CHANGE OF SUMMER THERMAL CONTROL USE IN HOMES AFTER ELECTRICITY SHORTAGE CAUSED BY 3.11 DISASTER IN JAPAN

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1. INTRODUCTION

Electricity shortages prevailed in many areas of Japan after the earthquake that occurred in Tohoku on March 11, 2011. Fukushima Daiichi Nuclear Power Plant reactors caused explosions after tidal waves resulting from the earthquake destroyed their cooling systems. Subsequently, atomic generation safety was questioned. Almost all electricity generation by nuclear plants was halted in Japan after the disaster. Electricity conservation was requested by government in the national interest. Excessive air-conditioning and illumination were discouraged. Circumstances were most severe in the Kansai area, where half of the electricity generation capacity was done by nuclear power generation. In summer 2011, electric utilities in Kansai asked businesses and households to reduce electricity consumption by up to 15 percent.

Surveys of Japanese residents' energy use are exemplified as follows. Enai et al. (1978) presented a method to estimate kerosene consumption according to the degree-days. Ojima et al. (1980) surveyed the actual situations of energy use for electricity, gas, and kerosene of nine cities throughout Japan and various building types. Hong (1993) analyzed the relationships between annual energy use and the housing attributes for four apartments in Tokyo and found the effects of the floor space, the number of family members, the income, and the cooling and heating systems on energy use. Sawachi et al. (1994) introduced estimation formulae of energy use expressed as a function of cooling degree-days, the number of family members, the supplied water temperature, the annual mean outdoor temperature, the frequency of bathing and showers, and household income based on surveys of eight cities throughout Japan. Suzuki et al. (1995) compared the effects of apartment's thermal performance, living styles and energy conservation consciousness on monthly energy use among Sapporo, Kyoto and Naha. Mae et al. (2002) found 5 standard patterns of cooling time-zone and strong relation between cooling-application and outdoor air temperature for apartments in Hyogo prefecture. Mori et al. (2005) analyzed life style and energy consumption for detached houses in Kobe city and estimated energy consumption by heating and cooling pattern in consideration of dweller's energy-saving action and life style. Lin et al. (2007) compared summer energy costs of urban Osaka apartments by age of the residents and found that younger residents under 40 years old open windows more frequently when asleep, use electric fans more frequently, save electricity more and their cooling costs were lower than older residents.

This study was undertaken to clarify the following: 1) change of electric charge and setting temperature, 2) change of degrees of subjective evaluation of air conditioner use and window opening and habits of 'saving electricity', and 3) factors related to cooling charges and setting temperatures.

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2. METHODS

Surveys were conducted in 2004 and 2011 in southern Osaka city. Apartment buildings that had more than six floors and a hundred apartments facing south, west, and east were selected. Questionnaire sheets were distributed to all apartments in the buildings. Owned and rented, public and private buildings were selected almost evenly. The number of buildings was 24, to which 1,681 sheets were distributed in 2004; 290 of them responded by mail. Another survey of the same items was conducted at the same apartment buildings after the summer period of electricity conservation in 2011.

The questionnaire items were related to cooling behaviors, apartment attributes, evaluation of the residential environment, respondent attributes, and habits and ways of thinking about thermal comfort, thermal control usage, ecology and problems of urban warming. Table 1 shows the questionnaire items and categories.

Living environments were evaluated subjectively in three categories. Frequency of air conditioner use and frequency of window opening were evaluated subjectively on five-point scales. Electricity use and charging were reported both in terms of kilowatt hours and yen for May and August. The range of air conditioner temperature was also reported.

Table 1 Items and categories of the questionnaire

ATTRIBUTE of the APARTMENT
living area, area of veranda, number of rooms, floor
built year, living length, number of family, ownership
direction of the openings

EVALUATION of LIVING ENVIRONMENT
ventilation (too much, well, neutral, poor)
sunshine (a lot of, neutral, little)
view (good, neutral, poor)
glance from outside (anxious, neutral, free)
outdoor air (clean, neutral, dirty)
crime prevention (anxious, neutral, free)
noise outside (noisy, neutral, quiet)
noise from neighbor apartment (noisy, neutral, quiet)
dew on the windows or walls (a lot of, neutral, little)
humid or odor indoors (in close, neutral, released)
mold (a lot of, neutral, little)
insects (a lot of, neutral, little)
solar heat in summer (anxious, neutral, free)
glare of sunshine inside (a lot of, neutral, little)
mechanical cooling (effective, neutral, not effective)
heat inside in summer (bearable by natural cooling, neutral, intorelable without mechanical cooling)
overall satisfaction (5)

ATTRIBUTE of the RESPONDENT
age, sex, place of born and raised, chlonic illness
constitutions (tolerance to heat, cold, flu)
living styles (time, meals, energy use)
ways of thinking for thermal control, comfort and nature

USE of FANS
number of fans
frequency of use (5)

USE of AIR CONDITIONERS
number of air conditioners
year of the purchase
frequency of use (5)
satisfaction to the performance (5)
discontent to the performance
cooling cost (anxious, free)
cooling cost (economizing, free)
cooling cost in Yen and kWh for May
cooling cost in Yen and kWh for August
cooling cost in Yen and kWh for September
cooling temperature
use of air conditioner when asleep
ways of thinking for air conditioning (positive, neutral, negative)

USE of OPENINGS
use of openings when awaken in summer (4)
use of openings when asleep in summer (4)
width of open (5)
frequency of open when air conditioning (4)
frequency of keeping open the front door (4)
use of front screen door (3)

