Residential active cooling toward snowy cold region in japan and human temperature sensitivity for passive and low energy cooling

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ABSTRACT

Results of survey on residential active cooling as the diffusion rate of air conditioner in five principal cities of in Japan, and those associated "human temperature sensitivity" for passive and low energy cooling are described. Increase in air-conditioned houses throughout Japan was come out by the domestic survey of family income and expenditure, some local statistical data and their associated earlier studies. 87 % of the families throughout Japan has air conditioners in own houses. Especially, Sendai, one of snowy cold cities in Japan, has significantly increased 35 % in 1992 to 77 % in 2004. This is almost equivalent to 81 % in Okinawa which is most south-eastern prefecture in Japan. This means that residential active cooling in Japan has been making a gradual movement toward the snowy cold region. One reason might be that the rental air-conditioned apartments for single in snowy cold region might have increased in the last 15 years. In addition super-insulated and airtight houses without solar shading strategies are also increasing.
A primary investigation with a subjective experiment on "human temperature sensitivity" associated with their environmental-conscious behaviours was made in laboratories in my college in 2006 summer. A digital thermometer was set there and professors as subjects check indoor temperature and they also recorded their thermal sensation every morning, daytime and night time. In the beginning of the investigation, there were 2 to 3°C differences between "actual temperature" by the thermometer and "imaginary temperature" for most subjects between 25 and 30°C of the indoor air temperature. However the difference became gradually closed under the investigation. This process means that most subjects could gradually recognize a minimal-temperature difference in 0.5 to 1.0°C corresponding with passive and low energy cooling effects on solar shading and natural and nocturnal ventilation in the hot environment.
According to getting the human temperature sensitivity, the opportunity for their self-environmental-conscious behaviours such as opening/closing of the windows and the doors, pulling up/down the blind, and controlling fluorescent lamps somehow might be exploited.

1. INTRODUCTION

Thermal performance of building envelope including glazing dramatically affects indoor climate, thermal comfort of occupants, and space heating and cooling loads in buildings. In warm region for passive and low energy cooling, solar shading strategies or devices in buildings such as window awnings, pendent eaves, external blinds and wall surface greening, are essential for the inhabitants to be comfort in the buildings. Researchers and engineers regarding built-thermal environment, and architectural designers have been seeking and developing alternative strategies for reducing energy use, i.e. exergy consumption for space cooling of buildings (ex. Asada and Shukuya, 1998).
On the other hand, maximum electric power demand (bars in figure 1) in summer throughout Japan actually increases because of the use of air conditioners (a heavy line in figure 1). Japanese government and local government encourage people to review their lifestyles during summer and not to depend on air conditioners to save energy in their lives. Office workers have been requested to wear short-sleeved shirts without ties called "Cool Biz" since 2005. However, these activities with environmental slogans end up temporary campaigns so that the root of the problem can not be gone to.
The purpose of this study is to have a better understanding of basic mechanism why people first use air conditioners without some strategies for passive and low energy cooling. I first surveyed the variation of diffusion rate for households of the air conditioner in five principal cities in Japan. Second, a primary subjective experiment in the college was made to grasp the relationship between thermal condition and human behaviours whether inhabitants have self-environmental-conscious behaviours or not. Finally according to the results of the survey and the subjective experiment, the relationships among thermal condition, "human temperature sensitivity", their self-environmental-conscious behaviours due to residential active cooling toward snowy cold regions are discussed.

2. REALITY OF RESIDENTIAL ACTIVE COOLING IN JAPAN

2.1 Japan as a nation of air conditioners

Figure 2 shows the variation of the diffusion rate for households of air conditioner in Tokyo, Okinawa, Sendai, Nagano, and Sapporo according to the government

and local statistics. Followings place and a slash mean latitude in each city. The lower latitude is, the more the diffusion rate of the air conditioner grows.

