Survey on Thermal Environment in Residences in Surabaya, Indonesia: Use of Air Conditioner

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Abstract
This paper reports the results of the survey in Indonesia on the consciousness of the residents towards the use of air conditioner.

The questionnaire survey and measurements of the thermal environment were carried out. The higher the resident’s income is, the more the percentage of the residents who feel the air conditioner is necessary. Once they start to use air conditioners, they will not quit using. When the air conditioner is used, the room temperature is from 24 to 30 degrees C, similar to that in Japan. The air conditioner is usually used around 14:00 and during sleeping time. This is similar to Naha’s situation, a subtropical area in Japan. Also, the duration that the air conditioner is used is longer than that in Japan. The energy consumption for cooling is expected to increase in this area.

Keywords: use of air conditioner, hot humid climate, thermal environment, field survey, questionnaire

Introduction
In recent years, the energy consumption is increasing more and more in South East Asia1), with the developing economy.

In hot humid climate such as Indonesia, air conditioner has been prevailing2), thus an increase in energy consumption for cooling seems to become a serious problem in near feature. Furthermore the air conditioner will be used not only in the office but also in the residences.

Passive cooling systems suitable for hot humid climate are effective in saving energy. In developing a passive system, it is essential to understand various features of the region such as climate, life style, energy consumption, thermal environment, culture, economy and so on.

So far, we have investigated the thermal conditions in Indonesia and Malaysia3)-9). The results of the survey in Indonesia clarified that most of the residents in middle-income class think the air conditioner necessary. Thus it is anticipated the air conditioner will spread in the middle-income class in near future6)-9).

Based on these results, this paper reports the results of the survey, focusing on the consciousness of the residents towards the use of air conditioner.

Thermal environment was measured in several houses, and a questionnaire survey was also carried out in order to understand the relationship between the thermal condition and the use of air conditioner.

Several researchers in Japan report the indoor thermal condition of the residences when the air conditioners are used10)-12). Suzuki et al. report the heating and cooling conditions in the houses in Sapporo, Kyoto and Naha10). Bougaki et al. report the heating and cooling pattern and period on the bases of questionnaire survey11), 12). In these papers, the cooling condition during use of the air conditioner and the frequency of the air conditioner use are shown. The duration of the air conditioner use is not different between the regions in Japan, and it ranges from 5 to 7.5 hours. There are two peaks in the use of air conditioners except for Naha. One is around 14:00 in the daytime; another one is the period from 18:00 until the time when they go to bed. In Naha, there is only one peak, which is from late night until morning.

Survey of Thermal Environment

Area and climate
The surveyed area is in Surabaya (7° S 133° E) (Figure 1), which is located in the east part of Jawa Island in Indonesia. It is in hot humid climate.

There are two seasons, that is dry and wet seasons, and the precipitation is little in dry season from May to October. Figure 2 shows the monthly average temperature and relative humidity13). The temperature...
varies from 26 to 28 degrees C. The hottest months are October and November. The annual mean temperature is 27.1 degrees C. The monthly average of the relative humidity is from 60 to 85%. This paper reports mainly the results of the survey in July when the temperature is the lowest.

Outline of Investigation
The survey was carried out 1st - 15th July, 2002, a dry season in Surabaya.

Questionnaire
The questionnaire survey about the indoor thermal conditions was carried out to the low, middle and high-income people. Table 1 shows the contents of the questionnaire. Total of 118 answers was collected.

In this paper, the questionnaire results are classified by their income (Tables 2). Tables 3 and 4 show the details of the answers. The total number of the low-income people who answered the questionnaire was 34 persons, including 18 families. The total number of the middle-income was 39 persons (22 houses), and 4 out of 22 houses have air conditioners.

The total of high-income was amounted to 33 (16 houses), where 13 houses have air conditioners. Besides this, 10 students living alone in a rented room, and 2 students have an air conditioner in their room. Most of them are office workers or housewives (Table 3). Nearly halves of them are the male and female.

Measurement
Along with the questionnaire survey, the temperature and humidity in five houses were measured. These houses were selected from the houses that had been measured in the last survey during the wet season (February 2001)\(^4\). Four houses have one or two air conditioners in their bedroom or living room, while the rest one does not have air conditioners. Three houses with the air conditioner were classified into the high income and others were the middle income.

The outdoor temperature and relative humidity, and the global and vertical solar radiations were measured in the experimental house built in the campus of the Institute of Technology Surabaya University (ITS).

Measured Result of Outdoor Thermal Conditions
The average outdoor temperature from 5th to 12th, July was 27.5 degrees C and humidity was 67.2%. These values are almost the same as those of July in an average year (Figure 3).

Figure 3 shows the outdoor temperature and humidity on the 5th and 6th July 2002. The highest temperature of 30 degrees C was recorded at 14:00, while the lowest temperature around 23 degrees C at 6:00 in the morning. The relative humidity was 55 % in the daytime, and around 75 % in the nighttime.

Result of Survey
Based on the results of the questionnaire survey and the measured thermal conditions, the resident’s consciousness to the use of the air conditioner will be discussed in the following section.
Necessity of Air Conditioner

Figure 4 shows the percentage of the houses where the air conditioner is installed. In low-income houses, no houses have any air conditioners. On the other hand, 18% of the middle-income houses and 81% of the high-income houses have air conditioners. It is obvious that the possession of the air conditioner is closely related to high income.

The answer as to the necessity of air conditioner is shown in Figures 5 and 6, that is the consciousness of the residents towards the use of air conditioners, depending on the income or possession of air conditioner.

Whereas 26% of the low-income people think that air conditioners are necessary (Figure 5), 23% of the middle-income people regard air conditioning as necessary. This percentage rises to 71% among high-income people. The higher the income is, the greater the need for air conditioner becomes. Seventeen percent of the low-income people regard air conditioners as the waste of money. Such answer is not shown in the answer from high-income people. The answer whether they use air conditioner or not is shown in Figure 6.

More than 77% of the people who have air conditioner think that it is essential to have it. From this result, it is expected that once they start to use air conditioner, they will not quit using.

Thermal Conditions under Use of Air Conditioner

Measured Results in House without Air Conditioner

Figure 7 shows the measured temperature in the living room and the bedroom of the middle-income house (House A), which does not have air conditioners. The temperature in the living room ranges from 27 to 31 degrees C, and between 28 and 29 degrees C in bedroom during daytime. In the night, the temperature in the living room becomes lower than that in the bedroom, although it is around 27 degrees C, a relatively hot condition.

Since the measured air temperature in the living room falls rapidly at 6:00 AM on 5th, the residents must have opened the door and windows of the living room at that time. The bedroom temperature falls before 7:00 AM, and thus the windows and doors of the bedroom seem to be opened too. The situation is the same on 6th July, although the temperature decrease is not so significant as on 5th. Therefore, it can be concluded that the residents open the doors and windows in the morning. This is in accordance with the resident’s answer to the questionnaire that she opens the openings around 6:00 AM. Since the doors and windows are open, the room temperatures rise up relatively rapidly after 8:00 AM with the outdoor temperature.

Although the residents open the windows of the bedroom, the temperature increase is less than that in the living room. This is because that the opening area to the outside and the solar radiation coming into the room are less compared with the living room. In hot climate, it is very important to prevent the solar radiation from entering the room.
In the nighttime, the openings are closed because of the mosquitoes and for security reasons. While the temperature in the living room continues to decrease until morning, the temperature in the bedroom remains around 29 degrees C, uncomfortable condition for sleeping.

**Measured Results in Houses with Air Conditioner**

In Figure 8, the temperatures and relative humidity in two houses (House B and House C) are shown, where the air conditioners are installed in the bedroom.

The temperature falls rapidly, when the residents turn on the air conditioner. In House B, the air conditioner was used in the night, starting 23:00 (5th July) and kept on until 6:00 in the morning (6th July). In this house, the air conditioner is used during nighttime every day (Figures 8 and 15). The temperature when the air conditioner is turned on is around 28 degrees C. After that, the temperature decreases to 23 degrees C. Once the air conditioner is turned on, the temperature continues decreasing until morning. The air conditioner in this house might not have any temperature control systems.

When the air conditioner is turned on or off, the room temperature and humidity change rapidly (in Figure 8, the points of on/off are shown by arrows.). Since the house does not have a large heat capacity, the room temperature is easy to change. If the residents had turned off the air conditioner during nighttime, the room temperature would have increased easily. Therefore, it can be concluded that even though they can turn off the air conditioner, they choose the low temperature. After the air conditioner is turned off around 6:00 AM (5th-July and 6th-July, House B in Figure 8), the temperature and humidity rise up to the level of the outdoor air, since the residents open the door and windows at the same time. If they had kept the openings closed, the room temperature would have been kept lower during daytime.

In house C, the air conditioner is used both in the night and daytime. The operation starts 20:30 and is kept on until 6:00 in the morning. In the daytime, the air conditioner is used from 14:00 (6th-July). In this house, the air conditioner is used during nighttime almost every day, while sometimes during daytime. The air conditioner is turned on at around 28.5 degrees C, and the room temperature is kept constant at around 27 degrees C. The air conditioner in house C can control the room temperature, as the residents like. It can be said that the temperature around 27 degrees C is preferred by the residents. This temperature is the same chosen in Japan\(^4\).

In both houses (House B and House C), the air conditioners are used in the nighttime without a break probably for creating sleeping conditions comfortable for residents.

**Temperature When Air Conditioner is Used**

Figures 9 and 10 show the cumulative frequency of the temperature at which the residents start to use an air conditioner and the resulting lowest temperature. Figure 9 is the result in July (dry season) and figure 10 is in February (wet season). Here the word, “resulting lowest temperature” is used as the lowest temperature measured during the operation of the air conditioner.