Numbers in parentheses show the numbers of categories

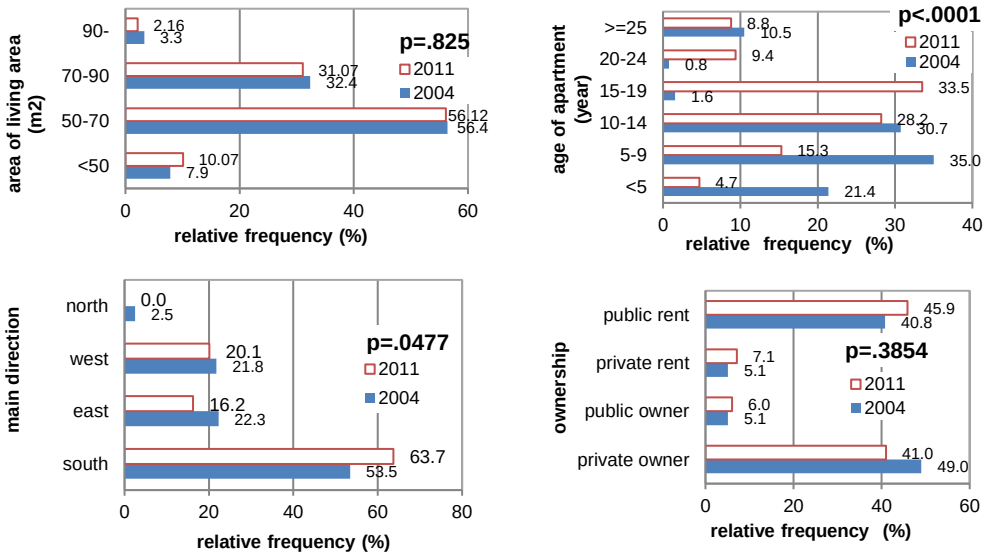

Fig.1 Attributes of the apartments

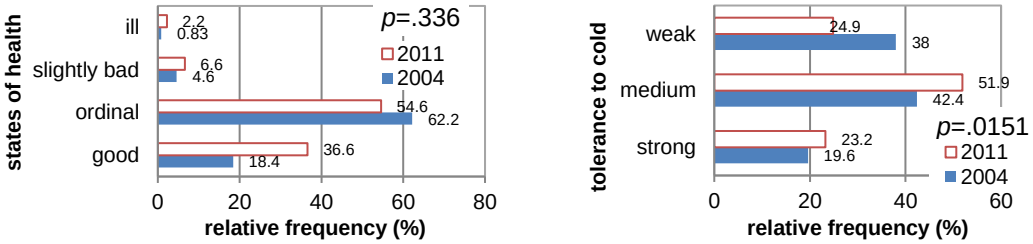

Fig.2 Attributes of the respondents

3. RESULTS

3.1 Surveys

In 2004, 1681 sheets were distributed to 24 apartment buildings; 290 were returned. In 2011, 1669 sheets were distributed; 185 were returned. The return rate was 17.3% in 2004; it was 11.0% in 2011.

3.2 Apartments

Figure 1 shows attributes of the surveyed apartments. Living areas of 50–70 m^2 were approximately 60%. Those of 70–90 m^2 were approximately 30% in both years. Directional facing of apartments differed slightly between years (p=0.0477). South-facing units were 53.5% in 2004 and 63.7% in 2011. No significant difference was found in house ownership. Public housing and private housing were each approximately 40%. Mean numbers of family members were 2.66 in 2004 and 2.36 in 2011.

3.3 Respondents

3.3.1 Basic attributes

In 2011, respondents were 32.4% male and 67.6% female; in 2004, 46.2% were male and 53.8% were female. The mean age of respondents was 46.5 years in 2004 and 54.3 years in 2011.

3.3.2 Constitution and state of health

Figure 2 shows the frequency distribution of tolerance to cold and distribution of states of health. Respondents' constitution such as tolerance to heat and illness, and living styles such as regularity of living time and meals were not