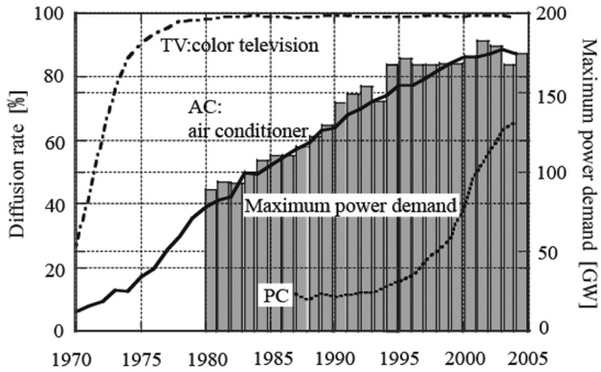

Figure 1. Diffusion rate of television, air conditioner and personal computer (lines) and the increase in maximum power demands throughout Japan (bars) (No data on the maximum power demands before 1980)

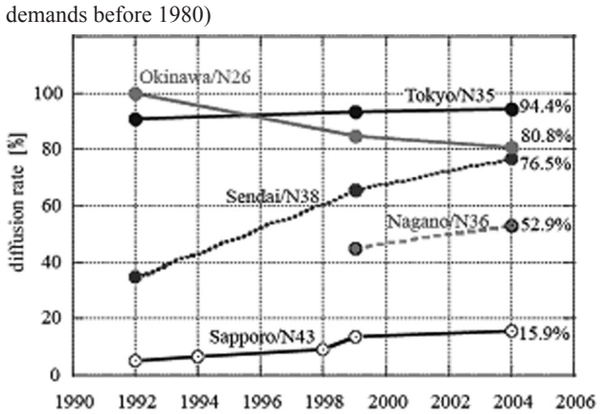

Figure 2. Diffusion rate of air-conditioner in five principal cities in Japan

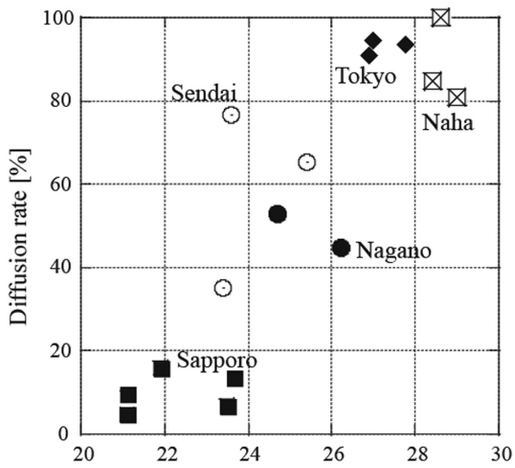

Figure 3. The average ambient temperature in summer of the five cities and those diffusion rates of air-conditioner

Figure 3 shows the relationship between average ambient temperature in summer and the diffusion rate. The diffusion rate in Tokyo has remained high steady-state at around 94%. Throughout Japan 87% of the families has air conditioners in own houses. On the other hand, those in snowy cold cities: Sendai, Nagano, Sapporo increase. Especially that in Sendai actually increases more than twice (35% in 1992 to 77% in 2004). In only subtropical region, that in Okinawa decreases. This might be due to difference in parent population between 1992 and 2004. The reality of diffusion in Okinawa is thought around 80% less than 95% of big cities such as Tokyo. This difference might be due to difference in average income (Kubota and Ahmad, 2006).

2.2 Residential active cooling toward snowy cold region

One of the snowy cold cities, Sapporo is the lowest diffusion rate but it increases more than twice from 1992 to 2004 as well as that of Sendai. Not only Sapporo but any other snowy cold cities, houses implemented solar shading strategies such as pendent eaves, external blinds, have not yet distributed. One reason for this is thought that those have been developed without considering snow coverage (Saito and Nasu, 2005). The other is thought that most buildings are designed for thermal comfort in long winter instead of thermal comfort in short summer. In addition buildings of late in snowy cold region become to be super-insulated without solar shading device so that they extremely overheated in summer. Originally in Japan, a traditional bamboo screen called “sudare” has been widely practiced in warm region. They can sometimes feel slightly cool or “suzussisa” sensation in their houses (Saito, Hojo, Kozuka, and Shukuya, 2000). Nevertheless, people in the cold district hardly have the conception that installs "sudare" on the window side in their own lifestyle.

Figure 4 shows a comparison of diffusion rate of air conditioner in 1992 and 2006 in the rental apartments in the urban districts. Data in 1992 was quoted from the past research (Bogaki et all, 1998). The data in 2006 was requested by the information retrieval system of the Internet that the real estate company managed.

