Cooling effects on fatigue recovery during summer sleep

Noriko Umemiya [a] and *Mitsunori* Suzuki [a]

[a] Department of Architecture and Building Engineering, Graduate school of Engineering, Osaka City University, Osaka, Japan. umemiyanor@osaka-cu.ac.jp.

Abstract. Sleep quality has been difficult to maintain recently, particularly for urban residents. This study investigates effects of cooling use on fatigue recovery during sleep for dwellings and residents with various attributes. Measurements of sleeping room thermal environments and questionnaire surveys were conducted for 188 Osaka apartment residents on 765 nights during four summers. Each resident recorded bedside air temperature and humidity and kept a diary reporting occupation of sleeping rooms, sleep, and cooling use at intervals of 30 min for seven days. Subjective sleep quality by the OSA sleep inventory was recorded every morning. Residents evaluated their dwelling environment and constitution and consciousness. Sunshine, sunlight glare, heating efficiency, outside air clearness in items of dwelling environment and heat tolerance, cold tolerance, circulation and stress in items of constitution were related directly to sleep quality. Data were divided into two categories for each item. The mean outdoor temperature during sleep was higher and lower for over and under 27.3°C, which was the median value. Results indicate the following for dwellings with high thermal insulation: a) when outdoor temperatures were higher, fatigue recovery scores were higher for 'not sunny', 'not cooling efficient' and 'not clear outside air' dwellings, with 'low heat tolerance' residents using cooling and higher scores for 'sunny' dwellings and 'good circulation' residents without cooling; b) when outdoor temperatures were lower, fatigue recovery scores were higher for 'cooling efficient' dwellings and 'low stress' residents without cooling. For dwellings with less thermal insulation, results showed the following: a) when outdoor temperatures were higher, fatigue recovery scores were higher for 'poor circulation' residents using cooling and were higher for 'high cold tolerance' residents without cooling; b) when outdoor temperatures were lower, fatigue recovery scores were higher for 'not sunny' dwellings without cooling.

Keywords. Sleep, cooling use, fatigue recovery
DOI: https://doi.org/10.34641/clima.2022.312

1. Introduction

Tropical nights with minimum temperatures higher than 25°C in Osaka, Japan were fewer than twenty days in the 1960s, but they became greater than 40 days on a regular basis in the 2010s (1). Good sleep quality has become difficult to maintain, especially in urban areas during summer. Kusaka et al. (2) predicted from simulation results that almost every August night in Osaka will be a tropical night in the 2070s. Okamoto-Mizuno et al. (3) investigated humid heat exposure effects on sleep and showed that air temperature 35°C/relative humidity 75% conditions caused more wakefulness and lower sleep efficiency than 29°C/50% or 29°C/75%; moreover, rapid eye movement stage and stage 3 sleep occurred less than at 29°C/50% or 35°C/50%. Horne et al. (4) clarified that sleep-related vehicle accidents accounted for 16% of all accidents on major roads in southwest England, and for over 20% of those on midland motorways. Air conditioner use is necessary, but the conditions for their use remain unclear. Nakayama et al. (5) analyzed responses to a questionnaire survey of 256 apartment residents in Osaka, which investigated effects of cooling use on the relation between residence thermal performance and sleep quality. Results demonstrated that a 'Fatigue recovery' score in OSA sleep inventory using subjective scales (6) was better for evaluation of residential heating and showed that cooling performance was better for residents with frequent cooling use. However, it was not related to the evaluation of residential heating and cooling performance for residents without frequent cooling use. Nakayama et al. described that the 'Fatigue recovery' score was unrelated to evaluation of solar heat annoyance from windows, irrespective of the cooling use. This study surveys the actual status of cooling use during sleep of Osaka apartments residents for four summers and over 700 nights, with analyses of cooling effects on fatigue recovery during sleep. The results clarify conditions for cooling use.

