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Air-Conditioner Use Effects on Thermal Environment in Bedrooms and Sleep Quality during Summer – Analysis of University Students in Osaka

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ABSTRACT: Analyses of thermal environment, thermal control behaviors, thermal sensations, and sleep quality yielded the following results indicating air conditioner (AC) use effects on sleep quality in 11 bedrooms during three periods of summer. 1) Outside temperatures were higher on AC use days but room temperatures during sleep were kept almost identical (25.7°C). 2) Sleep quality as evaluated by the OSA score was higher on AC use days. However, it was hotter and less acceptable on AC use days, although thermal comfort was not different. 3) On AC non-use days, the relation between thermal comfort and thermal sensation was stronger. Thermally acceptable ranges were wider on non-use days. 4) Relation between the OSA score and the degree of sound sleep was weaker on AC use days. The OSA score was more strongly related to thermal acceptability on AC use days than non-use days. 5) Differences in sleep quality were smaller between AC use days and non-use days than between the surveyed periods. Lower sleep quality in mid-summer was caused not by AC, but by higher room temperatures.

KEY WORDS: Sleep Quality, Thermal Sensation, Air Conditioner use

1. Introduction

Sultry nights with temperatures that remain higher than 25°C have become increasingly common in the urban area of Osaka, Japan, perhaps because of global warming and heat island phenomena. There were 23, 27, 10, 50, 57, and 55 sultry nights, respectively, in 1960, 1970, 1980, 1990, 2000, and 2010.

Common households possess 2–3 air-conditioners (AC), using them during sleep times. Decreased sleep quality caused by heat might affect work performance and health. Recently, increased heat stroke risk has become a matter of greater concern. AC use has become a heatstroke countermeasure. However, electrical power shortages related to the severe accident at the Fukushima Daiichi nuclear power plant caused by the Tohoku earthquake on March 11, 2011 possibly affected AC use. A government campaign of ‘electricity conservation’, *COOLBIZ*, calls for an AC temperature setting of 28°C.

Sakane et al. (2012) conducted a questionnaire survey of AC use by 362 residents in Osaka apartment houses in autumn 2012. Results show that 24.6% answered ‘very frequently use’ AC and 29.7% answered ‘frequently use’ AC on a four-point scale in daytime. In addition, 36.5% answered ‘very frequently use’ AC; 30.7% answered that they ‘frequently use’ AC during nighttime. However, 54.4% and 29.0% answered ‘keep open’ in daytime and nighttime on a five-point scale; 22.5% and 38.4% answered ‘keep closed’ windows in daytime and nighttime. Results show that people reported choosing AC use according to a daily preference.

In such circumstances, this study objects to clarify the followings. 1) How are indoor and outdoor thermal environment different between AC-use and non-use days? 2) How are sleep quality, thermal sensation, comfort, and acceptability improved by AC use? 3) How the

relations between sleep quality and thermal sensations different in between AC use and non-use days? 4) Are the relations different among periods in summer?

2. Methods

Eleven university students who lived in or near Osaka city participated in the survey during June 18–25 in early summer, August 27 through September 5 in mid-summer, and September 17–24 in late summer. Each survey was continued for more than seven successive days during the university summer vacation season. For that reason, some of them went outside their ordinary bedrooms because of travel or returned home or to work; thereby each became unable to attend the entire survey. Table 1 presents attributes of the subjects and the bedrooms.

The subjects measured the bedroom temperature at intervals of 10 min using data loggers. Relative humidity was recorded before and after sleep. Every morning, they filled questionnaire sheets related to the degree of sound sleep in four categories, thermal sensation in seven-point-scale, thermal comfort in four-point-scale, and acceptability in three-point-scale in bedrooms of the prior night. Sleep quality was also evaluated using OSA scales in mid-summer and late summer. At the same time, they kept a diary recording their absence or presence in bedrooms, personal AC use, window opening of the bedrooms and sleep at intervals of 30 min.

Oguri et al. (1985) developed the OSA sleep inventory to evaluate subjective sleep quality. Yamamoto et al. (1999) revised it. Generally, OSA is used for clinical purposes in Japan. It is a standard deviation calculated from subjective rating scales of sleep quality. It evaluates sleep at the time of awakening, based on responses to 16 questions. Each question response is given on a four-response scale: very good, somewhat good, somewhat bad, very bad. These questions yield standard scores of five factors. Averaged standard scores of five factors are defined as the OSA score. The higher the score is, the higher the sleep quality is indicated. The five factors are Factor I (Drowsiness when waking such as ‘I have the power of concentration’, ‘I feel a sense of liberation’ and ‘I feel clear-headed’), Factor II (Falling asleep and maintaining sleep such as ‘I was able to sleep soundly’, ‘I dozed off until I finally fell asleep’, ‘I got to sleep easily’, ‘I often woke up from sleep’ and ‘The sleep was shallow’), Factor III (Dreaming, such as ‘I had many nightmares’ and ‘I had many dreams’), Factor IV (Fatigue recovery such as ‘Fatigue persists after waking up’, ‘I feel languorous’ and ‘I feel unwell’), and Factor V (Sleeping duration such as ‘I have generally good appetite’ and ‘The sleep duration was long’).

Table1 Attribute of the subjects and the bedrooms

Subject	Attendance in the survey			Boarder or commuter	Building type	Bedroom area (m ²)	Bedding type	Sleeping time (hrs.)
	early summer	middle summer	late summer					
no.1	○	○	○	boarder	apartment	n.a.	tatami mat	7.9
no.2	○	△	○	commuter	apartment	15	bed	6.4
no.3	○	○	○	commuter	detached	12	bed	6.4
no.4	○	○	○	boarder	apartment	13	bed	8.6
no.5	○	△	○	commuter	detached	12	bed	8.5
no.6	○	x	○	commuter	detached	9	tatami mat	8.8
no.7	○	x	x	commuter	detached	9	tatami mat	10.2
no.8	○	○	○	commuter	detached	12	bed	8.1
no.9	○	x	○	boarder	apartment	12	tatami mat	8.5
no.10	x	x	○	commuter	detached	n.a.	bed	7.0
no.11	○	x	x	commuter	apartment	n.a.	n.a.	4.7

3. Results

3.1 Comparison among periods in summer

3.1.1 Thermal environment

An example of bedroom temperature and humidity, outdoor temperature and humidity, and behaviors in mid-summer for subject no.1 in mid-summer is presented in Fig. 1. We use outdoor temperature measured by local weather observatories. The respondent went outside the bedroom on the sixth and seventh night, so the survey was continued until the ninth day. He lived with his family in an RC apartment. He sometimes used AC, and sometimes opened windows. Indoor temperatures were sometimes lower than outdoor temperatures in daytime but usually higher than outdoor temperatures in nighttime.