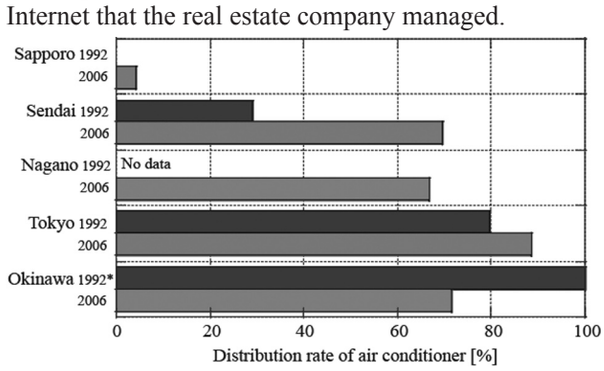

Figure 4. A comparison of the diffusion rate of air conditioner in the rental apartment in 1992 and 2006 *Data in only Naha city, prefectural capital in Okinawa

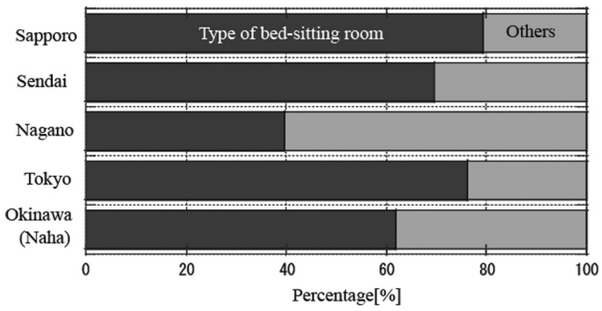

Figure 5. Percentage of a type of bed-sitting room for rent with air conditioner in total rental apartments (A survey in October, 2006)

There is a lot of air conditioner diffusion of the detached house in 1992 in Sendai and Sapporo and it is few in the rental housing with air conditioner. This result is thought for a strong correlation to exist in the home income (Bogaki et all, 1992, Kubota and Ahmad, 2006). On the other hand, in 2006 the rental apartments with the air conditioner excluding Okinawa have increased. Especially, it is the twice or more in Sendai diffusion same power as the entire diffusion rise.

Figure 5 shows a percentage of a type of bed-sitting room for rent with air conditioner in total rental apartments. Those in Sendai and Sapporo might have increased in the last 15 years. This suggests that the diffusion rate of the air conditioner originate in the rise of the installation rate of the rental apartment.

To the above-mentioned, residential active cooling in Japan has been making a gradual movement toward snowy cold region in Japan.

3. HUMAN TEMPERATURE SENSITIVITY

3.1 Outline of the subjective experiment

A subjective experiment and the questionnaire regarding the relationship between "human temperature sensitivity" and the environmental adjustment behavior of inhabitants as subjects were made in July in 2006. They were male 18 professors (=18 laboratories) at the School of Design in Sapporo City University and Sapporo School of the Arts. Both schools are sharing the campus. The room temperature was measured with one self-registering thermometer displayed digitally. This thermometer was set at the center of the room so that the subjects might confirm the display at any time. Their thermal sensation under the state of the windows and doors opening/shutting, the state of the electric lighting, and the exhaust fan in every morning, daytime, and the evening was recorded. Each floor space is 20 square meters, 4.5 meter in height, and window facing east. There is no air conditioner in all rooms.

3.2 Self-environmental-conscious behaviors

Figure 6 shows the cumulative frequency of the room temperature of all measurement period. The cumulative frequency of the S4, S5, S8, S12, and S18 as which internal heat generation and the number of collection of books were almost the same was shown in figure 6. The room temperature has changed within the range of 23 to 32°C while the ambient temperature was distributed in 14 to 32°C. There is a remarkable difference in each room temperature.

Figure 7 and 8 show the variations of the room temperature and the environmental adjustment behaviour in the S18 room and the S8 room in which striking features exist in all laboratories. In the S18 room, the environmental adjustment behaviour between 7/7 and 7/10 in the measurement beginning period is only use of the window blind. Afterwards, the windows and the doors were positively opened to 7/11 to 7/14 in the latter half of the measurement where the room temperature had begun to go up along with the rise of the outside temperature. On the other hand, the window was not opened in the S8 room through the measurement period. S18 and S8 have the difference of remarkable environmental adjustment behaviour. Therefore, 1 to 2°C has extended to the room temperature

