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Japanese residential air-conditioning: natural cooling and intelligent systems*

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Abstract

Japanese residential heat pumps (which commonly combine cooling, dehumidifying and heating in a single system) are unlike American room air conditioners in a variety of ways. A key to the difference follows from the traditional Japanese focus on heating or cooling persons rather than spaces. When this focus is coupled with the widespread use of inverter technology, solid-state electronics, Japanese cultural norms, the constraints of house form, and the islands' climate, the result is a sophisticated system unlike anything available elsewhere. In addition to a large number of standard remote-control options, some Japanese systems can perceive and learn user preferences, while others can generate pre-recorded and algorithmic fluctuations of wind and temperature. We discuss some of the implications (both for users and for energy consumption) of these innovations. We also consider the results of a small survey of Japanese air-conditioner owners in which we found that despite the sophistication of their heat pump systems a significant majority prefers natural cooling. Most, for example, open windows and pursue other natural cooling strategies before using their air conditioners. While they view the devices as urban necessities, they also report limited knowledge of their machines' advanced features.

This research examines the design, cultural context and use of Japanese air-conditioning systems, along with some of the behavioral and theoretical issues raised by their unique form. After discussing traditional Japanese housing and heating and cooling technologies, we describe contemporary Japanese heating/cooling systems, speculate about the differences between US and Japanese systems, and present preliminary findings on Japanese cooling behavior from a small sample of Japanese air-conditioner owners.

The evolution of Japanese residential heating and cooling

Heating in Japanese dwellings has developed according to an entirely different principle from that which governs residential heating in the US. While American furnaces and heaters are designed to warm large spaces, most often whole houses, traditional heating in Japan involves either warming small spaces close to residents, or warming the residents themselves. Only rarely is heating a whole room or an entire building considered. Given the openness of the traditional Japanese house (discussed below), Japanese heating technologies are designed to heat persons rather than places. Until quite recently, builders and landlords in Japan have not considered making provision for heating or cooling. Few houses or apartments intended for ordinary working or middle class families come equipped with any sort of heating system. Much in the same way that people in the US often own their own refrigerators, Japanese households ordinarily provide their own heating and cooling equipment.

Before the 1950s, the *hibachi* and *kotatsu* were the primary heating devices used in Japanese homes. The hibachi is a charcoal brazier made of porcelain over which persons warm their hands. The kotatsu could be called a 'foot warmer'. Traditionally, a charcoal fire was placed in this small container on a base of ashes. The container was then placed under a wooden frame or table covered with a *futon*

*The paper reports initial findings from two larger studies. These concern (1) human/machine interactions in built environments, from which Fujii is constructing a model of the behavioral control of indoor environments, and (2) the relationships between culture, markets and the technological base that may help to explain the striking developmental differences between Japanese and US air-conditioning systems.

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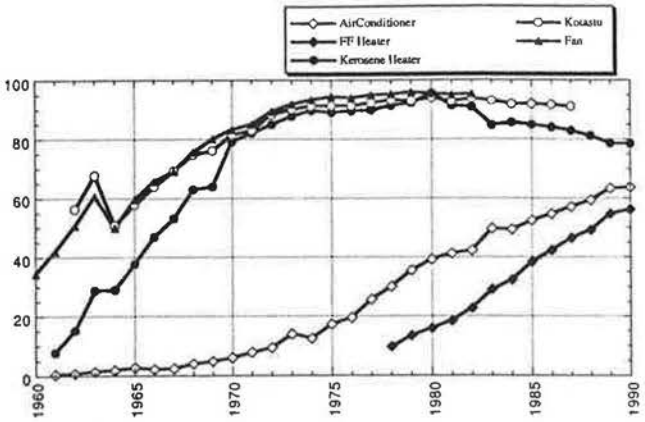


Fig. 1. Heating and cooling equipment saturations (percent of all households).

or coverlet around which family and friends would sit*.

In the 1950s and 1960s, charcoal heaters were largely replaced by kerosene or gas room heaters, and the electric kotatsu. By the 1980s, heat pump systems (i.e., combination air-conditioning and heating systems) appeared on the market. As their efficiency increased and their cost declined, they became quite popular [1]. During the same period, gas and kerosene room heaters came to be equipped with fans for air movement. But, despite these improvements in space heating, the person-heating kotatsu is still a common feature of the Japanese home. In 1987, over 92% of all households reported owning a kotatsu [2]. A less-common technology somewhere between the room heater and kotatsu is the electric resistance-heated "hot carpet". Figure 1 shows trends in ownership of the most common heating and air-conditioning equipment.

Traditional Japanese houses, commonly referred to as "houses made of wood and paper" [3], are well suited to the hot and humid conditions of the Japanese summer. They are open-plan dwellings whose large windows are equipped with movable bamboo or pile shades that protect residents from the heat of the sun and help to manage winds. Japanese house design developed in harmonious relationship with the Japanese island climate, where winter winds characteristically blow from the north and monsoon rains and hot humid summer winds originate in the south. In the summer, residents of traditional houses might fan themselves with a hand fan called *uchiwa*. Over the past 20 years electric fans have become common.

Modern Japanese dwellings, and particularly urban apartments, lack the openness and passive cooling of the traditional Japanese house. Dwellings located in urban areas are constructed more tightly to protect residents from dirty and noisy urban environments and to control winter heat loss. Crime, noise and pollution also discourage urbanites from opening windows and doors to take advantage of natural cooling opportunities (e.g., lower nighttime temperatures and cool breezes). These same conditions encourage the use of air conditioners.

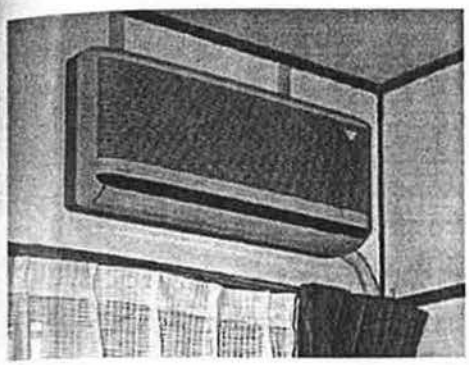
As a result, air-conditioning has now been widely adopted by Japanese households. The Ministry of Finance reported in 1990 that 72% of all housing units were equipped with heat pump air-conditioning systems* [2], a statistic that suggests the Ministry's categorization of air conditioners as 'luxury goods' may have become dated.

Typical Japanese residential heat pump systems

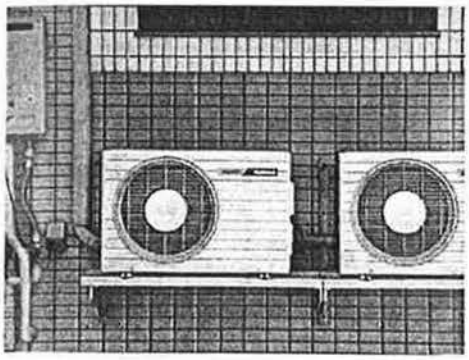
Almost all Japanese residential heat pump systems are of the "ductless-split" type, with an exterior compressor and an interior heat exchanger unit, connected through a small hole in the wall by electrical cables and coolant piping. The interior unit, which is equipped with a heat exchanger and a fan (see Figs. 2 and 3), functions as a condenser when cooling and as an evaporator when heating. Both interior and exterior units are fairly small. For example, the size of one typical system's interior unit is 360 mm × 790 mm × 160 mm, while the corresponding exterior unit measures 510 mm × 780 mm × 250 mm. The interior unit weighs 10 kg and the exterior unit 40 kg. