

# CONTROLS FOR JAPANESE RESIDENTIAL HEATING/AIR CONDITIONING SYSTEMS

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Japanese residential heating/air conditioning systems controls were investigated to understand typical patterns of Japanese resident's heating/air conditioning use. This was a preliminary survey for a larger study of the interaction between behavior and transitions of environment.

Recently, heating/air conditioning systems for residential houses in Japan have become quite sophisticated. Most systems function as coolers, dehumidifiers and heaters. They are equipped with thermostat and micro electronic devices that enable them to automatically start/stop working at the times desired by the residents. One consequence of this increased sophistication is that the units have become much more complicated for residents to use efficiently.

20 residents interacted with these new "intelligent" HVAC systems. It appeared that the residents tended to try not to use systems when they first feel hot. They try to open window and to do without air conditioning first.

It is inferred that some residents may not understand how to use their systems efficiently. This suggestion is based on findings such as (1) elderly people did not try to control air conditioning systems if they did not know how to use them, and (2) women may tend not to read explanatory leaflets, even when they did not know how to use systems.

Findings are going to be applied to the development of a model of the interaction between human behaviors and thermal environment.

## JAPANESE RESIDENTIAL HEATING/AIR CONDITIONING

### Heating

The traditional way of heating in Japan is to heat a small space quite close to residents or to warm residents instead of whole room or home. Almost of all houses for ordinary people are not equipped heating system. Residents have to get heating devices.

Before 1950s, *hibachi* and *kotatsu* were the most popular heating devices in the winter in traditional Japanese homes. *Hibachi* is a charcoal brazier made of porcelain and filled with ashes and charcoal.

People warmed their hands over a *hibachi*. *Kotatsu* is a foot warmer. Traditionally a charcoal fire was placed in a small container filled with ashes and set under a wooden frame covered with a *futon* or coverlet.

In the 1950s and 1960s, charcoal heating devices were replaced by electric devices, kerosene devices or gas devices. A gas heater and a kerosene heater become popular among ordinary homes. *Kotatsu* was improved to be equipped with an electric heater instead of a charcoal heater. After 1970s, a heat

pump (HP) Air Conditioning/Heating system began to prevail. Both the gas heater and the kerosene heater have been improved to be equipped with fans for outlet and intake. *Kotatsu* is still a common used heating device. In 1986, 91.7% of Japanese homes have *kotatsu*.

### Air Conditioning

Traditional Japanese houses, which are called "house made of wood and paper", are designed to protect their residents from hot and humid conditions in the summer. They have wide openings with sun shades - which are made of pile or bamboo - to take the wind as well as to protect residents from heat of the sun. This is one traditional form of passive cooling in Japan. Sometimes, residents fan themselves with a traditional handy fan called *Uchiwa*, or use an electric fan.

On the contrary, houses of today in urban areas are built tight in order to protect their residents from the dirty and noisy environment in cities. People who are living in urban areas can not help using air conditioner to feel comfortable instead of opening windows.

Nowadays, Residential Air Conditioning is popular. The Ministry of Finance reported that 57.7% of residential houses have HP Air Conditioning system in 1986, although it is regarded as one of the luxury goods by Government. However, this does not mean that Japanese people are rich, but means that a lot of Japanese can not live without air conditioning system.

## ILLUSTRATIONS OF TYPICAL RESIDENTIAL HP SYSTEMS IN JAPAN

### Split Systems for Small Units

Almost of all residential HP systems consist of two units. One is an exterior unit and the other is an interior unit. An exterior unit is equipped with a compressor and a heat exchanger. This heat exchanger works as a air-cooled condenser in cooling periods while it works as an evaporator in

heating periods. An interior unit is equipped with a heat exchanger and a fan for intake and outlet. Both units are small. For example, the size of one interior unit is 360H, 790W and 162D (mm) while that of an exterior unit is 505H, 780W and 245D (mm). The weight of an interior unit is 9.5 kg while that of an exterior unit is 40 kg. Usually, interior units are installed on walls near ceilings while exterior units are installed on roofs, on outside walls near window, on cat walks, or anywhere it have enough space. An exterior unit and an interior unit are linked with pipes and power wires. The systems do not have any fresh air inlet.