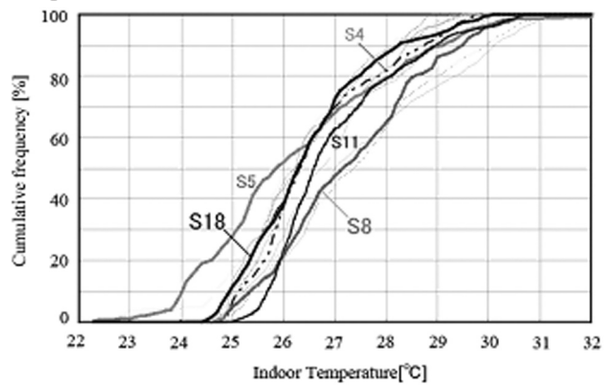

Figure 6. Cumulative frequency diffusion of room temperature of all

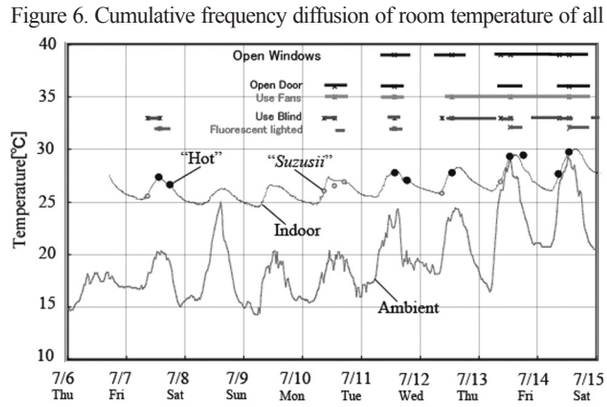

Figure 7. Variation of the ambient and indoor temperatures and transfiguration to the self-environmental-conscious behaviours in the room of Subject-18(S18)

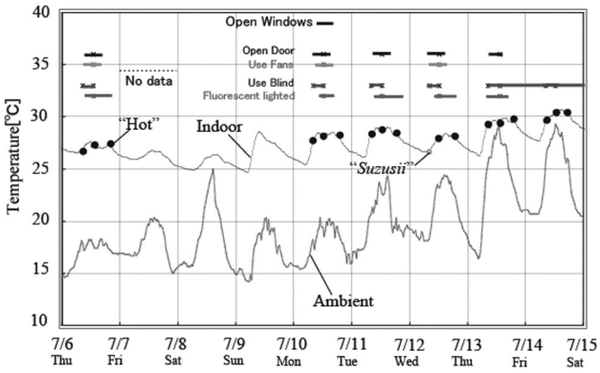

Figure 8. Variation of the ambient and indoor temperatures and constant of behaviours in the room of Subject-8(S8)

Table 1. Change to the self-environmental-conscious behaviours on the way of the experiment

Room	Windows night	Windows daytime	Fans	Door	Blind	F. lamps
S4	×	△→○	◎	○	down→down/up	○
S5	◎	○	◎	○	down/up	×
S8	×	×	△	○	down	○
S11	×	△→◎	◎	○	down	○
S18	×→◎	○→◎	◎	○	down/up	○

◎:Open(ON) actively, ○:Open, △:Open occasionally, ×:Close(OFF)

Therefore, 1 to 2°C has extended to the room temperature difference of both in the latter half of the measurement. Table 1 shows the change in the environmental adjustment action in five rooms. The changes to the self-environmental-conscious behaviors of S4, S11 and S18 on the way of the experiment can be seen in table 1. As shown in Figure 6, the period that the room temperature becomes 28°C or less is 80 percent in the S4, S11 and S18. The room temperature of S6 stays around 60 percent since the environmental adjustment behavior of S8 was quite changeless in figure 8 and table 1.

3.3 Human temperature sensitivity

The follow-up survey was executed at the beginning of September after the experiment. Figure 9 is a result from an answer to the question on "How much is the room temperature in which this summer was able to be spent in the laboratory without trouble for you?" It was answered that 11 professors who corresponded to 60 percent were able to spend it with 27 to 30°C without trouble. Moreover, in the beginning of the investigation there were 2 to 3°C differences for most professors between "actual temperature" by the thermometer and "imaginary temperature" between 25 and 30°C of the room temperature. However, the difference became gradually closed. This process means that most subjects could gradually recognize a minimal-temperature difference in 0.5 to 1.0°C corresponding with passive and low energy cooling effects on solar shading and natural and nocturnal ventilation in the hot environment. They observed the display of the thermometer every day, and it is thought that the imaginary room temperature can be gradually corresponding to the "actual temperature" by the thermometer.

