SURVEY ON COOLING COSTS AND RELATED FACTORS FOR APARTMENTS IN AN URBAN AREA OF OSAKA

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ABSTRACT

A questionnaire survey was carried out to assess cooling behaviors and cooling costs for 290 apartments in an urban area. 1) Cooling costs are strongly related to the number of air conditioners, the months of occupation, and the air conditioner usage frequency during sleep. Lifestyle and ecological interest do not decrease costs. 2) Target temperatures of air conditioning are strongly related to the air pollution outdoors, and to the frequency of window opening. Cooling temperatures are affected by the residents' constitution. 3) Both cooling temperature and air-conditioner use frequency are higher for residents worried more about dew, humidity, odors, and mold. 4) Air-conditioner use frequency is higher for residents who are annoyed by glances from outside and for those with a higher preference of outdoors. 5) South openings are related to the lower cooling costs and higher cooling temperatures, whereas west openings are related to higher cooling costs.

INTRODUCTION

Surveys of Japanese residents' energy use are exemplified by those of Ojima et al. (1980), Enai et al. (1978), Hong (1993), Sawachi et al. (1994), and Suzuki et al. (1995). Ojima et al. surveyed the actual situations of energy use for electricity, gas, and kerosene in nine cities for both detached houses and apartments and for both rented and owned houses. Different levels and proportions of energy use were apparent according to building types and cities. Hong analyzed the relationships between annual energy use and the housing attributes and noted that the floor space, the number of family members, the income, and the cooling and heating systems affected the energy use. Enai et al. presented a method to estimate kerosene consumption according to the degree-days. Sawachi et al. introduced estimation formulae of energy use based on surveys of eight cities. The cooling energy usage was expressed as a function of cooling degree-days, whereas energy used for hot-water supply was expressed as a function of the number of family members, the supplied water temperature, the annual mean outdoor temperature, the frequency of bathing and showers, and household income. Suzuki et al. surveyed living styles and energy conservation consciousness, along with monthly energy use in three cities.

The present study surveyed cooling behaviors and cooling costs for apartments in urban areas. The factors related to the cooling costs, target temperatures that the residents set when air conditioning, subjective air-conditioner use frequencies, subjective openings use frequencies, and their mutual relationships were investigated. Methods to bear the summer heat using less energy consumption are necessary to improve the attributes and performance of residences along with the behavior and consciousness of residents.

evaluation of the residential environment,

Table 1 Items 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)

METHOD

Survey was carried out in the south city area of Osaka in autumn in 2004. Apartment buildings that had more than six floors and a hundred apartments facing south, west and east were picked up. Questionnaire sheets were distributed to all apartments in the buildings. Owned and rented, public and private buildings were almost evenly chosen. Number of the buildings was twenty-four, 1,681 sheets were distributed and 290 of them responded by mail.

Items of the questionnaire were about cooling behaviors, attributes of the apartments, attributes of the respondents, and habits and ways of thinking on thermal comfort, thermal control usage, ecology and problem of urban warming. Table 1 shows the items and categories of the questionnaire.

Living environments were subjectively evaluated into three categories. Frequency of air conditioner usage and frequency of window opening were subjectively evaluated on five-point scales both when awake and asleep. Electric costs were answered both in kWh and Yen for May, August and September. Differences between the costs in August and those in May expressed in