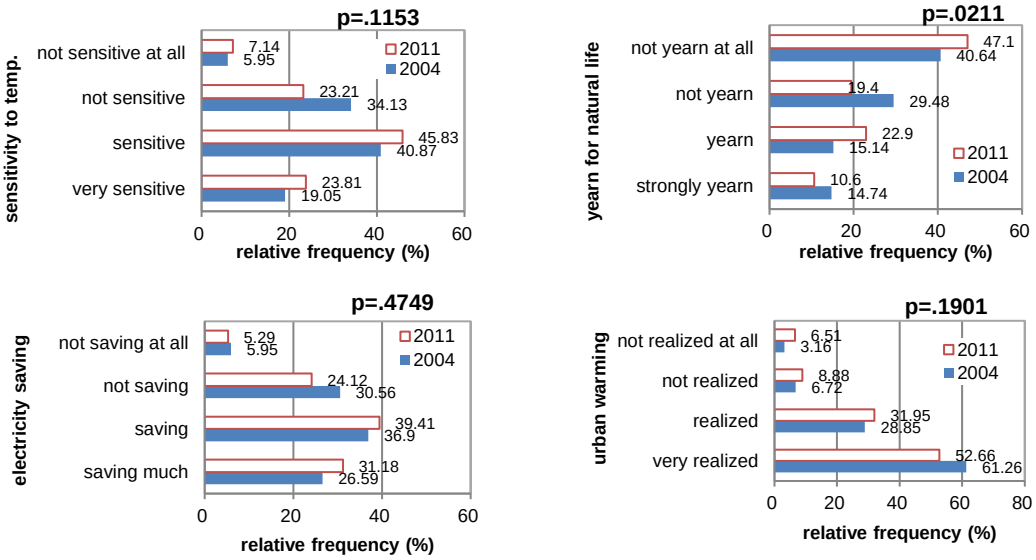

Fig.3　Consciousness of the environment

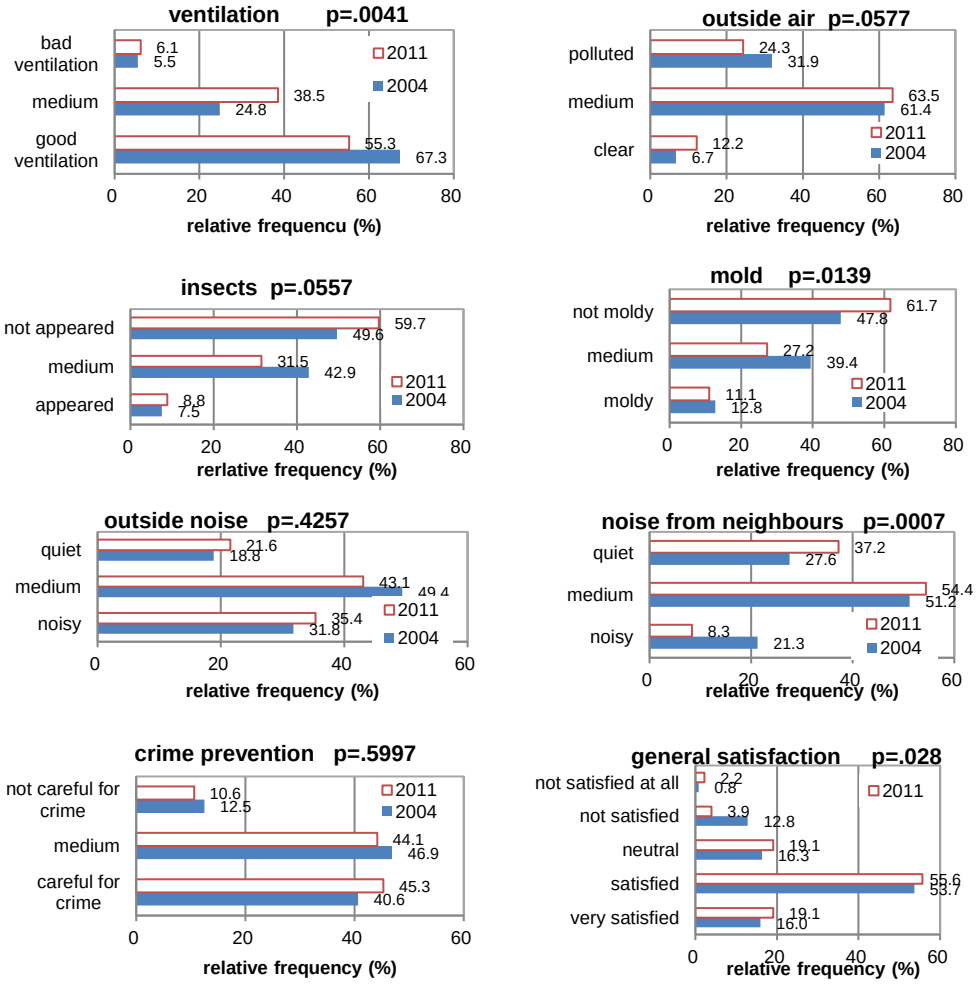

Fig.4　Subjective evaluation of living environments (continued)