Fig. 2 presents the mean daily indoor and outdoor temperatures for the surveyed periods. The mean indoor temperatures (during sleep) were 26.5°C (25.7°C), 27.7°C (27.2°C) and 25.7°C (25.4°C) in early, middle and late summer. Mean outdoor temperatures (during sleep) were 24.1°C (21.8°C), 26.0°C (23.3°C) and 22.6°C (20.2°C) in early, middle and late summer.

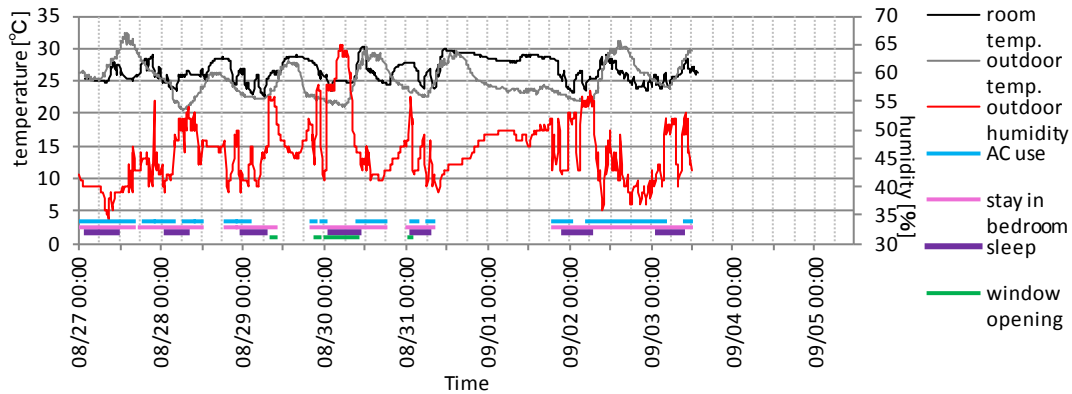


Fig.1 An example of the records of thermal environment and thermal control behaviors

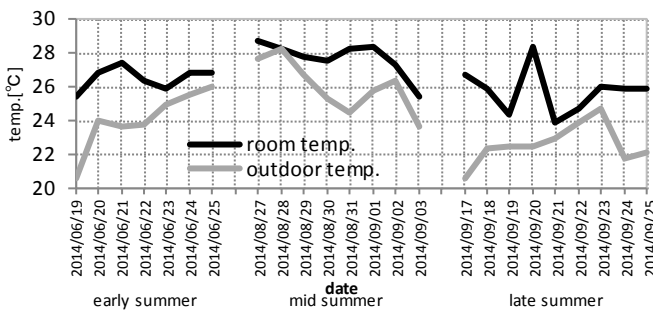


Fig.2 Daily mean temperatures for three periods

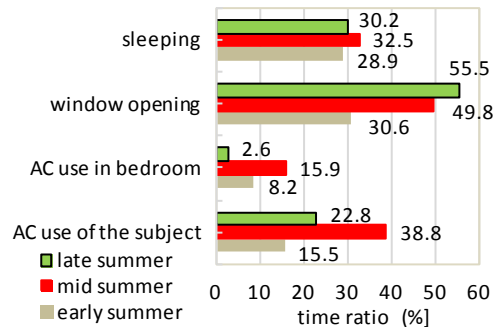


Fig.3 Time ratio of behaviors for the periods

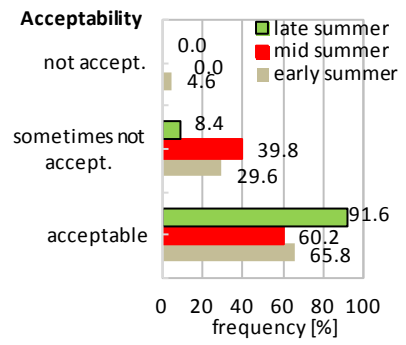
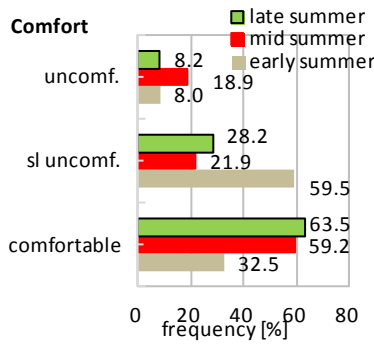
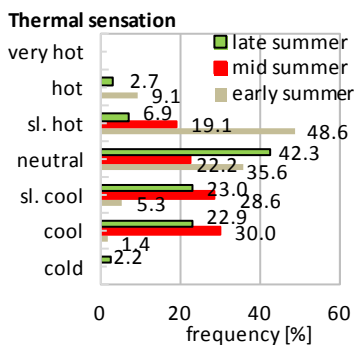


Fig.4 Frequency distribution of thermal sensation, comfort and acceptability for periods

3.1.2 Behaviors

Fig. 3 shows the average time ratio of sleep, window opening and AC use in the bedroom and AC use of the respondents for 24 hours for different periods. These time ratios are based on records from diaries of respondents kept at 30 min intervals. The time ratio of presence in bedroom was 51.2%. Respondents rarely stayed in bedrooms during daytime. The time ratio of sleep was not different among periods. The time ratio of window opening in bedrooms was 30.6% in early summer, 49.8% in mid-summer and 55.5% in late summer. Windows of bedrooms were sometimes kept open during absence. The time ratio of AC use in bedrooms was 8.2% in early summer, 15.9% for mid-summer and 2.6% for late summer. Respondents did not usually use AC and did not open windows in early summer. The AC use days during sleep were 11 days in early summer, 15 days in mid-summer, and 4 days in late summer. The AC non-use days during sleep were 54 days in early summer, 27 days in mid-summer, and 48 days in late summer.

3.1.3 Thermal sensation

Fig. 4 shows a frequency distribution of thermal sensation, comfort, and acceptability in different periods. Results show that, 'slightly hot' was most frequent (48.6%) in early summer; 'cool' was most frequent (30.6%) in mid-summer; and 'neutral' was most frequent (42.3%) in late summer (in uniformity test among periods, $p < .0001$). It was hottest in early summer and most cool in mid-summer. 'Slightly uncomfortable' was most frequent (59.5%) in early summer; 'comfortable' was most frequent (59.2%) in mid-summer, but 18.9% responded 'uncomfortable'; 'comfortable' was most frequent (63.5%) in late summer ($p = .007$). 'Comfortable' was the least in early summer and 'uncomfortable' was the most in late summer. 'Acceptable' was most frequently reported in all periods and 'Acceptable' was 91.6% in late summer and 'sometimes not acceptable' was 39.8% in mid-summer. But there were little statistically significant difference by periods in thermal acceptability ($p = .092$).

Fig. 5 portrays the ratio of 'comfortable' and 'acceptable' in each category of thermal sensation in different periods. Relations between thermal sensations and thermal comfort changed with the period. The ratio became higher as the thermal sensation became warmer in early summer. It was unrelated to thermal sensation in mid-summer. It became lower as the thermal sensation became cooler in late summer.

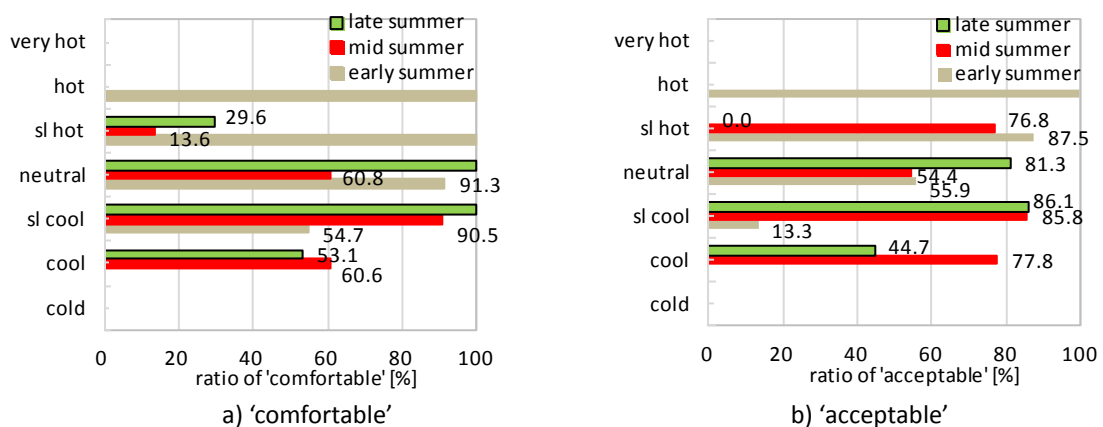


Fig.5 Comparisons of ratios of 'comfortable' and 'acceptable' in each category of thermal sensation among periods

Relations between thermal sensation and thermal acceptability changed with the **period**. The ratio became higher as it became hotter in early summer. It was unrelated to thermal sensations in mid-summer. It became lower as the thermal sensation became cooler or warmer in late summer.

3.1.4 Sleep

Fig. 6 portrays frequency distributions of the degree of sound sleep for periods. The frequency distribution was similar for early and late summer. Actually, 'somewhat good' was the most frequent response for both periods: 47.8% for early summer and 45.7% for late summer. For mid-summer, 'somewhat good' was the most frequent. It was 44.2%, but 'sleep somewhat bad' was 30.0%. The degree of sound sleep was similar in early and late summer (in uniformity test among periods, $p=.22$).

Fig. 7 presents OSA scores compared between mid-summer and late summer in each subject. Each score represents the mean of seven nights. The average score was 45.5 in mid-summer and 48.1 in late summer. The OSA score was lower in mid-summer than in late summer, except for subject no. 3.

Fig. 8 presents a comparison of profiles of the mean vote of each OSA scale between mid-summer and late summer. Scales are ordered in the figure from factor I to V. The lower value shows better sleep. Complete sleep was better in late summer than in mid-summer. Mean votes of Factor I (Drowsiness when waking), Factor IV (Fatigue recovery) and Factor V (Sleeping duration) were higher in late summer than in mid-summer, although few differences were found in Factor II (Falling asleep and maintaining sleep), and no differences in Factor III (Dreaming) between middle and late summer. Differences in liberation in Factor I, languorous in Factor IV and good appetite in Factor V were significant in t-test .