### No Air Duct

Commonly used HP systems have no air duct. Conditioned wind through a heat exchanger blows from an outlet of an interior unit. It is necessary to install an interior unit in each room to be air conditioned.

### Cooling, Dehumidifying & Heating

As is well known, a HP system can be operated not only as a cooling device but also as a heating device by changing the arrangement of a compressor, a condenser and an evaporator. Many residential HP systems are designed to be used for cooling, dehumidifying and heating. They have a switch to change operating modes by changing the arrangement.

HP systems are mainly used for cooling. So, they are called the systems "air conditioners" or "room coolers" in Japan.

### Controls

Recent systems have remote control panels. Operations by residents are sent to the system by infra red waves or sound wave which residents can not hear.

Typical controls for Japanese residential heating/air conditioning systems of today are as followings;

**Main (Work/Stop).** Residents push to start air conditioning, and they push again to quit air conditioning. It is not a power switch, some buttons are prior to this button. For example, a "timer" button can be operated although a "main" switch is at "stop".

**AC Mode Changing Switch.** As mentioned before, HP systems can cool, dehumidify or heat rooms. Therefore they have a switch to change operation modes. The switch is called "Operation Change". Recent systems have only one button. Residents who want to change operation modes push the button, then the mode changes by turns such as the following.

*Auto->Cooling->Dehumidifying->Heating->Circulating->Auto->.....*

**Thermostat.** The button used to set the desired temperature is named "room air temperature set". Recent control panels have two buttons and a digital display to indicate desired room temperature. One button is named "up", the other is named "down". An older type of thermostat has a slide switch to set desired room temperature.

**Fan Control.** It is usually named "Wind Velocity" or "Wind Volume". Wind Velocity can be changed by 3 to 7 steps. It also has "Auto" Fan Control Mode.

**Wind Direction.** If residents push the button named "Wind Direction Control", He or she can change angles of a flap at an outlet in order to control wind direction.

Angles of a flap can be controlled automatically if residents push the button named "Wind Direction Auto". In heating, an angle of a flap is set horizontally when the wind from outlet is not warm, and it is set for the wind to blow 45 to 75 degree downward. In cooling and dehumidifying, a flap swings continually between horizontal to 45 degree downward automatically.

**Timer.** Residents can set the desired time to start or to stop air conditioning with the button named "Timer".

We can divide timers into two types according to the method to be set the desired time. With one types of timers, residents have to calculate and let the timers know how many hours are left until it becomes the desired time. While, with the other types of timers--which have quartz clocks, resident can set the time to turn their air conditioning systems on or off as if they use alarm clocks.

A few systems can calculate the time when they should start to work according to the room temperature at the time, the desired room temperature and the desired time to reach the desired temperature.

**Other Buttons.** Some residential air conditioner have buttons for special controls. Some interesting buttons are the following.

**Thermal Comfort Feedback.** Some of residential air conditioners made by one company have "Thermal Comfort Control" switch. The switch enables the air conditioner to perceive residents' evaluation about air temperature as the input for feedback control.

According to their explanatory leaflet, the switch consists of 3 buttons named "(A) I feel cold.", "(B) I feel Comfortable." and "(C) I feel hot". The leaflet recommends users to push button A when they feel cold, to push button B when they feel comfortable and to push button C when they feel cold. When button A is pushed, the desired temperature will be set automatically at the temperature 1 or 2 degree higher than room temperature at the time, while it will be set automatically at the temperature lower than room temperature at the time when button C is pushed. If button B is pushed, condition at the time will be memorized by an electronic device of the system.

**Adjust Control to the Residents' Behavior.** Other systems are equipped with a button to choose a preset control of temperature and wind velocity to fit the residents. One of the systems has 3 buttons and each button has its own name--"danran (for living room)", "manabi (for children's room or study room)" and "yawaragi (for elderly people's room)" (see Table 1).