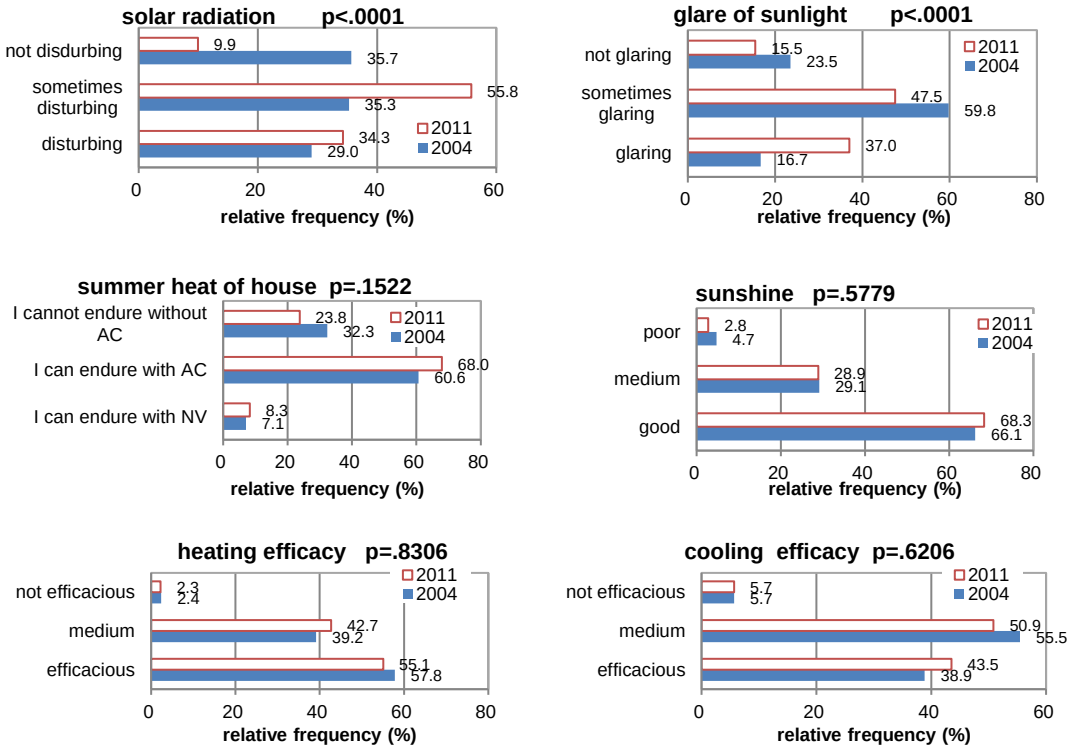

Fig.4 Subjective evaluation of living environments

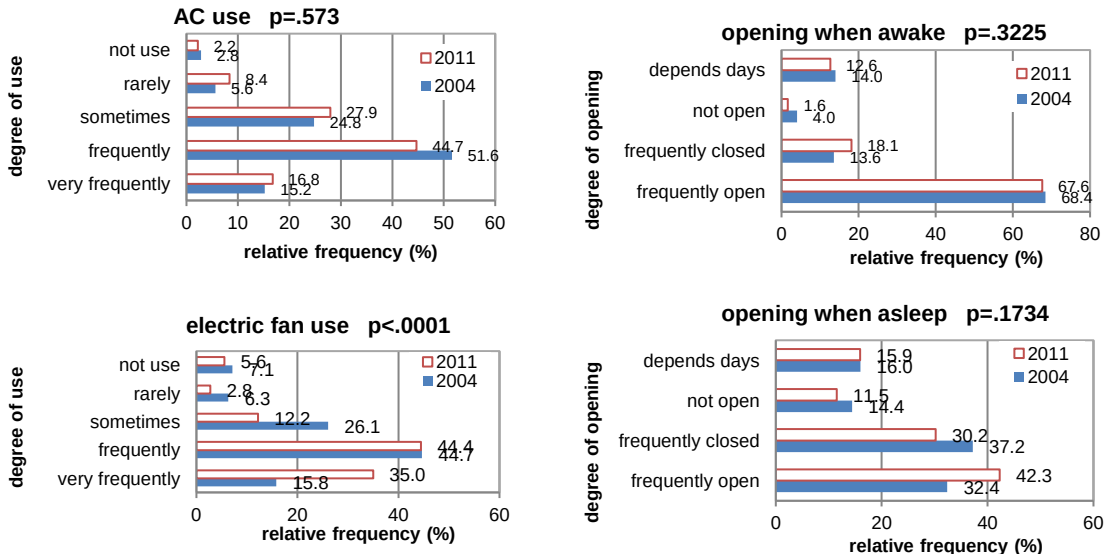

Fig.5 Subjective evaluation of the degree of thermal control use

different between 2004 and 2011, except for tolerance to cold (p=0.0151). No differences were found in states of health between 2004 and 2011.

3.3.3 Consciousness of the environment

Occupants degrees of consciousness related to the environment were also compared during 2004–2011. Figure 3 presents a comparison of the sensitivity to temperature, preference for natural

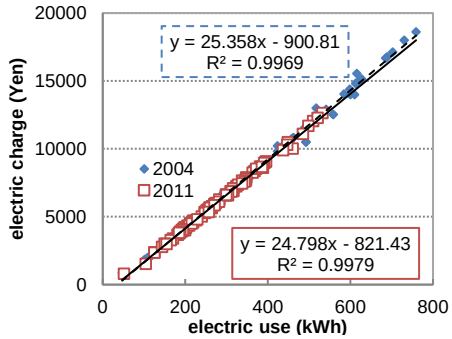

Fig.6 Electric use and electric charges

life, habit of saving electricity and realization of urban warming. Little difference was found in respondents' consciousness of the environment, except for yearning for a natural life (p=0.0211). Degrees of subjective habits of 'saving electricity' did not differ between 2004 and 2011 (p=0.4749).

3.4 Subjective evaluation of living environment

Figure 4 presents a subjective evaluation of living environments. Ventilation (p=0.0041), mold appearance (p=0.0139), noise from neighboring apartments (p=0.0007), disturbance by solar radiation (p<0.0001) and disturbance by glare by sunlight (p<0.0001) differed. Ventilation was poorer, mold appearance was less, and solar radiation heat and glare of sunlight were more disturbing in 2011 than in 2004. General satisfaction with the apartment was higher in 2011 than in 2004 (p=0.028). Weather conditions in summer in 2004 and 2011 were as normal as those of an average year, although solar radiation and glare were evaluated as more disturbing in 2011 than in 2004.

3.5 Thermal control use

3.5.1 Subjective evaluation of thermal control use

Figure 5 shows a subjective evaluation of the degree of thermal control use. The degree of electric fan use increased significantly in 2011 (p<0.0001), but degrees of AC use and window opening did not differ significantly between 2004 and 2011 (p=0.5753).

3.5.2 Electric charge

Figure 6 presents a comparison of the relations between electricity use (E_u) and electricity charges (E_c) in 2004 and 2011. Regression equations are also shown in the figure. Subtraction of E_c in 2011 from E_c in 2004 produced 104 yen in average, 346 yen in maximum and -79 yen in minimum. These equations show that the electricity charge can be estimated by electric use. The difference between years can be ignored. The response rate of electric use in kilowatt hours was as low as 27.2% in 2004 and 28.6% in 2011, probably because of the difficulty of checking old billing figures. The ratio of responses for electric charges was 75.5% in 2004 and 53.5% in 2011. Therefore, electricity charges were examined in this study.

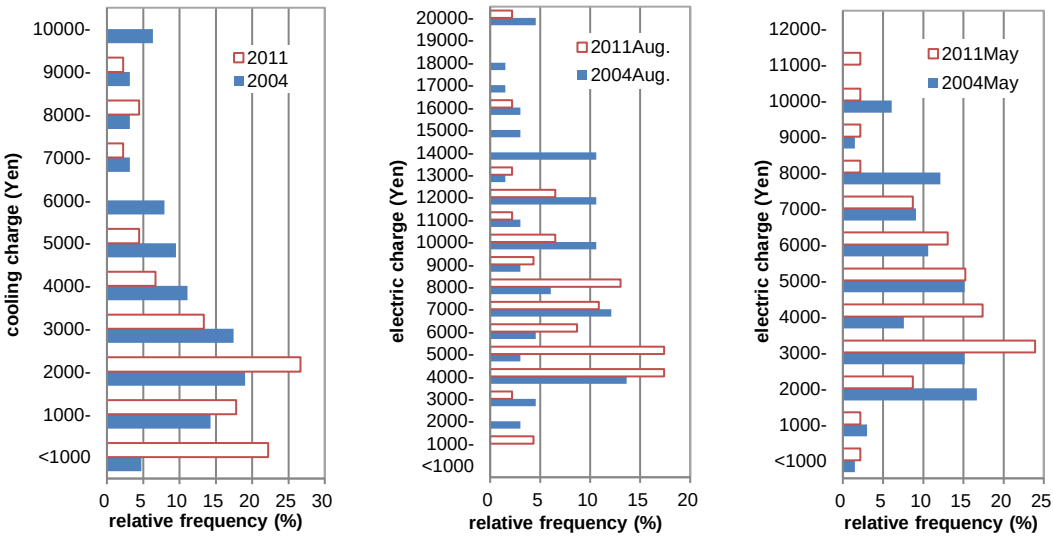

Fig.7 Frequency distribution of cooling charges, electric charges in August and May,

E_c=25.358E_u - 900.81 (r^2=0.9969) in 2004 (1)

E_c=24.798E_u - 821.43 (r^2=0.9979) in 2011 (2)

The difference between May and August was defined as the electricity charge for cooling in this study because cooling was the main reason for the increase in August.

Figure 7 presents a comparison of the frequency distribution of electric charge in May and August and cooling cost between 2004 and 2011. The electricity charge in May was 515 yen (6.0%) lower in 2011 than in 2004. The electricity charge in August was 2253 yen (23.7%) lower in 2011 than in 2004. The cooling charge was 1811 yen (43.8%) lower in 2011 than in 2004.

3.5.3 Air conditioner use

3.5.3.1 Air conditioners

Figure 8 presents a comparison of air conditioner use between 2004 and 2011. More respondents were satisfied with AC in 2011 than in 2004 (p<0.0001). The frequency of 'satisfied' responses was 61.5% in 2004 and 57.1% in 2011, but 'very satisfied' responses increased from 5.3% to 21.1%. The dissatisfaction rate of AC was lower for almost all items, except for 'not cool' and 'windy'. Dissatisfaction with 'high electric charge for cooling season' decreased from 72.9% to 55.6%. The AC performance might be improved or occupants might have become more familiar with

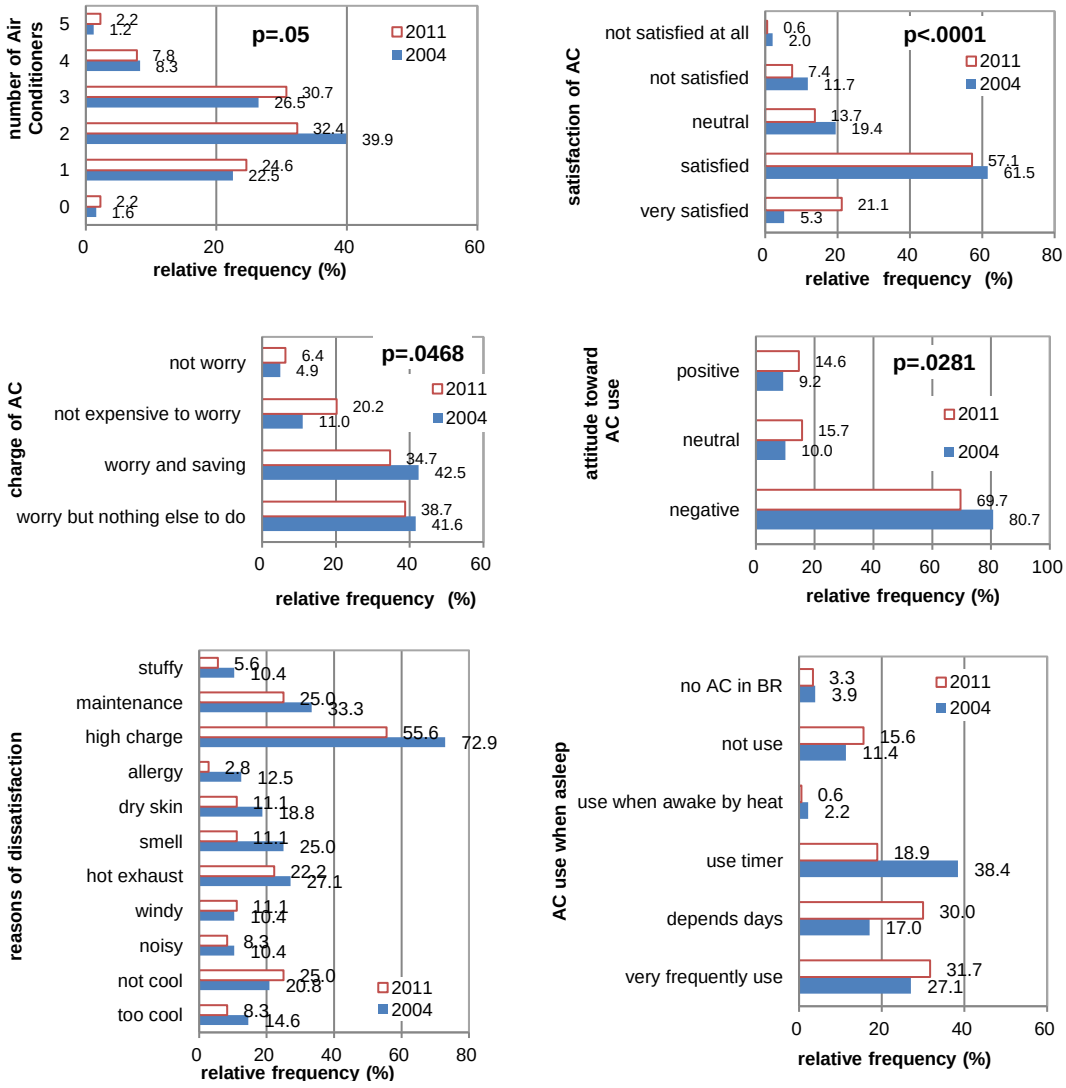

Fig.8 Numbers and subjective evaluation of air conditioners

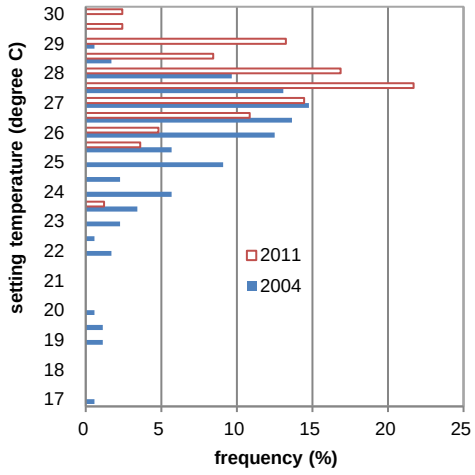

Fig.9 Setting temperatures of air conditioners

AC use during 2004 and 2011. However, more than half of respondents expressed concern about electricity charges during the cooling season.

Regarding electricity charges during the cooling season, the respective frequencies of 'worry but nothing else to do' and 'worry and saving' responses were 41.6% and 42.5% in 2004, and 38.7% and 34.7% in 2011. However, the frequency of 'not expensive to worry' increased from 11.0% to 20.2%. This result also demonstrates that electricity charges by AC were unloaded during 2004–2011.

Respondents came to think more positively about AC use in 2011. 'Negative' responses decreased from 80.7% to 69.7% and 'neutral' and 'positive' increased. However, 70% of the respondents still thought negatively about AC use in 2011. The response of 'very frequently' of AC use when asleep increased from 27.1% to 31.7%, although 'depends on the day' increased from 17.0% to 30.0%. However, 'use a timer' decreased from 38.4% to 18.9%. This survey does not clarify whether 'very frequently use' includes 'use a timer' or not. Moreover, timers might be difficult to use. Timers might not be regarded as effective or comfortable.

3.5.3.2 Setting temperatures of AC

Figure 9 presents a comparison of the frequency distribution of setting temperatures between 2004 and 2011. The setting temperature is defined as the central temperature of the reported cooling temperature ranges in this study. Most frequent setting temperatures were 27.0°C in 2004 and 27.5°C in 2011. However, the distributions were entirely different. The setting temperature was higher in 2011. Settings were 17.0°C to 29.0°C in 2004, and were 23.5°C to 30.0°C in 2011. Regarding temperature settings, 10.5% in 2004 and 8.6% in 2011 did not respond or responded as 'unknown'. The mean setting temperature was 26.0°C in 2004 and 27.5°C in 2011. In the government's electricity-conservation campaign after the disaster, cooling temperatures was requested to be set at 28°C. This result attests to the success of the government campaign.

4. COMPARISONS OF COOLING CHARGES

4.1 Comparison by thermal control use

Figure 10 shows mean cooling charges by the degree of thermal control use in 2004 and 2011. The cooling charge increased along with the degree of AC use in 2004 (p<0.0001) and 2011 (p<0.0001), although the difference in responses of cooling charges of 'very frequently' and 'frequently' was smaller in 2011.

Cooling charges were related to the degree of window opening when awake, p=0.0037 in 2004 and 0.0190 in 2011. The relation between the cooling charge and degree of window opening was stronger when asleep than when awake: p=0.0027 in 2004 and p<0.0001 in 2011. Effects of the use of natural ventilation were stronger in 2011, especially when asleep. The relative frequency of 'frequently open' responses increased from 32.4% in 2004 to 42.3% in 2011. The cooling charge for 'frequently open' in 2011 was approximately half of that in 2004. However, the relative frequency of 'frequently open when awake' was 68.4% in 2004 and 67.6% in 2011, as shown in Figure 5.

4.2 Comparison by living environment evaluation

Figure 11 shows mean cooling charges by degrees of living environment evaluation in 2004 and 2011. Cooling charges increased as the degree of disturbance of solar radiation indoors