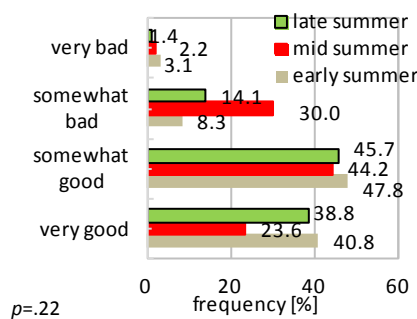


Fig.6 Frequency distribution of degree of sound sleep for periods

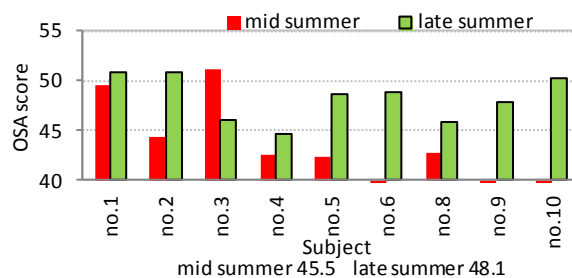


Fig.7 Comparison of mean OSA scores in each subject between periods

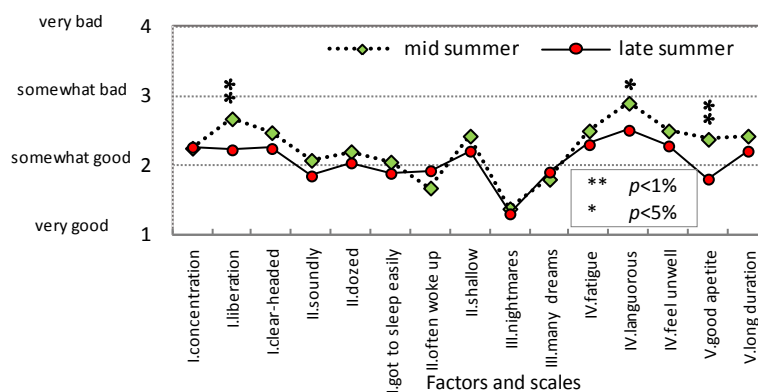


Fig.8 Comparison of profile of OSA scales between periods

Fig. 9 shows the mean OSA scores for respective categories of thermal sensation, comfort, acceptability, and degree of sound sleep for middle and late summer. The OSA score was almost identical for each category of thermal comfort both in middle and late summer (in Kruskal-Wallis test, $p=.57$ and $.61$, respectively). The OSA score was higher for 'comfortable' in mid-summer ($p=.022$), but no difference was apparent in late summer ($p=.37$). Differences of mean OSA scores were not 3.1 in mid-summer, but 1.6 in late summer between 'acceptable' and 'sometimes not acceptable' ($p=.14$ and $.54$, respectively). Fig. 10 shows the mean bedroom temperature during sleep for each category of degree of sound sleep for periods. The OSA score became lower from 'very good' to 'somewhat bad' in the degree of sound sleep in the middle and late summer ($p=.002$ and $.0006$).

Fig. 11 presents the mean bedroom temperature during sleep for each category of degree of sound sleep for early, middle, and late summer. The degree of sound sleep was unrelated to the bedroom temperature in early summer ($p=.50$). The mean bedroom temperature was 26.1°C for 'very good', 27.6°C for 'somewhat good', and 'somewhat bad' in mid-summer ($p=.26$). It was 24.2°C for 'very good', 25.2°C for 'somewhat good', and 25.4°C for 'early summer'.

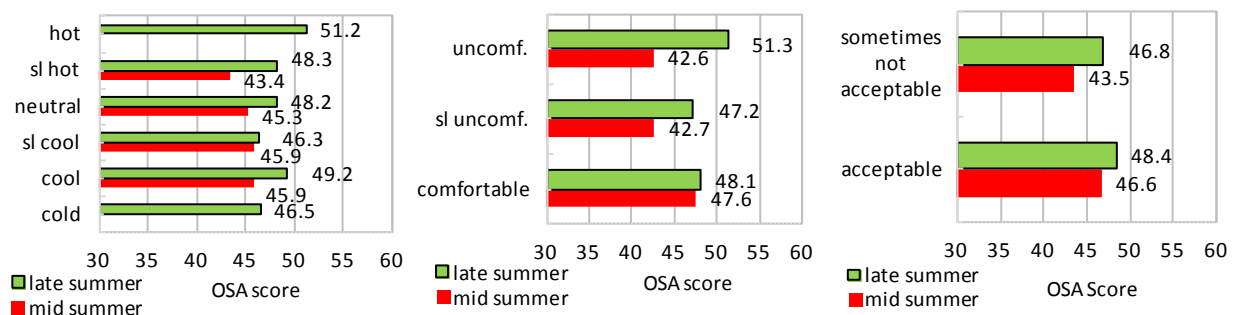


Fig.9 Comparison of mean OSA scores for each category of thermal sensation, comfort and acceptability between periods

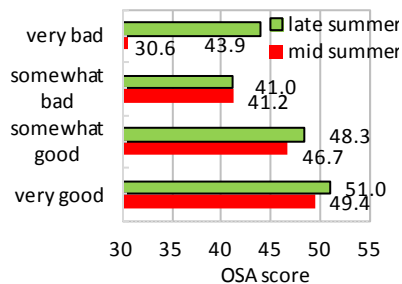


Fig.10 Comparison of mean OSA scores for each category of sound sleep between periods

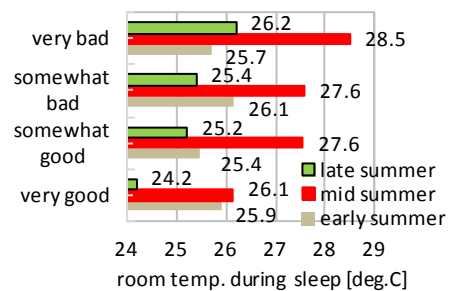


Fig.11 Comparison of mean room temp. for each category of sound sleep between periods

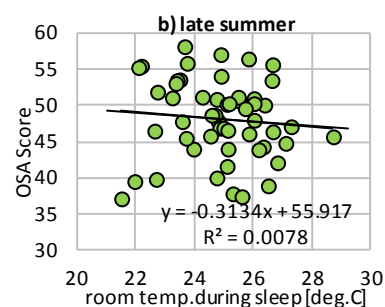
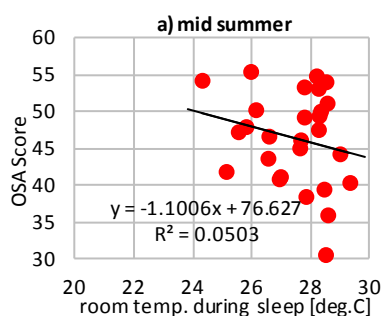


Fig.12 Relations between room temperature during sleep and OSA score for mid-summer and late summer

‘somewhat bad’ in late summer ($p=.071$). Differences of the temperature between ‘very good’ and ‘somewhat good’ were larger than that between ‘somewhat good’ and ‘somewhat bad’. Room temperature was related to the degree of sound sleep in late summer, although the relation was weak in mid-summer.