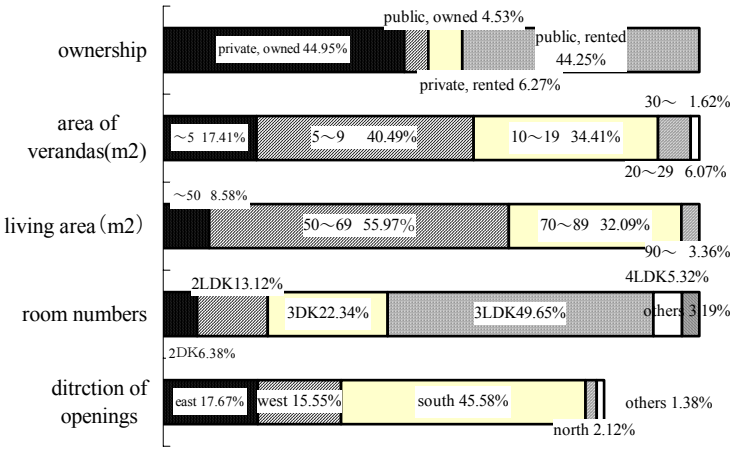


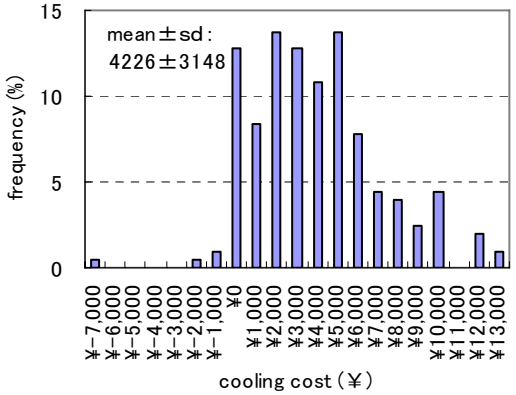
Fig.1 attribute of the apartments

Yen were defined as the cooling costs in this study. Although the costs in kWh were sometimes not acquired, difference between the highest summer month and the averaging month for natural ventilation was regarded as the cooling costs of air conditioning. The ranges of the target temperatures when air-conditioned were answered and the central points of the ranges were defined as the cooling temperatures.

RESULTS

Figure 1 shows the attributes of the respondents. Living area was most frequent for between 50 m^2 and 69 m^2. Nearly half of the apartments were consisted of three bedrooms, living room, dining room and kitchen. This size of apartments are typical and ordinal for the urban area. 45.6%, 17.7% and 15.6% of the main openings of the apartments faced to south, east and west respectively. Rates of the response were lower for the private and rented apartments. It can be said that it reflects the resident's lower interest for living environment.

Figure 2 shows the frequency distribution of the cooling costs. The costs ranged between –7,000 Yen and 13000 Yen and the average was 4226 Yen and the standard deviation was 3148 Yen. Figure 3 shows the frequency distribution of the cooling temperatures. The average was 25.97℃ and the standard deviation was 2.02℃ but the most frequent temperature was 27.5℃.



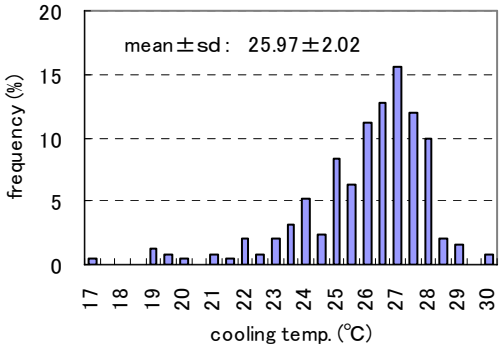


Table 2 Averaged cooling cost, cooling temperature, and subjective frequency of conditioner use

(to be continued)

	cooling cost (¥)			p%	cooling temp.(℃)			p%	air conditioner us			p%
ATTRIBUTE of the APARTMENT												
family number (<3)	4189	<	5348	10	(-)				2.5	>	2.1	1
length of living (<10)	3593	<	5658	1	(-)				2.53	>	2.1	1
living floor (<6)	(-)				25.79	<	26.16	20	(-)			
with south openings	4465	<	5441	20	26.18	>	25.65	10	2.35	>	2.2	20
with west openings	5326	>	4386	20	(-)				(-)			
residencial area (>69m²)	5609	>	4410	20	(-)				(-)			
with bamboo blind	5924	>	4134	5	(-)				(-)			
EVALUATION of the LIVING ENVIRONMENT												
good ventilation	(-)				(-)				2.36	>	2.18	20
good view	5497	>	4311	10	(-)				(-)			
glance from outside	(-)				(-)				2.43	>	2.17	2
clean air outdoors	(-)				25.80	<	26.46	2	(-)			
noise from neighbour apartments	(-)				(-)				2.42	>	2.25	20
few appearance of dew	(-)				25.80	<	26.29	10	2.42	>	2.08	1
tolerance to odor	(-)				25.83	<	26.43	5	2.41	>	2.00	1
few appearance of mold	(-)				(-)				2.52	>	2.11	1
few appearance of insects	3988	<	5652	2	(-)				(-)			
agreeable solar heat in summer	3823	<	5313	5	(-)				2.49	>	2.20	1
few occurrence of glare	3618	<	5121	10	25.58	<	26.09	10	(-)			
efficiency of air conditioning	(-)				(-)				2.39	>	2.19	10
bearable heat by only natural coolin	4090	<	6265	1	(-)				2.55	>	1.69	1
overall satisfaction	(-)				(-)				2.35	>	2.18	20
ATTRIBUTE of the RESPONDENT												
age (<40)	3379	<	5266	2	(-)				(-)			
sex (female)	5053	>	3653	10	26.09	>	25.73	20	(-)			
tolerance to heat	(-)				26.14	>	25.54	5	2.37	>	2.10	5
tolerance to cold	(-)				25.74	<	26.31	5	(-)			
tolerance to flu	(-)				25.75	<	26.17	10	(-)			
good circulation	4364	<	5343	20	25.75	<	26.30	5	(-)			
good health	(-)				26.29	>	25.72	5	2.60	>	2.15	1
keeping regular time	4132	<	5554	10	26.18	>	25.68	10	2.43	>	2.09	1
having breakfast	(-)				26.08	>	25.25	10	(-)			
without smoking habit	4281	<	5459	10	(-)				2.36	>	2.22	20
stay long at home daytime	(-)				(-)				2.19	<	2.40	5
little awake by heat	(-)				25.78	<	26.16	20	(-)			
preference of natural cooling	4406	<	5746	10	26.09	>	25.66	10	(-)			
sensitivity to heat or cold	(-)				25.82	<	26.15	20	(-)			
preference of coutact to outdoors	(-)				(-)				2.40	>	2.10	2
saving water	4297	<	5449	20	(-)				2.41	>	2.09	1
saving electricity	4305	<	5522	10	26.10	>	25.74	20	2.46	>	1.96	1
realizing urban warming	(-)				26.03	>	25.46	20	2.31	>	2.07	20