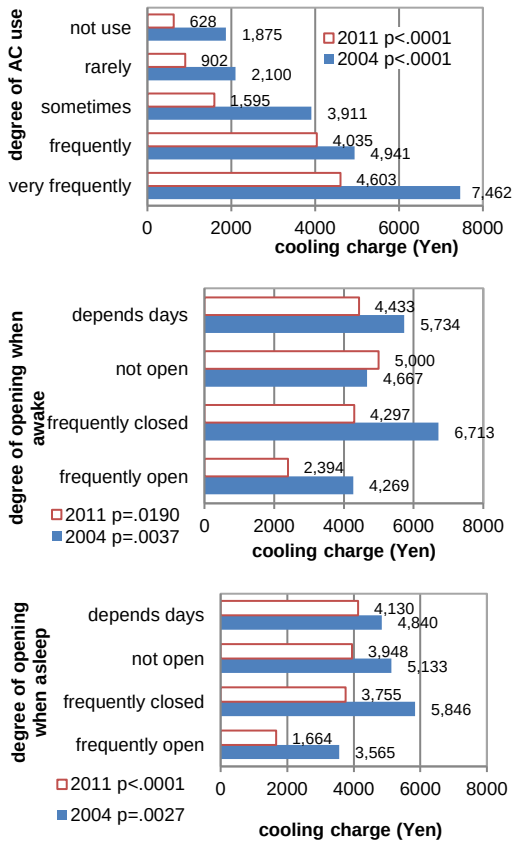

Fig.10 Mean cooling charges by TC use

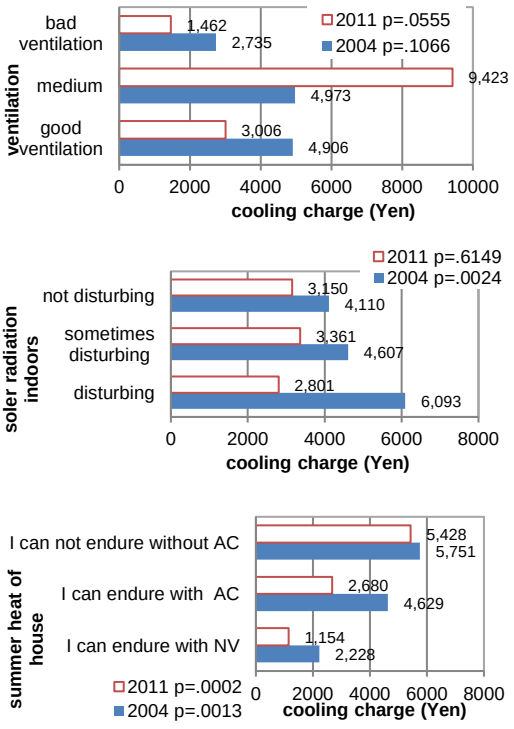

Fig.11 Mean cooling charges by living environment evaluation

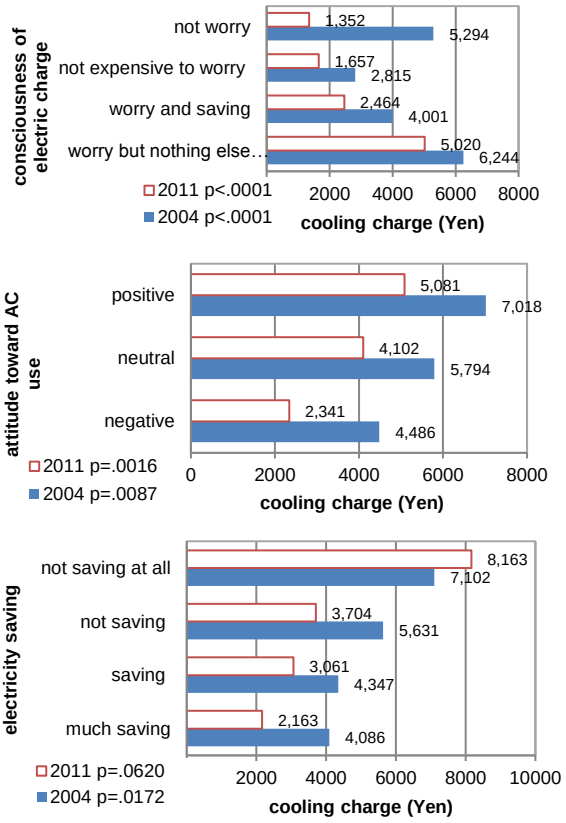

Fig.12 Mean cooling charges by consciousness and habits

increased in 2004 (p=0.0024). However, no relation was found for 2011 (p=0.6149). The evaluations of solar radiation indoors were greatly different between 2004 and 2011 (p<0.0001) and relative frequency of 'not disturbing' was 35.7% in 2004 and 9.9% in 2011, as shown in Figure 4. Disturbances of solar radiation indoors increased in 2011. Effects of the disturbances on cooling charges do not appear in 2011. Effects of the glare of sunlight indoors on cooling charges in 2004 and 2011 were similar.

Relations between the degree of ventilation and cooling charge were small in 2004 and in 2011, p=0.1966 in 2004 and p=0.0554 in 2011. Mean cooling charges were the highest, 9,423 yen for 'medium' in 2011, where charges were almost identical for 'medium' and 'good' in 2004. The relative frequency of 'good ventilation' decreased and that of 'medium' increased in 2011, as shown

in Figure 4. The distribution differed between years, but the effects of ventilation on the charge were not so different. Occupants who evaluated ventilation of the houses as ‘medium’, neither good nor bad might not have the chance of feeling the ventilation of the houses because they depended on AC.

Cooling charges related to the degree of summer heat indoors both in 2004 (p=0.0013) and 2011 (p=0.0002). Cooling charges were almost equal in 2004 and 2011. They were 5,751 yen in 2004 and 5,428 yen in 2011 for ‘I cannot endure without AC’. Frequency distribution of summer heat evaluation indoors was not different between 2004 and 2011, as shown in Figure 4. However, mean charges for ‘I can endure with AC’ and ‘I can pass with natural ventilation’ in 2011 were about half of those in 2004.

4.3 Comparison by consciousness and habits related to cooling

Figure 12 shows mean cooling charges by degrees of consciousness and habits related to cooling in 2004 and 2011. Cooling charges differed greatly by consciousness of cooling charge (p<0.0001 for both years) and attitude toward AC use (p=0.0087 in 2004 and 0.0016 in 2011). However, cooling charges were only slightly different by habits of saving electricity, especially in 2011. p=0.0620 in 2011, although p=0.0172 in 2004. Electric charges in May were also only slightly different by habits of saving electricity in 2011 (p=0.0612). It can be said that habits of ‘saving electricity’ had only slight effects on electric charges and cooling charges in 2011.

5 COMPARISONS OF TEMP. SETTINGS

5.1 Comparison by thermal control use

Figure 13 shows mean temperature settings by degrees of thermal control use in 2004 and 2011. Temperature settings increased as the degree of AC use decreased in both 2004 (p=0.0183) and 2011 (p=0.0320). However, there was little difference by the degree of opening windows especially in 2011: p=0.8166 when awake and 0.1725 when asleep in 2011, but 0.0647 when awake and .0572 when asleep in 2004. The relation between the set temperature and the degree of thermal control use was stronger in 2004 than in 2011.

5.2 Comparison by living environment evaluation

Figure 14 shows mean setting temperatures by the degree of living environment evaluation in 2004 and 2011. Setting temperatures did not differ by living environment evaluation.

5.3 Comparison by consciousness and habits related to cooling

Figure 15 presents mean temperature settings by degrees of consciousness and habits related to cooling in 2004 and 2011. Responses related to temperature settings for ‘worry and saving’ and ‘worry but nothing else to do’ were not different in 2004 and 2011. They were, respectively 0.6 K in 2004, and 0.5 K in 2011. The temperature settings were unrelated to habits of saving electricity both in 2004 (p=0.3353) and in 2011 (p=0.2776). Although the temperature difference between 2004 and 2011 was greater for ‘saving’ than for ‘slightly saving’: 2.1 K for ‘saving’ and 0.8 K for ‘slightly saving’.

6 CONCLUSIONS

Summer thermal control use in apartments in Osaka in Japan was examined in 2004 and 2011. 1) Electricity charges were lower in 2011 by 6.0% in May and by 23.7% in August. The cooling charge was lower by 43.8%. The mean setting temperature was 26.0°C in 2004 and 27.5°C in 2011. 2) Degrees of air conditioner use and window opening and habits of ‘saving electricity’ did not differ. 3) Cooling charges related to the degree of window opening stronger when asleep than when awake. Habits of ‘saving electricity’ showed only slight effects on electric charges and cooling charges in 2011. 4) Relations between temperature settings and the degree of thermal control use were stronger in 2004 than in 2011. Temperature settings did not differ by living environment evaluation or habits of saving electricity either in 2004 or in 2011.