*Table 1. Preset Temperatures (Centigrade)*

<u>Buttons</u>	<u>Heating</u>	<u>Dehumidifying</u>	<u>Cooling</u>
Danran	22	24	27
Manabi*	20	24	26
Yawaragi	24	26	28

\* Temperature changes in 0.5 degree every 30 minutes from 1 hour after its start

## **WHY JAPANESE HP SYSTEMS DIFFER SO MUCH FROM THOSE MANUFACTURED IN THE USA**

### **Split System for Small Units**

The reason why popular HP systems in Japan are split systems for small unit has a great deal to do with the features of houses in Japan.

First, there is no space to install a central system in an ordinary house. In 1983, average of total floor area of a house in Tokyo district is 67.28 square meters. Each of residential houses is divided into 2 or 3 small bed rooms, a dining room, a kitchen and a bath room, although its total floor area is not large enough. So, it is the best answer that each room has its own small unit. Also, there is not enough floor area for air conditioning systems to be installed on the floor in each room. So, an interior unit is installed on the wall near ceiling in order to leave as large a space as possible.

Second, many systems are installed after houses have been completed. In such case, it is convenient to install split systems which consist of interior units and exterior units, because it is not necessary for both units to penetrate the wall of houses. They need only a small shaft for pipes and power wires with which both units are linked.

### **No Air Duct**

First, Japanese do not have a custom of cooling or heating whole house. They think that it is waste of energy to cool or heat the rooms not occupied. So, air conditioners which distribute conditioned air to all of the rooms are not required.

Second, Air conditioning systems are installed after occupancy. Residents who want the systems have to get them at an electrical goods store. Installation requires a lot of time (and money is not common among ordinary people).

Moreover, Japanese houses do not have enough clearance space between ceiling and roof for ducting.

### **Cooling, Dehumidifying & Heating**

The climate of Japan has a rainy season and hot a humid summer. It is sticky in the rainy season before summer, the humidity ratio increases over 80% while the average exterior temperature is just over 20 centigrade. So, dehumidification (which does not cool air) is an effective way for residents to feel comfortable.

As mentioned before, Japanese have to get and install not only cooling devices but also heating devices in their small houses. Some people prefer the system available for heating as well as cooling in order to save money and space.

### **Controls**

In Japan, the people who decide which system will be installed are not building service engineers or architects but the residents who will use the system. This means that it is chosen and bought at a electrical store in the same way as a TV set or a refrigerator.

The basic performance of the system by one electric maker is identical with that of the systems made by the others. So electrical makers try to attract residents by added value, such as option of control or design.

## **INVESTIGATION OF USAGE AND CONTROL BY RESIDENTS**

The usage and control of residential HP air conditioning systems was investigated to grasp typical patterns of control for Japanese Residential Heating/Air Conditioning Systems in a preliminary survey for a study of the interaction between behaviors and transition of environment. 20 residents who have residential HP systems in their rooms where they always make themselves comfortable and live in the Tokyo metropolitan area were asked to answer a questionnaire about air conditioning. They are some of my colleagues or their families. Table 2 shows principal questions in the questionnaire.

*Table 2. Principal Questions in the Questionnaire*

1. What are you doing when you make yourself comfortable?
2. What kind of clothes do you wear?
3. What will you do if you feel slightly warm? And what will you do if you feel still slightly warm after the first action?
4. Is it troublesome to open windows during daytime/night?
5. Which do you like better, natural indoor climate or air conditioned room?
6. Which do you think healthy, natural indoor climate or air conditioned room?
7. Which do you think economical, natural indoor climate or air conditioned room?
8. Which do you feel comfort, natural indoor climate or air conditioned room?
9. In what case do you use an air conditioner?
10. What kind of control switches does your system have? How do you use those switches?
11. Do you use an air conditioner when you go to bed? Do you leave windows open during night?
12. What do you do if you find any control which you don't know how to operate?
13. What kind of heating devices do you use?

Table 3 shows a list of the 20 residents who answer the questionnaire. The residents were asked to imagine the state of relaxing at 10:30 a.m. on a day off. Findings through this investigation are not available for generalization because of its small sample size of 20, but they can be applied to a larger project which includes the development of a model which deals with the interaction between human behavior and thermal environment and the data analysis of larger investigation with the model. A list of behaviors in a certain environment is made from these findings.

