90% of the total votes. On the other hand, the most common level of sensation among the Kuala Lumpur respondents was 2, and fewer people chose 1 than 3 (neutral). The averages were 1.5 in Surabaya and 2.1 in Kuala Lumpur, a difference of approximately 0.6. The air conditioners were set to temperatures that created cold or cool thermal sensations, especially in Surabaya. In Kuala Lumpur, almost 25% of the respondents responded with "1."

![Fig. 8. Set-Point Temperature of Air Conditioner](image)

Fig. 8. Set-Point Temperature of Air Conditioner

![Fig. 9. Thermal Sensation During Sleep](image)

Fig. 9. Thermal Sensation During Sleep

2.2.2.3 Clothing during sleep

Fig. 10 shows what kind of clothing the respondents wore during sleep. This question was asked only in Surabaya. In order to see the differences caused by gender and generation, the results are shown for each family member. Most respondents, except for mothers, wore a T-shirt and light shorts during sleep. Most of the mothers answered "others," which means the traditional Muslim clothing. On the whole, the respondents wore light clothing when they slept while using an air conditioner.

2.2.2.4 Countermeasures when feeling cold or cool in bedroom

Fig. 11 shows the countermeasures residents took when they felt cold or cool in the bedroom. Respondents were allowed to make multiple selections for this question. In both cities, more than half of the respondents said they chose to use a blanket while
More than half of the Surabaya respondents who answered that they used a blanket did not choose another countermeasure. Thus, most of them reacted to the cold environment by using a blanket, not by "raising the temperature setting" or "turning off the AC." On the other hand, the respondents in Kuala Lumpur often chose "raise the temperature setting" and "turn off the AC" along with "use a blanket." The respondents in Kuala Lumpur also chose other countermeasures more often than the respondents in Surabaya.

Fig. 10. Clothing During Sleep in Surabaya

Fig. 11. Countermeasures when Feeling Cold or Slightly Cold in Bedroom

2.2.2.5 Health problems

Although in both cities the majority reported having no health problems, about half (45.7%) of the respondents in Surabaya and 27.0% in Kuala Lumpur complained of some health problems while staying in an air-conditioned room (Fig. 12.). Symptoms such as feeling dry, cold, or sick were reported by many people. Other symptoms such as headache, stomachache, tingling in the eyes, nosebleed, dehydration, choking, and not being able to sweat were also reported. It is clear that these health problems were caused by using air conditioners set at low temperatures.

Fig. 12. Health Problem

3. Discussions

The questionnaire results concerning living conditions and air conditioner usage showed the following.

First, the respondents use air conditioners at low set-point temperatures for a long time while sleeping. Second, they feel cold when they use air conditioners, and some of them find countermeasures. These results are very interesting but difficult to understand. The use of air conditioners might be connected with not only the indoor thermal environment but also the respondents’ living conditions or their feelings (subjective assessment of the indoor thermal environment). In this paper (Part 1), the authors showed the questionnaire results focusing on the respondents living conditions. In the following paper (Part 2), they will especially focus on their subjective assessment of the indoor thermal environment.
3.1 Increase in air conditioners
A field survey by Uno in Surabaya in 2003 reported that air conditioners were installed in one of the bedrooms in the homes of middle-income families with four to five members\(^1\). In the current study, the authors found that air conditioners were installed in more than two bedrooms and, furthermore, even in the living room. This indicates that the use of air conditioners has been increasing. Fig.13 shows the relationship between the number of family members and the number of air conditioners. In both cities, there is no clear correlation between them.

Uno’s 2003 study also showed that the use of air conditioners was perceived by residents to be a luxury\(^1\). However, Fig.14, which shows the relationship between household income and the possession of air conditioners in Surabaya, shows that there is almost no correlation between family income and the number of air conditioners. This result may indicate that thermal stress is a strong incentive to enhance the quality of the indoor environment irrespective of income. In Kuala Lumpur, a similar situation can be seen. An air conditioner is no longer considered a luxury item.

Fig.14. Correlation between Number of Air Conditioners and Family Income

3.2 Opening/closing of windows and air conditioner operation
In hot and humid regions, people are used to opening windows and doors during the day for natural ventilation. For that purpose, architects usually design houses with large and operable openings, as well as small, permanent upper openings. When air conditioners are introduced in residential buildings, the residents cover unnecessary openings with plastic, paper, or boards to keep the cool air inside the room or prevent the infiltration of outside heat\(^2\). The schedule of air conditioner use and the window-opening schedule in Fig.15 show that only a small fraction of the residents in Surabaya open their windows during air conditioning operation. On the other hand, the results in Kuala Lumpur show that many residents open their windows while using air conditioners. Because such behavior influences energy consumption, the authors will examine the details in a future study.