2. Research Methods

2.1 Measurement of sleeping room thermal environments

Residents of 6–15-floor concrete buildings with family-type apartments in an urban area of Osaka recorded air temperature and relative humidity in sleeping rooms for seven successive days in summer. Air temperatures were recorded every ten minutes automatically using a button-shaped thermo-logger. Humidity was recorded by residents before and after sleeping. Residents themselves set sensors at their bedside according to instructions. **Fig.1** presents a view of sensors set near a sleeping mattress (futon). Because residents might decline participation in the survey because they disliked strangers entering their private sleeping rooms, sensors and questionnaire sheets were delivered and returned by mail. A manual instructed respondents to avoid several places as sensor positions: places with higher air movement of electric fans or air conditioners, places with direct sunlight, places near heating devices such as television sets or artificial lighting, and places at the back of a shelf. Layouts were drawn of the sleeping rooms, showing positions of the sleeping mattress, the sensors, air conditioner, electric fan, and windows. The acquired data were examined carefully. If the sensor position was presumed to be

If the sensor position was presumed to be inadequate to measure the room air temperature, then those data were not used for analyses. Inadequate sensor positions were also recognized from recorded temperatures. Outdoor weather data measured at 10 min intervals were acquired from an Osaka weather observatory in central Osaka city, about 10 km north of the surveyed apartments.

2.2 Questionnaire survey

Residents recorded a 'cooling use diary' with the times of sleep beginning and end, occupation of the sleeping room, cooling and electric fan use, and opening and closing windows of sleeping rooms at intervals of 30 min. **Fig.2** depicts an example.

Every morning, respondents also evaluated sleep quality and thermal sensations of the prior night. If diary data clearly differed from recorded temperature changes, then data of that night were deleted. Data from sleep with children under two years old, and data showing extreme night owl sleep habits were not used.

Fig.1 Sensors and futon in sleeping room

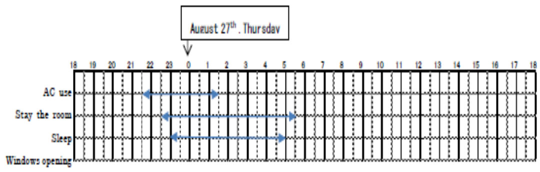


Fig.2 Example of 'Cooling use diary'

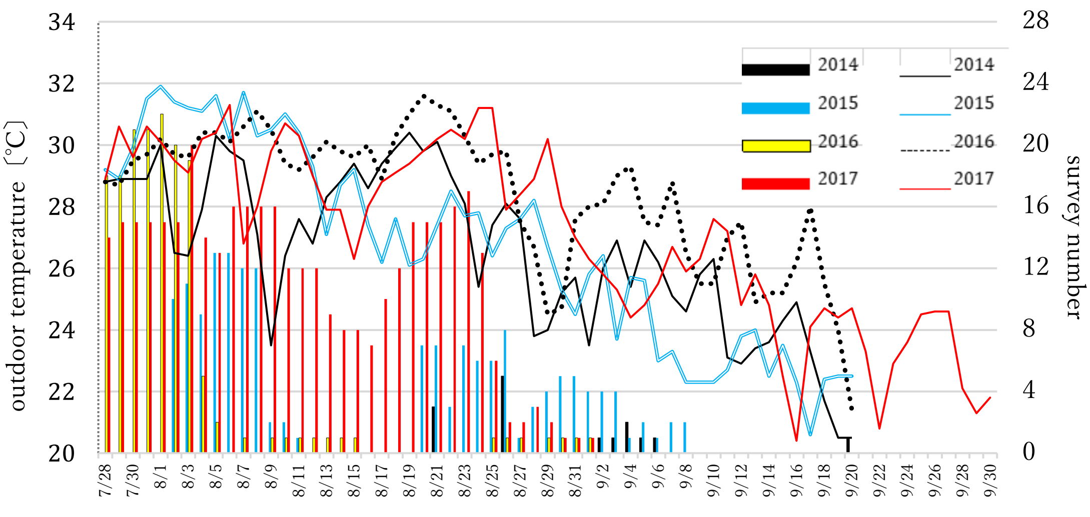


Fig.3 Daily survey number and mean outdoor temperature for four summers

Finally, records of 765 nights at 188 apartments during four summers were accumulated. **Fig.3** shows the numbers of daily measurements and daily mean outdoor temperatures for those periods.

The sleep evaluation scale OSA-MA inventory measures five factors of sleep: 1) drowsiness when waking, 2) falling asleep and maintaining sleep, 3) dreaming, 4) fatigue recovery, and 5) sleep duration, in addition to a profile of sleep using 16 bipolar four-point scales. The present study used this prevailing sleep scale produced by Oguri, Shirakawa and Azumi [6], with successive category method on the bases of 634 healthy students with regular lifestyles in Japan and revised by Yamamoto et al. [7] for middle-aged people with data from 580 middle-aged respondents.

The scales for Factor I are 'I have the power of concentration', 'I feel a sense of liberation', and 'I feel clear-headed'. Those for Factor II are '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'. Those for Factor III are 'I had many nightmares' and 'I had many dreams'. Those for Factor IV are 'Fatigue persists after waking up', 'I feel languorous', and 'I feel unwell'. Those for Factor V are 'I have a generally good appetite' and 'The sleep duration was long'. 'I can answer the questions in a crisp manner' was not used for considering the cases for which respondents could not answer immediately after they awakened. Fifteen scales were used for the present study.

Each question response was given on a four-response scale: very good, somewhat good, somewhat poor, and very poor. These questions yield standard scores of five factors, the averages of which are 50 and standard deviations are 10. Averaged standard scores of five factors are defined as the OSA score. Higher scores indicate higher the sleep quality.

Data of numbers and basic attributes of people sharing the sleeping room, air conditioner setting temperature, and sleep clothing every night were obtained. Sunshine, circulation, outdoor air clarity, view, outdoor noise, cooling efficiency, heating efficiency, mold presence, insect presence, muffled moisture and smell, and dwelling security were asked. Basic attributes were also found from other questionnaire sheets: air conditioner attributes and health state, heat tolerance, cold tolerance, poor circulation, perspiration occurrence, and recent mental stress and mood states of the respondents.

3. Attributes of dwellings and respondents

3.1 Dwelling attributes

Fig.4 portrays a frequency distribution of living areas: 60–69 m^2 were 36.7%, 70–79 m^2 were 22.7% and 50–59% were 21.1 m^2. The average living area was 59.4 m^2. Residences with three bedrooms, a living room, a dining room, and kitchen were 32.5%, which was the most frequent plan. The building 5th floor residents were 12.0%, 6th were 11.3%, and 7th and 8th were 7.3%. The average building floor was 5.8. South, North, East and West oriented sleeping room were 48.2%, 19.6%, 19.6% and 17.0%.

Energy conservation laws, which prescribed insulation amounts, were enacted in 1979 and were amended greatly in 1991 and in 1999. Thermal insulation levels were estimated by the year of apartment building construction. As **Fig.5** shows, those before 1991 were 35.8%, 1992–1998 were 33.1%, and those after 1999 were 34.1%. Frequencies of the three classes were almost equal.

Fig.6 presents the sleeping room environment evaluation. About 60% evaluated circulation and sunshine as good. Almost 70% evaluated the outdoor air as normal. Of respondents, 53.2% evaluated heating efficiency as good; 38.1% evaluated it as normal. Also, 43.7% of respondents evaluated cooling efficiency as good; 46.5% evaluated it as normal. Cooling efficiency of sleeping rooms was evaluated as lower than the heating efficiency. Of respondents, 24.7% reported that condensation occurred often in sleeping rooms, 11.9% often found mold, and 14.5% felt moisture and smells were muffled. In addition, 19.6% felt that the solar heat was annoying, whereas 25.0% felt the indoor solar glare to be annoying. Also, 25.2% evaluated the outdoors as noisy. Poor security of the sleeping room was reported by 38.5% of respondents.