**What kind of controls do you have?**

Figure 1 shows control switches and the number of people whose HP system has each switch. 80% of

*Table 3. A List of the Residents*

No	Age	Sex	Behavior at 10:30
A	23	female	watching TV sitting on the floor
B	10	male	studying
C	71	male	listening to music sitting on a chair
D	30	female	reading a book or watching TV reclining on the floor
E	38	male	watching a video movie or TV sitting on the sofa
F	29	male	watching TV reclining on the floor
G	34	male	reading a book reclining on the sofa
H	29	female	reading a newspaper with listening to the radio
I	37	male	being at table
J	41	female	watching TV sitting on the sofa
K	42	female	watching TV sitting on the floor
L	42	male	watching TV reclining on the floor
M	64	female	knitting
N	33	female	watching TV or knitting
O	28	female	watching a video movie or TV reclining on the sofa
P	40	male	reading a newspaper sitting on the sofa
Q	29	female	reading a newspaper sitting on the sofa
R	30	male	being at table
S	21	female	reading a book sitting at the window
T	30	male	watching TV

the residents own HP systems with remote control panel. Figure 1 shows controls marked by residents as the buttons of which they are aware. It is inferred that people who do not mark do not know whether they have those buttons. Figure 2 shows whether residents' systems are available for heating or not. 50% of the residents own HP systems which is available for heating, and 60% of them use the systems as a heater, too. 40% of them use alternative heating equipment like fan heater.

**Which do you like better, AC or Natural ?**

Figure 3 shows residents' preference and knowledge about air conditioning compared with natural indoor climate. 90% of residents think that natural indoor climate is better for the health than an air conditioned room and 70% of residents prefer natural indoor climate to an air conditioned room. But only 20% of residents think that natural indoor climate is more comfortable than air conditioned room. It is obvious that Japanese residents recognize that air conditioning is more comfortable

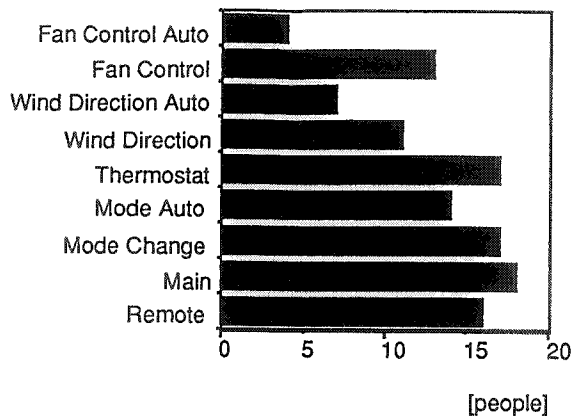


Figure 1. What kind of Control Do You Have?

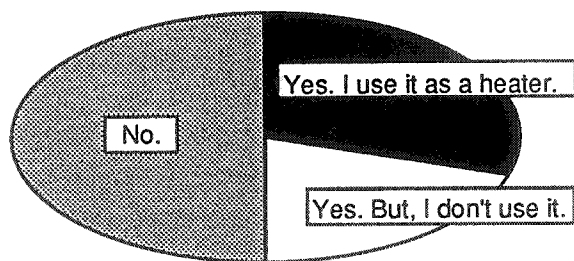


Figure 2. Is Your System Available for Heating?

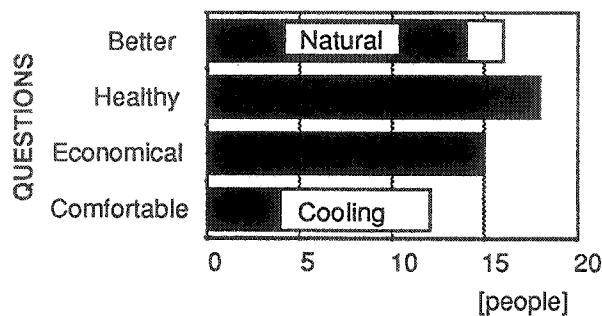


Figure 3. Which Do You Think ..... ?

than natural indoor climate although most of them regard natural indoor climate as "the better thing" in their principle.

These results show that a conflict between comfort and health, and comfort and stated preference is in Japanese residents' mind. This conflict might be connected with one of Japanese typical way of thinking--What they say is not always what they think or believe in their own mind. They sometimes mention the ideal while they mention the realities in the other time. In this case, the ideal is their belief in nature, and one of realities is that an air conditioned room is comfortable for them.