Fig. 12 depicts relations between the mean bedroom temperature during sleep and the OSA score for middle and late summer. The OSA score became slightly higher for the lower bedroom temperature in mid-summer ($r=-.22$), although little correlation was found between OSA score and room temperature in late summer ($r=-.09$).

3.2 Comparison between AC use days and non-use days

The AC non-use day is defined as the day on which respondents did not record AC use in the diary at all during sleep. However, the AC use days include from days of AC use through the night to days of AC use for only 30 min.

3.2.1 Thermal environment

Fig. 13 shows the daily mean outdoor temperature and mean outdoor temperature during sleep for AC use and non-use days. The daily mean outdoor temperatures were 24.6 °C and 23.4 °C for use and non-use days (in t-test, $p=.005$). Mean outdoor temperatures during sleep were 22.6 °C and 21.4 °C for use and non-use days ($p=.002$). Differences between use and non-use days were 1.2 K for both daily temperature and temperature during sleep. However, p -values showed that subjects chose to use AC according to the outdoor temperature during sleep.

Fig. 14 presents a comparison of mean bedroom temperature during sleep between use and non-use days for three periods. Differences between use and non-use days were 1.2 K in early summer, 1.1 K in mid-summer and 0.9 K in late summer. Slight differences were apparent in bedroom temperature during sleep between use and non-use days. The mean bedroom temperature during sleep was 26.4°C (25.7°C) and 26.3°C (25.7°C) for use and non-use days for total three periods.

3.2.2 Behaviors

Fig. 15 shows average time ratios of sleep, window opening, and AC use in bedrooms and AC use of the respondents for AC use and non-use days. The time ratio of sleep was not different between use and non-use days. Time ratios of window opening in bedrooms were 24.5% for use days and 47.8% for non-use days. Windows were kept closed for about half of the day even for non-use days. The time ratio of AC use of the respondents was 18.4%. The

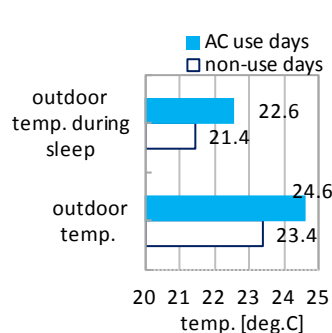


Fig.13 Comparison of mean outdoor temp. between AC use and non-use days

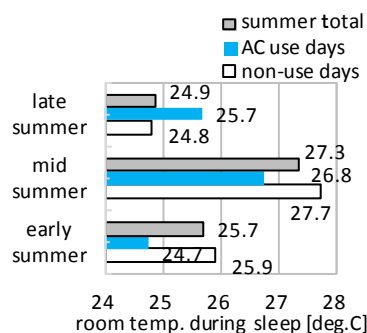


Fig.14 Comparison of mean room temp. between AC use and non-use days

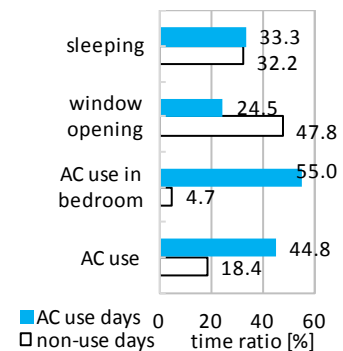


Fig.15 Comparison of time ratio of behaviors between AC use and non-use days

time ratio of AC use in bedrooms was 4.7% for non-use days. However, the AC use ratio and AC use ratio in bedrooms were similar for use days. Respondents used AC outside the bedrooms for non-use days.

3.2.3 Thermal sensation

Fig. 16 shows a frequency distribution of thermal sensation, comfort and acceptability for AC use and non-use days. Results show that 'slightly hot' was the most frequent (23.4%) for use days, although 'neutral' was the most frequent (38.3%) for non-use days (in uniformity test between AC use and non-use, $p=.19$). The mean bedroom temperature during sleep was almost identical for use and non-use days as noted in 3.2.1, but respondents felt hotter for use days, although 'cool' and 'neutral' were the second most frequent.

Actually, 'slightly uncomfortable' was most frequent (43.3%) for use days, although 'comfortable' was the most frequent (51.9%) for non-use days. Little difference was apparent in thermal comfort between use and non-use days ($p=.80$).

For use days, 'acceptable' was 53.3%; 'sometimes not acceptable' was 43.3%. Actually, 'acceptable' was 75.6% and 'sometimes not' was 22.7% for non-use days. For both use and non-use days, 'acceptable' was the most frequent, but less frequent for use days than for non-use days ($p=.031$).

Fig. 17 presents ratios of 'comfortable' and 'acceptable' for each category of thermal sensation for use and non-use days. The ratio of 'comfortable' was higher in 'cool', 'slightly cool', and 'neutral' for use days than for non-use days. The ratio of 'comfortable' was the highest in 'slightly cool' for non-use days, although the ratio in 'neutral' was similar for use and non-use days. The ratio of 'acceptable' was higher in 'slightly cool', 'neutral' and 'slightly hot' for non-use days than use days. Figures show that use days were more comfortable but less acceptable than non-use days, irrespective of thermal sensation.

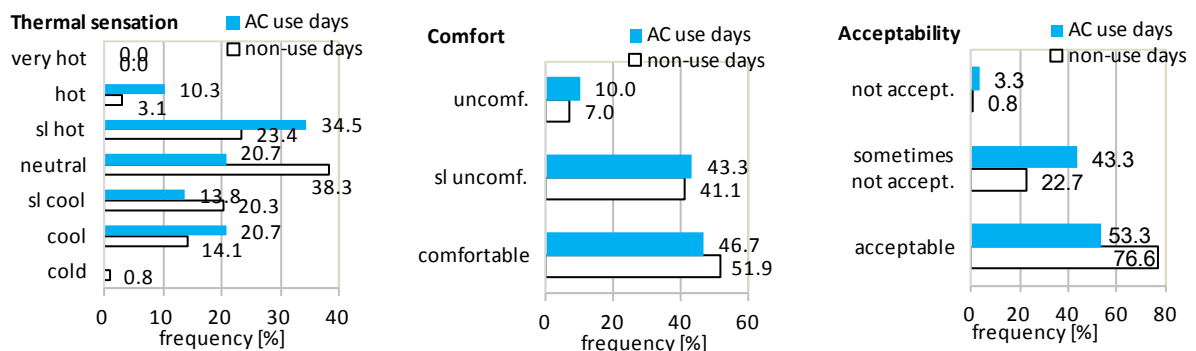


Fig.16 Frequency distribution of thermal sensation, comfort and acceptability for AC use and non-use days

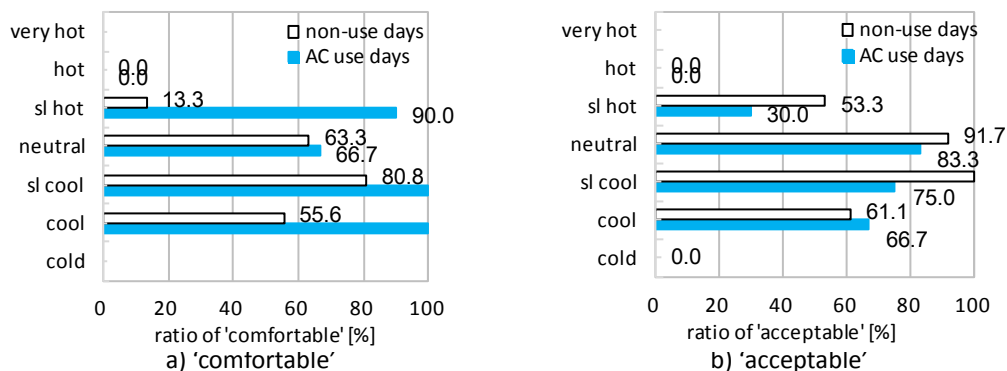


Fig.17 Comparisons of ratios of 'comfortable' and 'acceptable' in each category of thermal sensation between AC use and non-use days

3.2.4 Sleep

Fig. 18 displays the frequency distribution of the degree of sound sleep for AC use days and non-use days. Actually, 'very good' was 50%; 'somewhat good' was 40% for use days. Results show that 'very good' was 32.6% and 'somewhat good' was 46.5% for non-use days. The degree of sound sleep tended to be better for use days than for non-use days (in uniformity test between AC use and non-use, $p=.238$).

Fig. 19 presents OSA scores compared between use days and non-use days in each subject. The OSA score was better for use days than for non-use days in nos. 1, 3, 6 and 9. However, nos. 2 and 6 were the opposite.

Fig. 20 shows mean OSA scores for use and non-use days for mid-summer and late summer. The mean OSA score was 47.9 in mid-summer and 50.2 in late summer for use days. They were 44.1 in mid-summer and 48.0 in late summer for non-use days. Difference of mean scores and p -values of t -tests between use and non-use days were 3.9 and 0.023 in mid-summer, and 2.3 and 0.39 in late summer. The OSA score was higher for use days than for non-use days in mid-summer. However, little difference was apparent between use and non-use days in late summer.

Fig. 21 presents a comparison of profiles of mean vote of each OSA scale between use and non-use days. Sleep for use days was better than non-use days. Concentration in Factor I, soundly in Factor II, many dreams in Factor III, fatigue in Factor IV and good appetite in Factor V were higher for use days. Little tendency was apparent among factors.

3.2.5 Relation between thermal environment and sleep

Fig. 22 shows a comparison of the mean OSA score of each category of thermal sensation, comfort and acceptability between AC use and non-use days. OSA score slightly correlated to thermal sensation only for use days ($p=.0659$). OSA score became higher for cooler sensation for use days, but no relation was found between OSA score and thermal sensation. OSA score did not so relate to thermal comfort for both use and non-use days. The mean

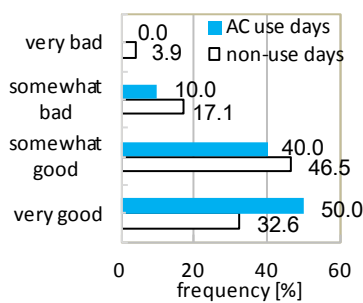


Fig.18 Frequency distribution of degree of sound sleep for AC use and non-use days

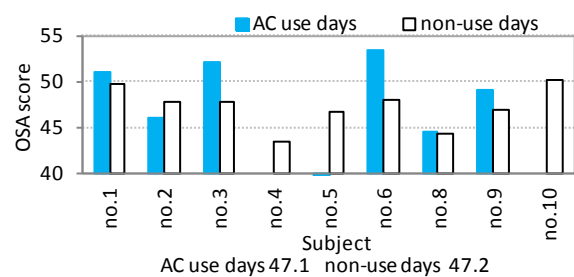


Fig.19 Comparison of mean OSA scores in each subject between AC use and non-use days

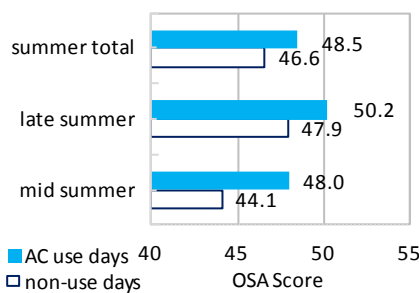


Fig.20 Comparison of mean OSA scores for periods between AC use and non-use days

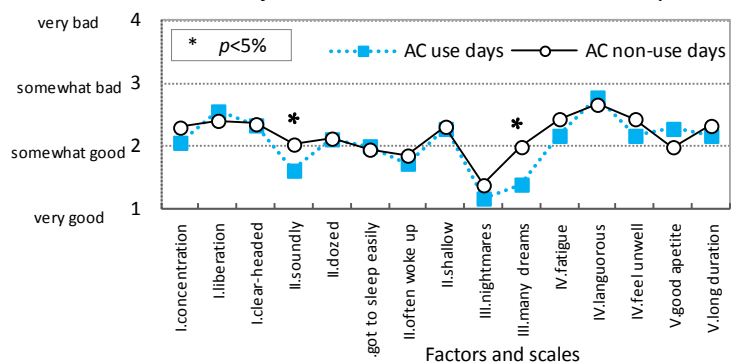


Fig.21 Comparison of profiles of OSA scales between AC use and non-use days

OSA score for 'acceptable' was 52.0 and 'slightly acceptable' was 45.0 for use days. OSA score was high when thermal acceptability was high for use days ($p=.0062$). However, little relation existed between OSA score and thermal acceptability for non-use days ($p=.18$). OSA related to thermal sensation and acceptability, but not to thermal comfort for use days. OSA little related to thermal sensation, comfort and acceptability for non-use days.

Fig. 23 shows the mean OSA scores of respective categories of the degree of sound sleep between use and non-use days. The OSA score was unrelated to the degree of sound sleep for use days ($p=.058$). However, the mean OSA score for 'sleep soundly' was 50.4, for 'sleep somewhat soundly' was 47.4, for 'not sleep somewhat soundly' was 41.7 and for 'not sleep soundly' was 37.3 for non-use days. The OSA score was related to the degree of sound sleep for non-use days ($p=.0001$). The degree of sound sleep is one scale of OSA Factor II. Factor II was higher in OSA for non-use days and OSA score was lower when the degree of sound sleep was low for non-use days, although factors other than Factor II became dominant when the degree of sound sleep was high for use days.

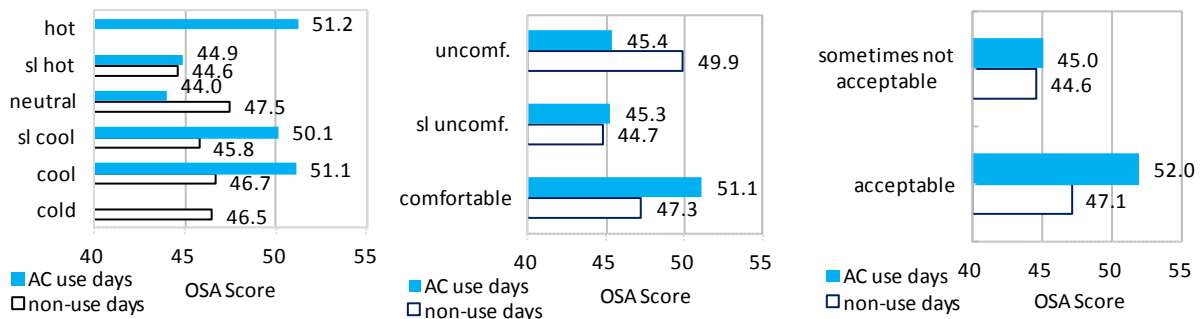


Fig.22 Comparisons of mean OSA scores for each category of thermal sensations, comfort and acceptability between AC use and non-use days

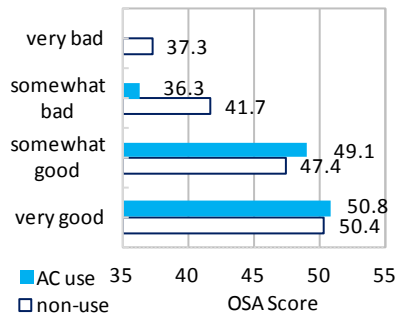


Fig.23 Comparison of mean OSA scores for each category of sound sleep between AC use and non-use days

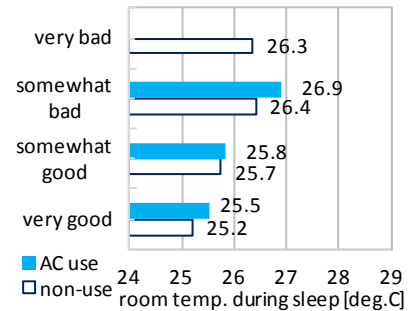


Fig.24 Comparison of mean room temperatures for each category of sound sleep between AC use and non-use days

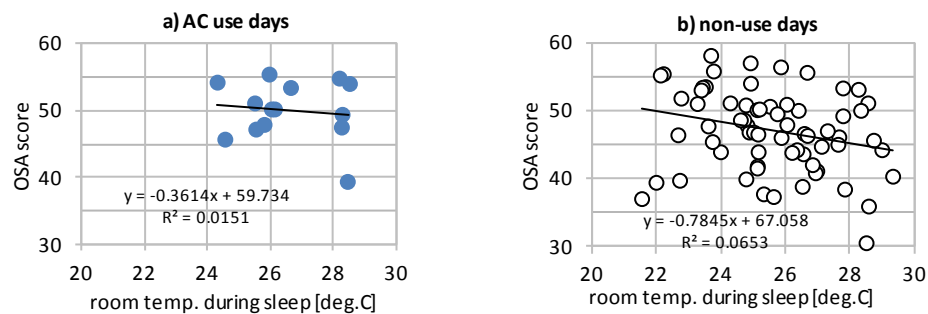


Fig.25 Relations of room temperature during sleep and OSA score for AC use and non-use days

Fig. 24 shows the mean bedroom temperature during sleep for each category of degree of sound sleep for use and non-use days. Degree of sound sleep was unrelated to bedroom temperature for AC use days ($p=.68$). However, the mean bedroom temperature was 25.2 for 'sleep soundly', 25.7 for 'sleep somewhat soundly', 26.4 for 'not sleep somewhat soundly', and 26.3 for 'not sleep soundly' for non-use days ($p=.064$). The relation was not significant, but the degree of sound sleep tended to be low when the bedroom temperature was high in non-use days. As Fig. 25 shows, the coefficient of correlation between the mean bedroom temperature during sleep and OSA score was -0.26 for non-use days, where little correlation was found between room temperature and the OSA score for use days. These figures show that room temperatures did not relate to the degree of sound sleep or sleep quality for use days.

4. Discussion

4.1 Comparison among periods

Mean room temperatures were 27.2°C for mid-summer and 25.4°C for late summer. However, 'cool' was most frequent for mid-summer; it felt cooler. The relative frequencies of 'comfortable' responses were around 60% for mid-summer and late summer. However, mid-summer was more uncomfortable because about 20% felt 'uncomfortable' for mid-summer. 'acceptable' responses were about 60% for mid-summer and more than 90% for late summer. It can be said that it was cooler for mid-summer than for late summer, but mid-summer was less comfortable and less acceptable.