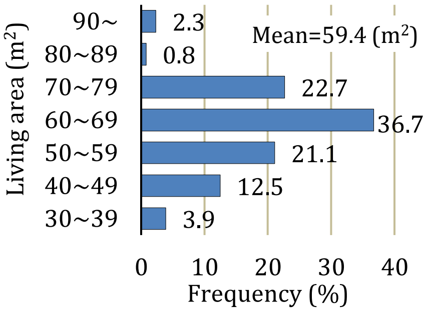


Fig.4 Frequency distribution of living area

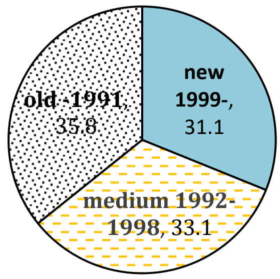


Fig.5 Frequency distribution of thermal insulation level

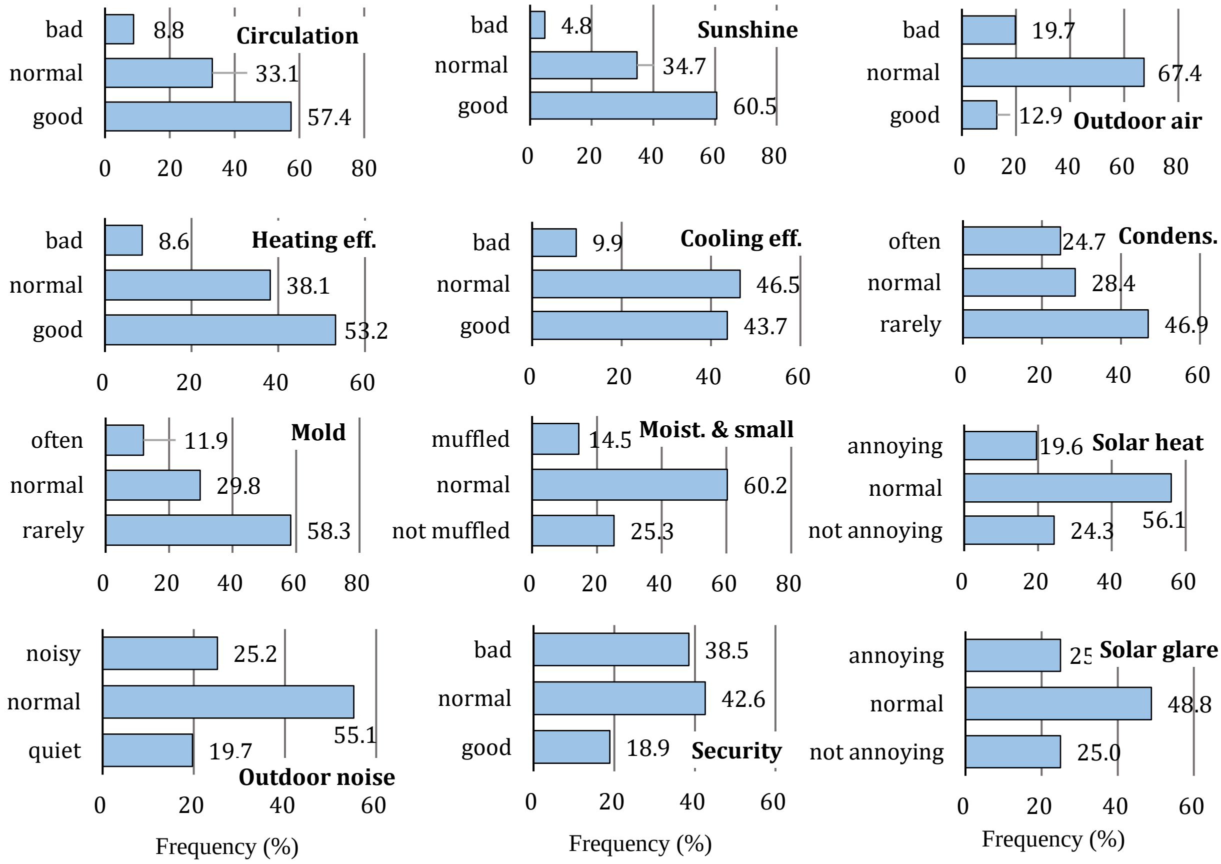


Fig.6 Frequency distribution of sleeping room environment evaluation

3.2 Resident attributes

Women were 61.2% of all respondents. Of respondents, those 50–55 were 16.3%, 65–70 were 11.6%, 40–45 were 10.9%; the average respondent was 52.9 years old. Residents reported as very healthy were 15.6%, healthy were 40.2%, and those of normal health were 36.1%. Those who were self-reported as vulnerable to heat stress were 19.5%, whereas those with little vulnerability were 17.9%. Those self-reported as weak against cold stress were 30.5%; those who were strong against it were 22.2%. Much mental stress was reported by 3.2%. Some stress was reported by 23.7%. A little stress was reported by 45.2%, but 25.8% reported no stress. **Fig.7** portrays the distribution of mental stress and poor circulation. Little perspiration and slight perspiration were 23.2%. Frequent poor circulation was reported by 21.1% of respondents. Often, sometimes, and none were each 23.2%.

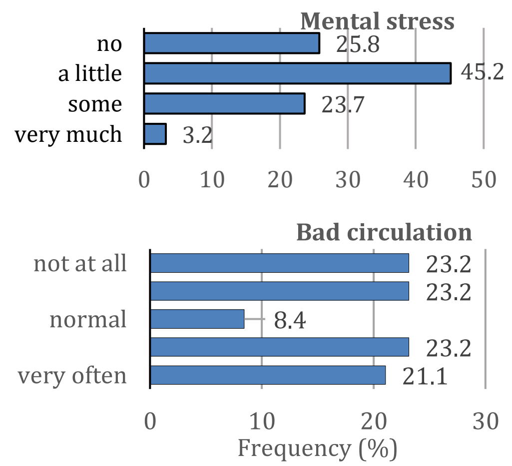


Fig.7 Frequency distribution of respondent attributes

4. Thermal environment, sleep quality and thermal sensation

Fig.8 portrays a distribution of mean outdoor and indoor temperature during sleep. **Fig.9** shows the distribution of mean difference (outdoor–indoor). Mean outdoor and indoor temperatures were 27.2°C and 27.9°C. The mean difference was -0.73 K and 0, -1 and -2 K were dominant. The mean and standard deviations of relative humidity were 71.2±6.1% and 65.1±8.2% for outdoor and indoor.