#### Do you need air conditioning?

95% of residents regard cooling as the necessity. They think that it might be hard to live without an air conditioner or that they might have a hard time in some cases. Only resident M does not need cooling. She has never used any cooling device in spite of the fact that it is installed in her room. It is inferred that people who use HP systems recognize that an air conditioned room makes them feel comfortable.

No resident regards a HP Air Conditioning System as a status symbol although Japanese Government considers it as an exclusive consumers' good.

#### When do you use air conditioners?

**When You Feel Hot.** Figure 4 shows behaviors that residents do to control indoor climate when residents feel hot. 80% of them open window first. However, only 5% of them turn on air conditioning first. 70% of them start cooling second. 30% of them endure while although they feel hot. 30% of them cool their rooms only when visitors or when they are with members of the family. It is inferred that the Japanese principle that natural indoor climate is better than air conditioning has an influence their behaviors to start air conditioning.

**Air Conditioning When You Go To Bed.** Figure 5 shows the usage of air conditioner when residents go to bed. 9, or 45% of the residents don't use their air conditioners at night. 6 of 9 stop their air conditioner when they go to bed. Another, 45% of the residents use their air conditioner while they are sleeping. The reason is that it is comfortable for them. And 8 of 9 use timers to stop operation of air conditioning after they fall in sleep.

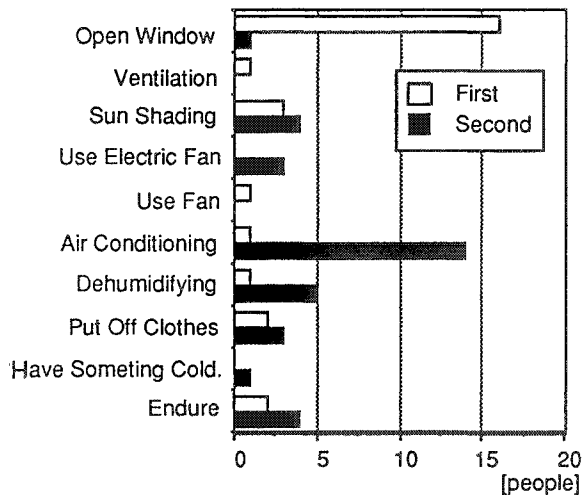


Figure 4. What Do You Do If You Feel Slightly Warm?

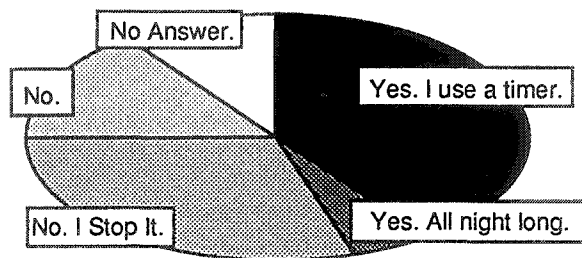


Figure 5. Do You Use An Air Conditioner When You Go to Bed?

**Opening Windows When You Go To Bed.** Figure 6 shows whether residents leave windows open or not during night. 20% of the residents leave windows open during night. It had been one of popular style to feel comfortable and is still popular in rural area where houses don't stand close together. However in urban area where houses stand roof to roof, it is impossible for their residents to leave windows open during night because it is dangerous or it makes indoor climate become worse. 75% of the residents think it troublesome to do so. For instance, 45% of the residents are afraid of being peeped or their houses being broken into by someone, while 40% of the residents complain that dirty air or noise from

outside come through the windows if they are opened. 3 residents complain that the wind blows hard through rooms. 2 of 3 live in multi story apartment buildings. It is inferred that problems caused by urbanization such as crime and pollution affect behaviors to start air conditioning.

**When You Get Up.** 80% of the residents don't use their air conditioner when they get up. The reason is that they think it is good for health and that it is comfortable enough for them without air conditioning in the morning.

#### How do you control your air conditioner?

Figure 7 shows how the residents operate their control switches. When the residents feel slightly warm although their rooms are air conditioned, 85% of them use "thermostat" to down the set of their desired temperature first, and only 10% of the resident use "fan control" button. It is clear that "thermostat control" is more familiar than "fan control".