Averages of the left side and the right side are compered by t-test. P values are shown.

Subjective evaluation of the frequency of air conditioning; 1. Too much, 2. Much, 3. Neutral, 4. Less, 5. Tc

Table 2 shows averaged cooling costs, averaged cooling temperatures and averaged subjective frequency of air conditioner use when the respondents are divided into two opposite groups for each question. Averaged costs, temperatures and frequency for the groups of the left hand and the right hand in the table are compared by t-test. The significant levels of the

Table 2 averaged cooling cost, cooling temperature, and subjective frequency of conditioner use

	cooling cost (￥)			p%	cooling temp.(℃)			p%	air conditioner us			p%
USE of AIR CONDITIONERS												
number of air conditioners (<3)	3944	<	6139	1	26.16	>	25.61	5	2.38	>	2.12	2
not frequently use of air conditioner	3164	<	5622	1	26.35	>	25.78	5		(-)		
consciousness of cooling cost	5217	>	3287	10		(-)			2.22	<	2.46	10
saving cooling cost	4261	<	5384	20	26.25	>	25.72	5	2.47	>	2.10	1
without air conditioning when asleep	2592	<	5313	2		(-)			3.02	>	2.15	1
negative thinking to air conditioning	4510	<	6091	10	26.06	>	25.54	20	2.42	>	1.81	1
USE of OPENINGS												
frequently open when awaken	4537	<	5892	20	26.13	>	25.15	1	2.40	>	1.81	1
frequently open when asleep	4217	<	5317	20	26.43	>	25.53	1	2.55	>	2.06	1
frequently open of the front door		(-)			26.16	>	25.82	20		(-)		
front screen door		(-)			26.29	>	25.87	20		(-)		

difference are shown from 1% to 20% in the table. The symbol of '(−)' represents that there is no significant difference between the left and the right. Frequency of air conditioner use is evaluated by the residents in five-point scale, 1. too much, 2. much, 3. neutral, 4. less, 5. too less, and the mean values are used.

There are significant differences of 1% level in the cooling costs by the living length, by the evaluation that it is easy to bear heat by natural cooling, by the number of air conditioners and by the frequency of air conditioner use. Difference of 2% relates to the appearance of insects, the age of the respondents, the frequency of air conditioner use during sleep. Difference of 5% is by the solar heat indoors in summer. Difference of 10% is by the number of family members, the view, the occurrence of glare, the habit of keeping regular time, the habit of smoking, the preference of natural cooling, the habit of saving electricity, the consciousness of the cooling costs, the negative thinking against air-conditioning.

The group without air-conditioner use when asleep has the lowest costs of 2592 Yen, and the group of not frequent use of air-conditioner had the second lowest costs of 3164 Yen. On the other hand, the group which summer heat is difficult to bear without air-conditioners has the highest cooling costs of 6265 Yen. The group with more than three air conditioners has the second highest costs of 6139 Yen, the group negative to air conditioner use has the third highest costs of 6091 Yen.