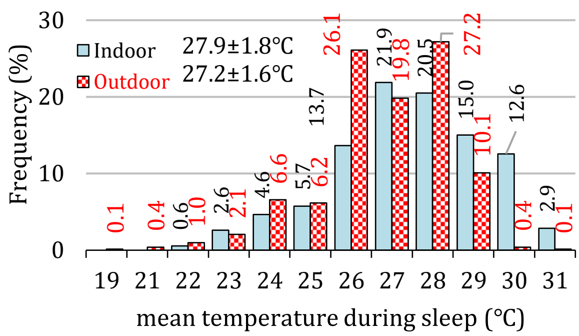


Fig.8 Mean indoor and outdoor temperature during sleep

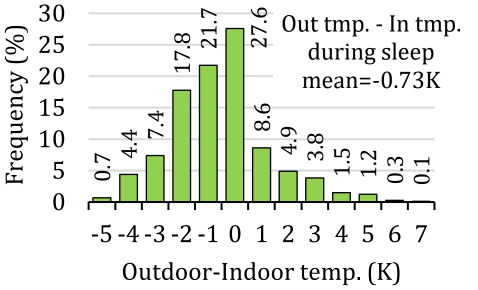


Fig.9 Distribution of outdoor-indoor temperature difference during sleep

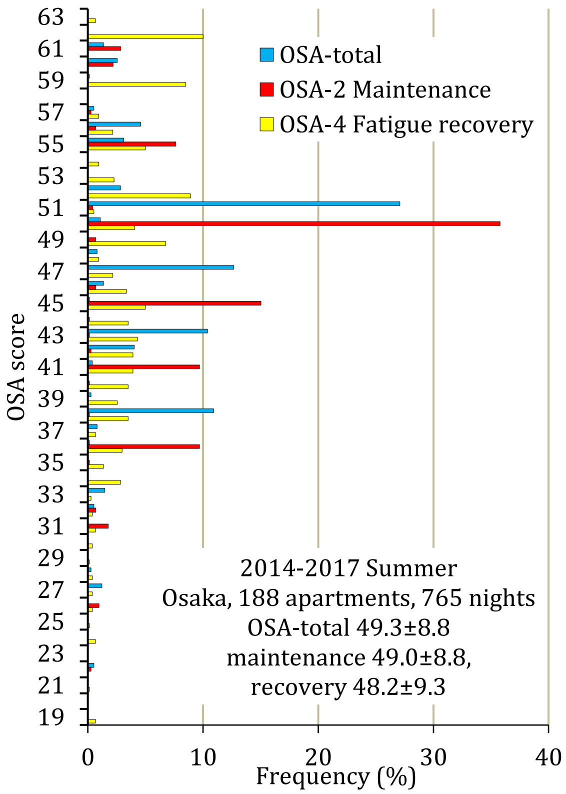