#### What will you do if you find controls not understand?

Figure 8 shows what will residents do if they find controls not understand. In this question, the residents are asked what will they do if they meet with any control which they don't know how to use. They are not asked if they have read the instruction leaflet first when they purchased systems.

Controls for Japanese residential heating/air conditioning systems are sophisticated, so it is assumed that some residents cannot make good use of the sophisticated controls. The ratio of people who answered that they are used to every control is 25%. All of them are male. 6, or 30% of the residents use controls the way that they assume to be correct while 7, or 35% of the residents consult an explanatory leaflet before they use control systems. 5 among 6 residents who control HP systems by their own operations are female while 4 among 7 residents who consult with a leaflet are male. 2 elderly residents neither operate in their way nor read an explanatory leaflet. Both ask someone how to operate. It is inferred that it might be difficult for elderly people to understand how to operate too sophisticated systems.

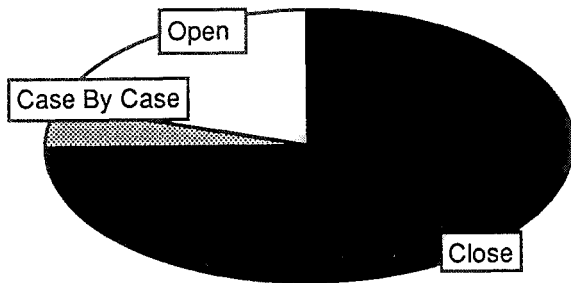


Figure 6. Do You Leave Windows Open During Night?

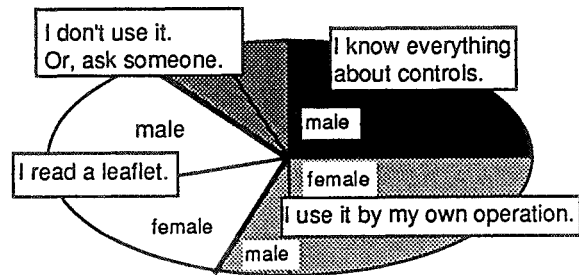


Figure 8. What Will You Do If You Find Controls You Cannot Understand?

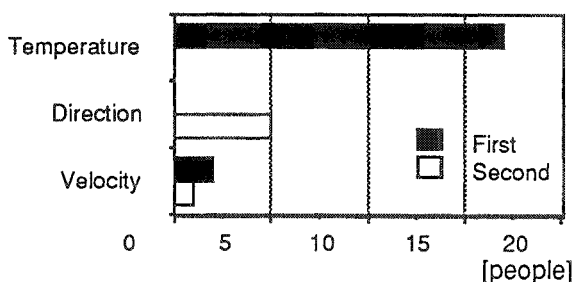


Figure 7. What Control Switch Do You Use?

What do you use as a heater?

30% of the residents use HP systems for heating. Its reasons are maintenance free, easy operation, safe, comfort and safe. One resident says that she uses HP systems because the system needs only a small space.

### PRELIMINARY CONCLUSIONS

The preliminary conclusions are that a typical pattern of 20 Japanese residents' heating/air conditioning system use is to try not to start air conditioning until they endure uncomfortable indoor climate. It is inferred that the pattern is caused by a Japanese traditional principle concerning about nature as well as efficient energy use.

However, some residents--especially females--tended to control systems without explanatory leaflets instead of using the correct operation of systems. It seemed that some of them misuse systems and waste energy. Also some males who say that they are used to every control might waste energy if they misuse

systems. It is inferred that too sophisticated controls which are difficult to understand discourage residents from reading leaflets and encourage them to misuse systems. Control buttons should be designed to be easy to understand correctly without explanatory leaflets. It is inferred that it would affect energy saving to teach residents how to control their systems efficiently. Further investigation and measurement in the fields to test these hypotheses are required on the next step.

It becomes popular among 20 Japanese residents to use air conditioner while he is sleeping. A timer may to be a useful control for both efficient energy use and comfortable thermal environment setting. Once residents fall asleep and become unaware of thermal comfort, it is not necessary to keep cooling.

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