The ratios of 'comfortable' and 'acceptable' were not different by thermal sensation for mid-summer. Thermal comfort and acceptability did not depend on thermal sensations in mid-summer.

Regarding the degree of sound sleep 'somewhat good' was reported by 40–50% of respondents for both periods, but the frequency of 'slightly bad' was 30% for mid-summer. The mean OSA score was 45.5 for mid-summer and 48.1 for late summer. Mean OSA scores for respondents were lower for mid-summer than for late summer. It can be said that sleep quality was lower for mid-summer than for late summer. Scores of Factor III (dreaming) and Factor II (maintenance) were similar, but scores of Factor I (waking up), Factor IV (fatigue), and Factor V (duration) were lower for mid-summer. The difference of the OSA scores presumably resulted from differences of Factor I, IV, and V scores.

The OSA scores were higher for 'comfortable' for mid-summer. Thermal comfort was related to OSA score for mid-summer, although OSA scores were not different by thermal comfort for late summer. Thermal acceptability was related to OSA score for mid-summer because the difference in OSA score for 'acceptable' and 'slightly unacceptable' was larger for mid-summer than for late summer. Thermal comfort and acceptability were related to sleep quality for mid-summer.

Room temperature was related to the OSA score or degree of sound sleep for mid-summer, but not related for late summer. The OSA score was related to the degree of sound sleep for both mid-summer and late summer. Relations between OSA scores and thermal sensation were weak for both mid-summer and late summer.

4.2 Comparison between Air-conditioner use days and non-use days

The room temperature during sleep was 25.7°C for both AC use days and non-use days, although outdoor temperatures during sleep were 23.4°C for AC use days and 21.4°C for non-use days. 'slightly hot' was 23.4% and most frequent on use days and 'neutral' was

38.3% and most frequent. Use days were significantly hotter than non-use days. No difference was found in thermal comfort between use and non-use days. 'acceptable' was 53.3% on use days and 75.6% on non-use days. Use days were more thermally acceptable than non-use days were. It can be said that thermal comfort was not different between use and non-use days, but non-use days were cooler and more acceptable.

The ratio of 'comfortable' was not different by thermal sensation on use days. On the other hand, the ratio of 'slightly cool' was the highest and related more to thermal sensation on non-use days than on use days. The ratio of 'acceptable' on non-use days was about two times higher than on use days. It was hotter but more comfortable. The range of acceptability was wider on non-use days.

Regarding the degree of sound sleep, 'very good' was 50% on use days and 32.6% on non-use days. Mean OSA scores were 48.3 on use days and 46.0 on non-use days. The score on use days was slightly higher than that on non-use days. The difference of mean scores among respondents was not significant. Little difference was found between use and non-use days for late summer, although the mean score on use days was higher than on non-use days for mid-summer. Little difference was found in OSA factor scores between use and non-use days. It can be said that the difference of sleep quality was not so great between use and non-use days.

The OSA score differed by thermal sensation and comfort on use days, although little difference was found in the OSA score by different thermal sensation, comfort and acceptability. The relation between OSA score and thermal sensation, comfort and acceptability was weaker on use days than on non-use days.

OSA score was related to degree of sound sleep tightly on non-use days, but slightly related on use days. Room temperature was not related to OSA scores on use-days, although OSA was lower for higher room temperature on non-use days.

4.3 Air-Conditioner Use Effects on Sleep Quality

AC use days were 15 in mid-summer; non-use days were 27. In late summer, the AC use days were 4; non-use days were 48.

It was cooler in mid-summer than in late summer in spite of higher room temperatures in mid-summer. Air-conditioner use might reduce temperatures, but rooms were slightly cooler on AC non-use days than on use days. AC use did not cause the coolness. It was rather slightly hotter on use days than on non-use days, although room temperatures were almost identical on use days and non-use days. The wide acceptable range on non-use days was rather notable. It was slightly hot, but comfortable on non-use days.

Sleep quality was worse for mid-summer than for late summer, and worse on non-use days than on use days. However, the difference between use days and non-use days was smaller than that between mid-summer and late summer. Not AC use, but higher room temperatures in mid-summer caused lower sleep quality.

The OSA score was related to the degree of sound sleep both for mid-summer and late summer. However, the relation was weak on use days. The relation between the OSA score and thermal acceptability was weak both for mid-summer and for late summer, but the OSA score was related to acceptability on use days. Presumably, AC use caused the weak relation between the OSA score and the degree of sleep quality. Furthermore, AC use caused a strong relation between the OSA score and thermal acceptability.

5. Conclusions

A survey of the thermal environment of bedrooms, sleep quality, and thermal sensations were conducted in summer during seven successive days for three periods for 11 bedrooms. The AC use days and non-use days were compared relative to thermal environment, sleep quality, and thermal sensations considering differences of periods. Number of AC use and non-use days during sleep in early, middle, and late summer were, respectively, 11,15, and 4, and 54, 27, and 48.

- 1) Outside temperatures were higher on AC use days but room temperatures during sleep were kept almost identical (25.7°C) for AC use days and non-use days.
- 2) Sleep quality as evaluated by the OSA score was higher on AC use days. However, it was hotter and less acceptable on AC use days than on non-use days, although thermal comfort was not reported as different between AC use and non-use days.
- 3) On AC use days, the relation between thermal comfort and thermal sensation was weaker. Thermally acceptable ranges were narrower on AC use days.
- 4) Differences in sleep quality were smaller between AC use days and non-use days than between mid-summer and late summer. Lower sleep quality in mid-summer was caused not by AC, but by higher room temperatures.
- 5) The OSA score was related to the degree of sound sleep both for mid-summer and late summer. However, the relation was weak on AC use days. Relations between OSA score and thermal acceptability were weak both for mid-summer and late summer, but the OSA score was related to the acceptability on AC use days.

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