Fig.10 Distribution of OSA sleep quality scores

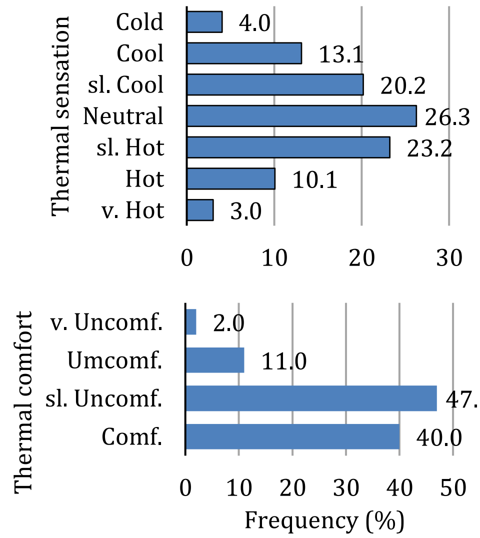


Fig.11 Distribution of thermal sensation during sleep

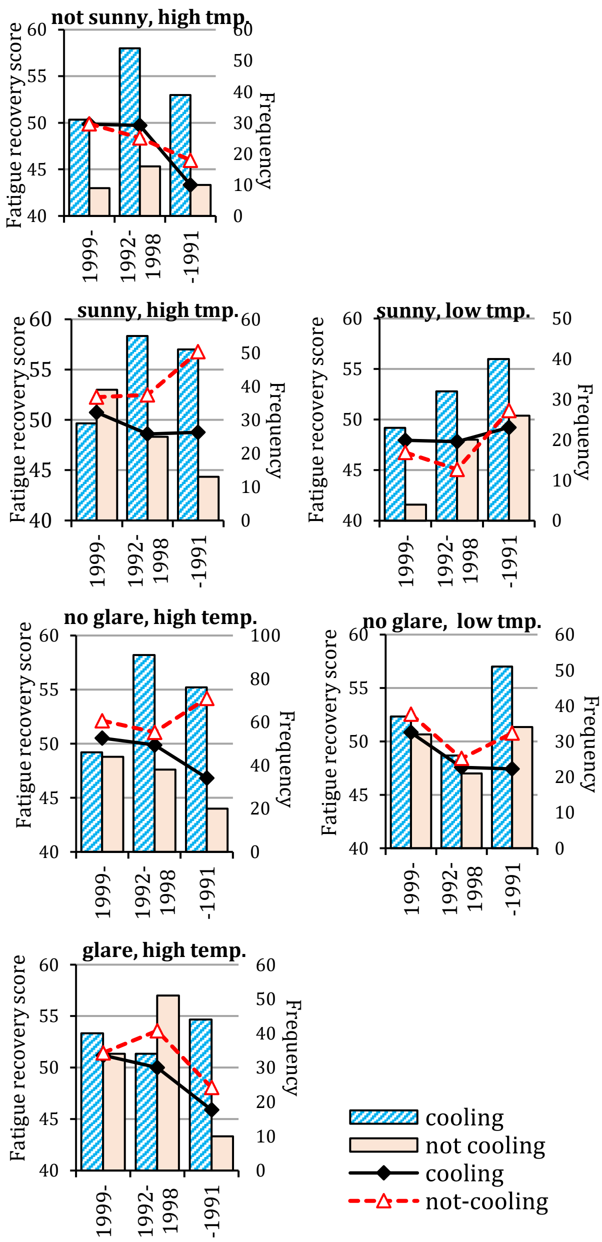
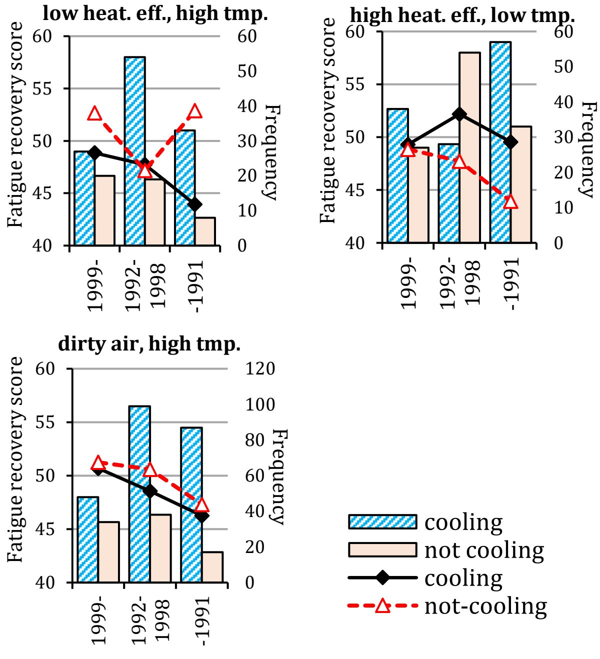