Fig.15. Schedule of Air Conditioner Operation and Opening/ Closing of Windows

4. Conclusions
A questionnaire survey was conducted in Surabaya, Indonesia, and Kuala Lumpur, Malaysia, both of which have hot, humid climates. The purpose of this study was to identify the indoor thermal conditions created by using air conditioners in residential buildings, in which residents have the opportunity to choose the temperature setting in their bedroom. The results of the survey showed that bedrooms are mostly occupied by one or two persons. Thus, they are still considered private, which allows individual users to decide on the temperature setting.

In both cities, the use of air conditioners has been increasing rapidly in recent years, and the mean operating time reported by respondents was longer than 9 h, which seems very long for domestic daily use. The use of air conditioners will have a significant
influence on the amount of energy used and on the global environment in the near future. Because it was shown that some of the residents opened their windows during the operation of an air conditioner, further research is needed to clarify the influence that this may have on energy consumption.

The respondents reported selecting a low temperature setting while sleeping, despite the fact that many of them reported that they were cold while sleeping. Of the residents who reported a cold thermal sensation while using the air conditioner, more than half of them said that they used a blanket while sleeping as a countermeasure to feeling cold. Many respondents also reported various health problems. This study indicated that, at the current time, air conditioners in residential buildings are not seen as luxury goods, which is different from the result reported by Uno[17] eight years ago.

Appendix:
QUESTIONNAIRE FOR RESIDENTS
Details are omitted in some questions.

- About your home.
Q. 1 Your family: Please fill in your and your family members’ ages and sexes in the following table.
Q. 2 Type of house
Q. 3 Number of stories
Q. 4 Structure of house
Q. 5 Electrical appliances: What kinds of electrical appliances do you have other than an air conditioner? Please fill in the number of units.
TV ( ), PC ( ), refrigerator ( ), washing machine ( ), rice cooker ( ), microwave oven ( ), fixed-line phone ( ), vacuum cleaner ( ), electric fan ( )
Q. 6 Plan of house
Q. 7 Address and map
Q. 8 Users of the bedroom
Q. 9 Opening and closing of windows for ventilation: Please use the numbers from Q. 6 to identify doors and windows.

Q. 10 Electricity charge: How much is your electricity bill every month?

Q. 11 Clothing during sleep: What kind of clothes do you and your family members wear while sleeping?
Q. 12 Annual income: If you don’t mind, please choose the total annual income of your family.

■ Use of air conditioners.
Q. 13 Manufacturer and price
Q. 14 Usage time of air conditioner(s): When do you use the air conditioner?
Q. 15 Set-point temperature of air conditioner: Please fill in what temperature the air conditioner is set to, along with the comfort level when using it at this set-point temperature.
Q. 16 Health: Has there been any change in your health or physical condition since beginning to use the air conditioner? If so, please fill it in.

ADDITIONAL QUESTIONNAIRE
Q. 1 Do you feel that you need an air conditioner in your daily life?
Q. 2 View concerning air conditioners: What is your opinion of air conditioners?
Q. 3 Are you conscious of the economic effects of using an air conditioner?
Q. 4 Thermal environment in bedroom with air conditioner: Please choose the most appropriate description of the thermal environment in the bedroom during normal use of an air conditioner.

【Bedroom 1】

| Set-point temperature | °C |
|-----------------------|----|
| Thermal sensation     |    |
| Comfort sensation     |    |
| More favorable environment |    |

Q. 5 Countermeasures when cold (or slightly cold) in the bedroom: What are the countermeasures that you take to address coldness when using the air conditioner in the bedroom? Please circle all that apply.

【Bedroom 1】

| Countermeasure                                      |  |
|----------------------------------------------------|--|
| Wear a jacket                                      |  |
| Wrap myself in a blanket                           |  |
| Open the windows to introduce air                  |  |
| Shut down the air conditioner                      |  |
| Do nothing because I like a cold environment       |  |
| Endure the cold environment                        |  |
| Have never felt cold                               |  |
| Other ( )                                          |  |

Q. 6 Electricity use: How do you feel about electricity use?

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