There are significant differences of 1% level in the cooling temperatures by the frequency of window opening when awake, by the frequency of window opening when asleep. Difference of 2% is related to the clean outdoor air. Difference of 5% are by the number of air conditioners, the tolerance to odors of the apartments, the tolerance to heat, the tolerance to cold, the condition of health, the poor circulation of the residents, the frequency of air-conditioner use and the habit of saving cooling costs. There are 10% of the difference by the south-facing openings, the appearance of dew, the occurrence of glare, the tolerance to flu, the habit of keeping regular time, the habit of taking breakfast, the preference of natural cooling of the residents. Cooling temperatures are higher for the higher frequency of window opening and the lower frequency of air-conditioning.

The group not frequently open when awake shows the lowest cooling temperature of 25.15℃,

and the group not taking breakfast shows the second lowest cooling temperature of 25.25℃. The group not realizing urban warming shows the third lowest cooling temperature of 25.46℃. The cooling temperature of the group not frequently open when asleep is 25.53℃ and the fourth. On the other hand, the group which outdoor air is not evaluated clean shows the highest cooling temperature of 26.46℃. The group tolerant to odors indoors and the group frequently open when asleep show the second highest cooling temperature of 26.43℃.

There are significant differences of 1% level in the subjective frequency of air-conditioner use by the number of family members, the living length, the dew, the humidity and odors, the mold, the solar heat, the heat in summer, the regularity of living, health, habit of saving water, saving electricity, saving cooling costs, use of air-conditioners when asleep, way of thinking on air-conditioning, usage of window opening when awake and asleep. Mean of the group those residents think the heat in summer is intolerable without mechanical cooling is 1.69, the highest. Mean of the group those residents do not use air conditioners when asleep is 3.02, the lowest. This group is also the lowest in the cooling costs.

Mean cooling costs is the lowest, 2,592 Yen and the mean frequency of air conditioner use is the lowest, 3.02 for the apartments that do not use air conditioners when asleep. Those cooling costs are higher by 2% significance level. And the frequency of air-conditioner use is higher by 1% significance level by the use of air-conditioners when asleep.

82.9% of the respondents want to use air-conditioners as little as possible, while 10.8% want to use as much as possible. 30.5% evaluate the warmth in summer intolerable without mechanical cooling, while 61.4% bearable if air-conditioners are used only when it is hot, and 7.0% answer it is bearable enough by only natural cooling.

69.2% chose the cooling costs as a defect of air-conditioning. To the question whether you worry about the cooling costs, 43.2% worry about and save it, 39.3% worry about it but admit as it is, 12.2% evaluate the costs are not so high, and 5.0% do not worry. 'Worry of cooling costs' in Table 2 means the former two groups and 'saving cooling costs' means the first group for the question.

DISCUSSION

Length of Living and The Cooling Costs

Apartments of length of living more than 10 years, apartments with more than three air conditioners are higher in cooling costs than the opposite groups by significance level of 1%. Relationship between number of air conditioners and cooling costs is proper. Cooling costs differ by age by 2% significance and by number of family members by 10%. The number of family members should be related to the number of air conditioners. Table 3 shows the results of chi-square tests among length of living, number of air conditioners, age and number of family. Length is related to age by 1% but does not to number of family and number of air conditioners. Number of family is related to age by 1%. Number of conditioners is related to age by 2%. Number of family is related to number of conditioners by 1%. It can be said that length of living is related only to age, not to number of conditioners and family members. Significance level of the difference in cooling costs by age is

Table 3 Results of chi-square test

	length of living		
age	1%	age	
number of family	(-)	1%	numer of family
number of air conditioners	(-)	2%	1%

2%, lower than that by length of living (1%). Therefore, relationship between the costs and the length is direct and does not be affected by the relationship between the costs and the number of conditioners and the number of family members.

Age And The Cooling Costs

The costs differ by the age by 2%, while the cooling temperatures and the frequency of air-conditioner use do not differ. Table 4 shows the results of chi-square tests between the items and frequency of window opening and air-conditioner use when awake and asleep. The age relates to the frequency of window opening during sleep by 5% and not to that when awake. Frequency of open is not low for higher age. On the other hand, Table 3 shows that age relates to the length by 1% and to the number of air conditioners by 2%. Age relates to the family number by 1%. Age is not a direct factor to the high cooling costs. It is proper to say that the higher age causes the longer length of living and the more number of air-conditioners, and the cooling costs become higher as a result.

Direction Of The Openings And The Cooling Costs, The Cooling Temperature And The Frequency Of Control Use

Cooling costs are lower by the south-facing openings (significant by 20%) and higher by the west-facing openings (20%). Cooling temperatures are higher by the south-facing openings (10%). Frequency of air-conditioner use is lower by the south-facing openings (20%). Summer heat is got through in by south-facing openings in spite of the higher cooling temperatures and the lower frequency of air-conditioner usage. Difference in solar heat might affect it. Table 5 shows the results of chi-square tests among south-facing openings, west-facing openings, glare, solar heat and bamboo screens. Solar heat is related to both south openings and west openings by 1% significance. Glare is related to west openings by 1% but not to south openings. Bamboo screens are related to south openings by 10% and to west openings by 1%. Screens are related to glare by 5% and to solar heat by 1%. Apartments with bamboo screens have more troubles of solar heat than glare. Bamboo screens are hangs to mitigate solar heat than glare. Table 2 shows that cooling costs are higher by 5% significance with bamboo screens. Cooling temperatures and subjective frequency of air-conditioner use do not differ by screens. Thus it can be said that the apartments with west-facing openings do not use behavioral adaptation such as setting lower cooling temperatures and using air-conditioners more frequently, but hang screens to mitigate solar heat. And despite of hanging screens, cooling costs are

Table 4 Results of chi-square test

Relationships to the subjective frequency of opening and conditioning

	freq. of opening		freq. of conditioning.	
	awaken	asleep	awaken	asleep
length of living	5%	(-)	1%	(-)
age	(-)	5%	(-)	(-)
appearance of insects	(-)	(-)	(-)	10%
view	(-)	20%	10%	20%
bearable heat by natural cooling	1%	1%	1%	1%
contact to the outdoors	1%	10%	10%	(-)
glance from outside	20%	2%	1%	1%
air pollution outdoors	20%	(-)	10%	(-)

Table 5 Results of chi-square test

	south windiws			
west windows	1%	west windows		
glare	(-)	1%	glare	
solar heat in summer	1%	1%	1%	solar heat in summer
bamboo screens	10%	1%	5%	1%

higher for the apartments. Effects of solar gain at the west-facing openings should be the cause.

Annoyance By Glances From Outside And The Frequency Of Air Conditioning

The frequency is higher by the annoyance by glance from outside by 2% significance, but cooling costs and cooling temperatures do not differ. Table 4 shows that the annoyance relates to the frequency of window opening when awake by 20% and when asleep by 2%. Frequency of window opening is not so low. It is supposed that curtains are often shut in the apartments annoyed by glance from outside and frequency of air-conditioning becomes high, but the cooling efficiency becomes high by curtains and there is no necessity of setting the cooling temperatures lower and as a result, the cooling costs are not so high despite of the air-conditioner use.

Preference Of Contact With The Outdoors And The Frequency Of Air-conditioning

The frequency of air-conditioner use is lower by the preference of contact with the outdoors even when staying indoors with 2% of significance. The cooling costs and the cooling temperatures do not differ. Table 4 shows that the preference are related to the frequency of window opening when awake, that when asleep and that of air-conditioning when awake by 1%, 10% and 10% of significance respectively. The difference is greater when awake. It is supposed that the preference does not make the costs higher, because cooling costs are related to the use of air-conditioning when asleep.

Air Pollution And The Cooling Temperatures

Cooling temperatures are higher when the air outside is assessed as polluted by 2% significance. The difference is the third greatest next to the frequency of window opening when asleep (1%) and that when awake (1%). Moreover the mean cooling temperature is 26.46℃ which is the highest. The cooling costs and the subjective frequency of air-conditioner use do not differ. Table 4 shows that air pollution outdoors is related to the frequency of window opening when awake and the frequency of air-conditioning when awake by 20% and 10% of significance respectively. There are no significant relations to the frequency of window opening and that of air-conditioning when asleep. The frequency of window opening is lower and the frequency of air-conditioning is higher for more polluted air when awake. The higher frequency of opening relates to the lower cooling temperatures for other items but it is the opposite for the air pollution. Further studies are needed.