Fig.12 Fatigue revovery score for different outdoor temp., sleeping room environment, and insulation level

Fig.10 depicts the distribution of OSA scores. The OSA-total score was 49.3±8.8. The most frequent score was 51. The OSA-total and OSA-2 (sleep maintenance) scores were distributed around 50.0, but OSA-4 (fatigue recovery) was distributed rather uniformly. **Fig.11** shows a distribution of thermal sensation. Neutral was 26.3%: the most frequent.

5. Dwelling insulation and Fatigue recovery

Sunshine, indoor solar glare, heating efficiency, and outdoor air in sleeping room evaluation items were related directly to OSA scores. Data were divided into two categories by each item to mitigate the direct effects by these items. Data were also divided into two by outdoor temperature 27.3°C, median of the mean outdoor temperature during sleep and by cooling use nights (64.5%) and non-use nights (35.5%).



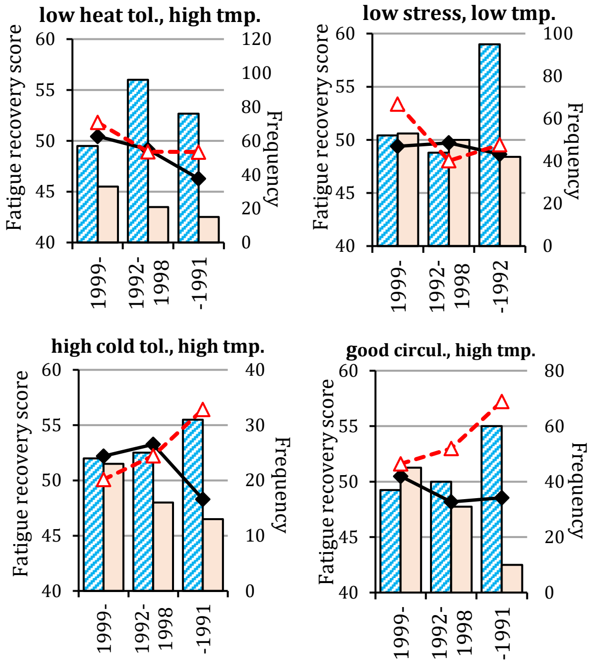


Fig.12 Fatigue revovery score for different outdoor temp., sleeping room environment, and insulation level (continued)

Fig.13 Fatigue recovery score for different outdoor temp., sleeping room environment, and insulation level

Fig.12 shows the relation between the insulation level and the fatigue recovery score. Lines show the score. Bars show the number of nights. The solid line and left colored bar are for cooling use nights and dotted line. The white bars are for nights with no cooling use. Higher and lower respectively mean over and under 27.3°C, which is the median of the mean outdoor temperatures during sleep.