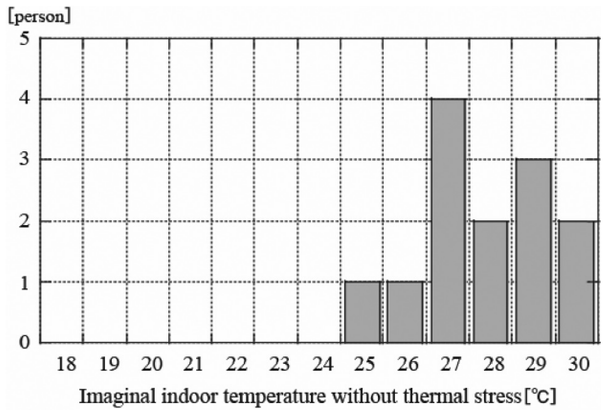

Figure 9. Frequency of diffusion on imaginary indoor temperature without thermal stress in the measurement

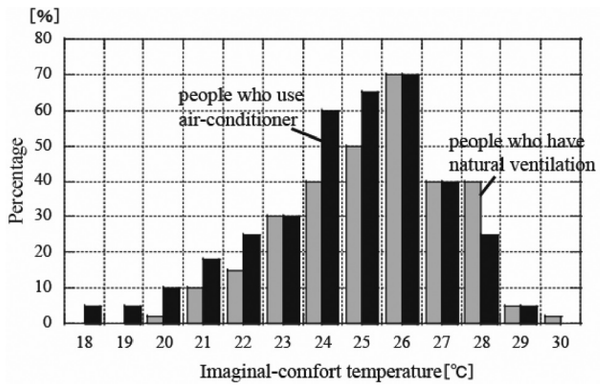

Figure 10. The temperature imagined to be thermally-comfortable in the summer of "people who usually use air-conditioner" versus "people who usually spend it by naturally ventilation" in Tokyo area (Survey in 1997).

Figure 10 shows the temperature imagined to be thermally-comfortable in the summer of "people who usually use air-conditioner" versus "people who usually spend it by naturally ventilation" in Tokyo area according to the previous study (Matsuoka, Saito and Shukuya, 1998). The peak of the temperature imagined to be comfortable with both is 26°C. The temperature imagined to be comfortable of the group of air-conditioner is 2 or 3°C lower than those of natural ventilation. When the temperature of the air conditioner is set, most people look at a digital display in the remote control. It is recognized that remote control display temperature 25 or 26°C is a comfortable temperature in the summer for many people. According to the results of the subjective experiment, the temperature imagined to be comfortable in summer is 25 to 26°C. That is, it's a preset temperature of the air conditioner in their rooms or in their cars. The temperature when we feel "hot" is recognized about 30°C

or more. It is thought that we are recognizing 5 degree difference between 25°C and 30°C by experiencing the cooling power with a strong air conditioner daily set to 25°C by the remote control. From the follow-up survey, there were a lot of professors who declared, "It is possible to spend it without trouble" as for 27 to 30°C as showing in Figure 9. The difference of a temperature difference like 0.5 or 1.0 degree between 25 to 30°C was able to be recognized by having observed the thermometer of their own room every day. This process means that most subjects could gradually recognize a minimal-temperature difference in 0.5 to 1.0°C corresponding with passive and low energy cooling effects on solar shading and natural and nocturnal ventilation in the hot environment. from 27 to 30°C. According to getting the human temperature sensitivity, the opportunity for their self-environmental-conscious behaviours such as opening/closing of the windows and the doors, pulling up/down the blind, and controlling fluorescent lamps somehow might be exploited.

4. CONCLUSIONS

The investigation result regarding the diffusion of the air conditioner throughout Japan was quoted, and the secular distortions were compared. 87 % of the families throughout Japan has air conditioners in own houses. Especially, Sendai, one of snowy cold regions in Japan, has exponentially increased 35 % in 1992 to 77 % in 2004. This means that residential active cooling in Japan has been making a gradual movement toward the northern cold regions.

Based on the result of surveys, a subjective experiment and the questionnaire regarding the relationship between "human temperature sensitivity" and the environmental adjustment behavior of subjects were made.

In the beginning of the investigation, there were 2 to 3°C differences between "actual temperature" by the thermometer and "imaginary temperature" for most subjects. However the difference became gradually closed under the investigation. This process means that most subjects could gradually recognize a minimal-temperature difference in 0.5 to 1.0°C corresponding with passive and low energy cooling effects on solar shading and natural and nocturnal ventilation in the hot environment. So it has been understood that there is a possibility being caused for self- environmental-conscious behaviors for passive and low energy cooling.

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