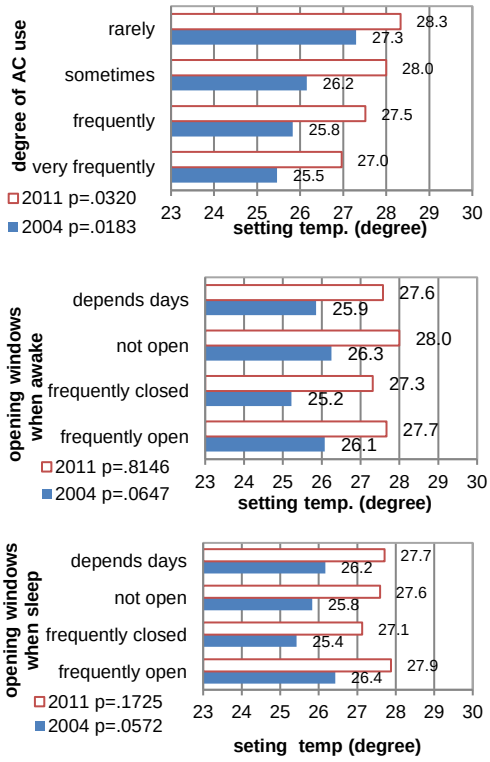

Fig.13 Mean setting temperatures. by TCuse

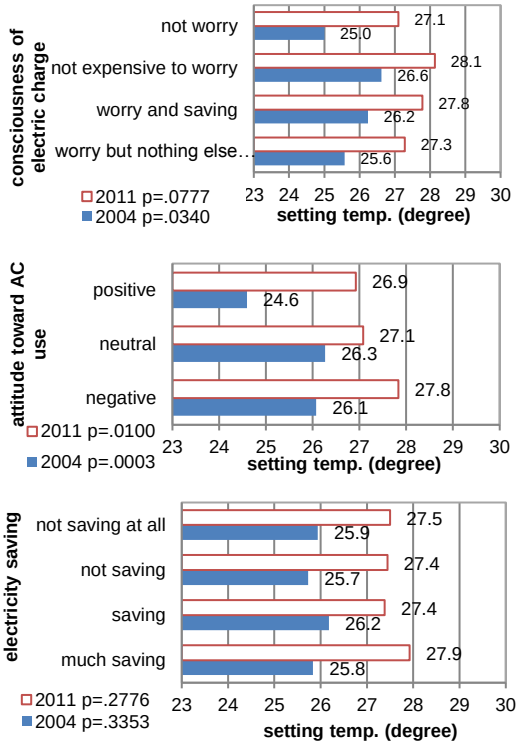

Fig.15 Mean setting temperatures by consciousness and habits of cooling

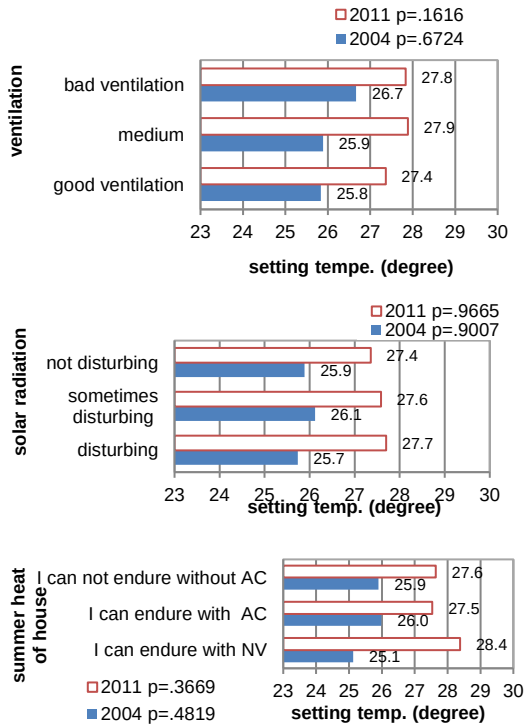

Fig.14 Mean setting temperatures by subjective evaluation of living environments

REFERENCES

1) Enai, M. and Aratani, N., 1978: Actuasituation of the thermal environment in theliving rooms, *Journal of AIJ*, 264, 91-97.

2) Hong, W., 1993: Analysis on the annual energy use and the housing property in the apartment houses, *Journal of AIJ*, 445, 53-61.

3) Lin, X. and Umemiya, N., 2007: Bearing the summer heat in urban Osaka apartments: Analysis by age, *Proceedings of the 6th International Conference on Indoor Air Quality, Ventilation and Energy Conservation in Buildings*, Ⅲ, 83-90.

4) Lin, X., Inoue, G., Umemiya, N., Nishioka, T. and Okura, R., 2005: Survey of life style in summer for apartment house occupants in Osaka City, *Summaries of Technical Papers Of Annual Meeting AIJ*, D-1, 859–860.

5) Mae, M., Nabeshima, M., EMura, K., Nagai, T., Nimiya, H. and Kamata, M., 2002: Study on Application of Cooling in Apartment -House,

Transactions of SHASE, 87, 41-50.
6) Mori, N., Moriyama, M. and Urushihara, S., 2005: Study on heating and cooling pattern in consideration of dweller's energy-saving action and life style in detached houses, *Transactions of AIJ*, 590, 43–48.
7) Ojima, T. and Masuda, Y., 1980: Research for residential energy consumption Part 4 —Research for all Japan residential energy consumption (2); Cooling, heating and hot water supply system and quantity of energy consumption, *Transactions of SHASE*, 12, 67-80.
8) Sawachi, T., Bohgaki, K., Yoshino, H., Suzuki, K., Akabayashi, S., Inoue, T., Ohno, H., Matsubara, N., Hayashi, T. and Morita, D., 1994: Energy consumption for different uses in dwelling and its estimation formulas Study of energy consumption in residential buildings from the viewpoint of life style, on the basis of national scale surveys Part 1, *Journal of AIJ*, 462, 41-48.
9) Suzuki, K., Matsubara, N., Morita, D., Sawachi, T., Bohgaki, K., 1995: A survey on heated and cooled environment in the municipal apartment-houses at Sapporo, Kyoto and Naha, *Journal of AIJ*, 475, 17-24.
10) Umemiya, N. and Lin X., 2006: Survey on Cooling Costs and Related Factors for Apartments in an Urban Area of Osaka, *Proceedings of International Conference on Enhanced Building Operations*, VII5-4, 1–8.