Fatigue recovery score was better for highly insulated dwellings under the following conditions: 1) Outdoor temperatures were higher; cooling was not used in sleeping rooms with good sunshine. 2) Cooling was used in sleeping rooms with indoor solar glare, irrespective of the outdoor temperature. 3) Outdoor temperatures were lower; cooling was not used in sleeping rooms with high cooling efficiency. 4) Outdoor temperatures were higher; cooling was used in sleeping rooms with poor outdoor air quality.

6. Respondent attributes and Fatigue recovery

Heat tolerance, cold tolerance, poor circulation, mental stress, cooling cost anxiety, and mood states in respondent attributes were found to be related directly to OSA scores. Data were divided into two categories by these six items.

Fig.13 portrays the relation between the insulation level and the fatigue recovery score. Fatigue recovery score was better for highly insulated dwellings under the following conditions: 1) Outdoor temperatures were high; cooling was used for respondents with low tolerance to heat. 2) Outdoor temperatures were low; cooling was not used for respondents with low mental stress.

Fatigue recovery score was better for less-insulated dwellings under the following conditions: 1) Outdoor temperatures were high; cooling was not used for respondents with high tolerance against cold. 2) Outdoor temperatures were high; cooling was used for respondents without poor circulation.

7. Conclusions

Sleeping room measurements and data from a questionnaire survey of 188 Osaka apartment residents for 765 nights during four summers clarified the following points about cooling effects on fatigue recovery during summer sleep. For residences with higher amounts of insulation, the following findings were obtained: 1) Cooling use is recommended for higher outdoor temperature nights for cases of a) poor sunshine, b) sunlight glare, c) low cooling efficiency, d) poor outdoor air dwellings, and e) residents with low heat tolerance. 2) Cooling use is not recommended for higher outdoor temperature nights for cases of a) good sunshine dwellings and b) good circulation residents. 3) Cooling use is not recommended for lower outdoor temperature nights for cases of a) dwellings with high cooling efficiency and b) residents with little mental stress. For residences with less insulation, the following findings were obtained. 4) Cooling use is recommended for higher outdoor temperature nights for residents reporting better circulation. 5) Cooling use is not recommended for higher outdoor temperature nights for residents with higher cold tolerance. 6) Cooling use is not recommended for lower outdoor temperature nights, for dwellings with poor sunshine.

8. References

[1] Japan Meteorological Agency https://www.jma.go.jp/

[2] Kusaka H., Iijima N., Ihara T., Hara M., Takane Y., Iizuka S. Future projection of heat stroke and sleep disturbance for 2070's August in Tokyo, Nagoya and Osaka. J. Environ. Eng., AIJ. Nov. 2013; Vol.78, No.693: 873-881.

[3] Okamoto-Mizuno K., Mizuno K, Michie S, Maeda A,. Iizuka S. Effects of humid heat exposure on human sleep stages and body temperature. Sleep. 1999; 22(6):767-773.

[4] Horne J. A., Reyner L. A. Sleep related vehicle accidents. BMJ. March 1995; 310:565.

[5] Nakayama Y., Umemiya N., Sakane T., Arai J., Kobayashi T. and Tachibana Y. Questionnaire survey of air-conditioner effects on sleep quality in summer -Analyses of falling asleep, maintaining sleep factor and fatigue recovery factor. Proceedings of the 6th International Building Physics Conference. June 2015; No.862: 1-6.

[6] Oguri Y., Shirakawa S., Azumi K. Development of OSA sleep inventory. Clinical Psychiatry. July 1985; 27(7):791-799. in Japanese.

[7] Yamamoto Y., Tanaka H., Takase M., Yamazaki K., Azumi K., Shirakawa S.. Standardization of revised version of OSA sleep inventory for middle age and aged. Brain Science and Mental Disorders. 1999; 10(4): 401-409. in Japanese.

The datasets generated during and/or analysed during the current study are not available because the university repository is under construction, but the authors will make every reasonable effort to publish them in near future.