In July, the starting temperature of air conditioner operation is concentrated from 28 to 30 degrees C during daytime, and from 26 to 29 degrees C during nighttime. The residents start to use the air conditioner during nighttime at slightly lower temperature than daytime. The lowest temperature ranges from 23 to 29 degrees C.

![Fig.9. Frequency and Normalized Cumulative Frequency of Temperature at Which Resident Starts to Use Air Conditioner and Resulting Lowest Temperature (dry season, July)](image)

![Fig.10. Frequency and Normalized Cumulative Frequency of Temperature at Which Resident Starts to Use Air Conditioner and Resulting Lowest Temperature (wet season, Feb.)](image)
during daytime, while from 23 to 27 degrees C during nighttime.

In February, the residents start to use air conditioner between 28 to 32 degrees C, and that the temperature during nighttime is lower than that during daytime. The lowest temperature is from 25 to 30 degrees C during daytime, and from 24 to 28 degrees C during nighttime.

In both seasons, the starting temperatures are not so different between daytime and nighttime. However the lowest temperature during daytime is higher than that during nighttime. There are two reasons for this. First, one is that the outdoor temperature when air conditioner is operated is higher during daytime than during nighttime. The second reason is that operating time of the air conditioner is longer during nighttime than that during daytime. If the air conditioner does not have temperature controls such as in house B, the temperature becomes quite low after a long operation of the air conditioner.

Comparing the starting temperature in February and July (Figure 11), the temperature at which the residents start to use air conditioner is almost the same. However the lowest temperature in July is lower than that in February. Since the outdoor temperature and the humidity ratio in July (dry season) is lower than in February, the air conditioner works well to decrease the room temperature in July than in February. The lowest temperature is affected by the efficiency of the air conditioner.

The temperature at which residents use air conditioner ranges from 24 to 28 degrees C, quite similar situation in Japan14, 15. Furthermore, if the temperature under air conditioning can be regarded as the comfortable temperature, the comfortable temperature may not depend on races16. Such a low temperature may give a serious influence not only on the energy saving but also on the resident’s health.

Set-point Temperature of Air Conditioner

According to the answers from the residents who have air conditioner in their houses, the set temperature ranges from 16 to 30 degrees C, and most of them set it under 25 degrees C (Figure 12).

The set-point temperature is lower than the realized actual conditions in the house (Figure 8). Ideal condition they want might not be satisfied because of the insufficient capacity of the air conditioner or the improper house construction. Since the houses have large openings and the low air tightness, the room temperature is greatly influenced by the outdoor conditions. Even though the air conditioner is used, it might not be easy to keep the room temperature low as the resident desire.

Some people also gave us information about the set-point temperature in their office. The temperature ranged from 16 to 24 degrees C (Figure 13), much lower than that in the residences. This situation seems similar to that in Japan. The people prefer lower temperature for work at offices.

Time When Air Conditioner is Used

Figure 14 shows the time when air conditioners are used. Most people answer that they use air conditioners from 21:00 to 6:00 AM during nighttime, and 13:00 to 15:00 during daytime.

In houses B and C, the residents use the air conditioner almost every night, and sometimes during daytime too, as can be seen from Figure 15. This is consistent with the result observed during the wet season4. The pattern of the use of air conditioner is similar throughout the year.

In Japan other than Naha, the residents use air conditioner around 14:00 and in the evening, and they turn it off before going to bed. On the other hand, people in Surabaya continue to use until morning. The same situation during nighttime can be seen in Naha, which is located in subtropical climate in Japan.

The duration of the operation is from 8 to 14 hours (measured results from 4 houses). It is longer than that in Japan.

Judging from these results, an increase in the energy consumption for cooling in the residences could become a serious problem in Indonesia.
Conclusion
This paper reports the results of the research focusing on the consciousness of the residents towards the use of the air conditioner. The questionnaire survey and measurements are carried out in Surabaya, Indonesia.

At present, 10% of the low-income people, 50% of the middle-income people, and 88% of the high-income people use the air conditioners. The 25% of the low-income people think an air conditioner is necessary. The percentage increases more, as the income becomes higher. Once they start to use air conditioner, they will not quit using.

The temperature when the residents use the air conditioner is from 24 to 30 degrees C, similar to that in Japan. The set-point temperature of air conditioner is lower than the realized actual conditions. It might be due to insufficient capacity of air conditioners.

The time when the air conditioner is used is around 14:00 and during sleeping time. This is similar to Naha’s situation in subtropical area in Japan. The duration that the air conditioner is used is longer than Japan.

Judging from these results, the increase in the energy consumption for cooling in the residences could become a serious problem in Indonesia.

Note
In Japan, the air conditioner is mainly used when the residents are active. On the other hand, the residents in Surabaya use it mainly in their sleeping time. The set-point temperature of the air conditioner and the comfort temperature might be different between active and sleeping times, although it is not discussed in this paper. It may need more consideration.

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