Dew, Humidity, Odors, Mold And The Frequency Of Air-conditioning

Frequency of air-conditioner use is higher for the more frequent appearance of dew, the more in closed humidity and odors and the more appearance of mold by 1% significance. Cooling temperatures are higher for the more dew, the more humidity and odors by 10% and 5% significance respectively. On the other hand, these three items are not related to the cooling costs. This fact can be explained if it is supposed that the apartments with more dew, more humidity and odors, and more mold use air-conditioners for longer time but with higher cooling temperatures.

Spread Of Insects And The Cooling Costs

Cooling costs are higher for the more spread of insects by 2% significance. Cooling temperatures and frequency of air-conditioner use do not differ. Table 4 shows that the insects are related to the frequency of air-conditioning when

asleep by 10% significance. The frequency when asleep might affect the cooling costs, because the apartments with lower frequency of air-conditioning when asleep show the lowest cooling costs and the lowest frequency of air-conditioning. Air-conditioners are used because insects are annoying especially when asleep, and the cooling costs become high, in spite of the residents are not aware of the use so much.

Constitution, Health And The Cooling Temperatures

Cooling temperatures are higher for the more subjectively tolerance to heat, cold, flu and the poorer circulation, and the more subjectively health by 5%, 5%, 10%, 5% and 5% significance respectively. Frequency of air-conditioner use is lower for the higher tolerance to heat and the higher health by 5% significance. Cooling costs are lower for poor circulation by 20% significance. Attributes of the respondents about their constitution and health do not affect the cooling costs and the frequency of air-conditioner use in general, although they affect the cooling temperatures. It is partly because of the effects of other families of the respondents than the respondents themselves.

Living Style and The Cooling Costs And The Frequency Of Air-conditioning

Cooling costs are lower, cooling temperatures are higher, and frequency of conditioner is lower for the habit of keeping more regular time by 10%, 10% and 1% respectively. The habit affects all the three. Frequency of air-conditioner use is lower for the habit of getting up early in the morning and the habit of keeping regular time for meals by 20% and 5% of significance respectively. But there are no difference in the cooling costs and the cooling temperatures. Cooling temperatures are higher for the habit of taking breakfast every day by 10% significance. But no difference in the cooling costs and the frequency of air-conditioner use. Living style of getting up early in the morning, keeping regular time in meals, and taking breakfast every day do not affect the lower cooling costs of the residences. Results of this study show that so called healthy living style about time does not decrease the cooling costs of the dwellings at least, although the introduce of daylight saving time are thought to decrease energy consumption in general.

Saving Consciousness, Saving Behavior And The Cooling Costs

Frequency of air-conditioner use is lower for the apartments of saving cooling cost, saving electricity and saving water by 1% significance each. Cooling temperatures are higher for the saving of cooling costs and the saving of electricity by 5% and 20% respectively. The cooling costs are lower for the apartments of saving cooling costs than those saving electricity. But the significance level of the difference is 10% for those of general saving of electricity while that is 20% for those of saving of cooling costs. Mean cooling cost of the apartments which saving water is 4,297 Yen, which is lower than that of those saving general electricity, 4,305 Yen. Habit of saving water is related to saving the cooling costs. It is because the apartments that save the water would save the electricity, which is more expensive than water.

Cooling costs are higher for the apartments worrying about the cooling costs by 10% of significance level. Frequency of air-conditioner use is also higher. No difference in the cooling temperatures. Actual situations of the apartments that use air-conditioners frequently worrying about the cooling costs but the cooling temperatures are not set higher.

Interest To Environmental Problems And The Air Conditioner Use

Cooling temperatures are higher by 20% significance and frequency of air-conditioner use is lower by 20% of significance for those

realizing urban warming. On the other hand, there is no difference in the cooling temperatures and the frequency of air-conditioning by the interest to environmental problems such as global warming. There is no significant difference in cooling costs by the realization and the interest. Thermal control behaviors change slightly by realizing but the interest cannot change the behaviors, much less the cooling costs. Merely the interest cannot save energy consumption in actual.

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REFERENCES

T. Ojima and Y. masuda (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, No.12, 67-80.

M. Enai and N. Aratani (1978), Actual situation of the thermal environment in the living rooms, Journal of AIJ, No.264, 91-97.

W. Hong (1993), Analysis on the annual energy use and the housing property in the apartment houses, Journal of AIJ, No.445, 53-61.

T. Sawachi et al. (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 oif national scale surveys Part 1, Journal of AIJ, No.462, 41-48.

K. Suzuki et al. (1995), A survey on heated and cooled environment in the municipal apartment-houses at Sapporo, Kyoto and Naha, Journal of AIJ, No.475, 17-24.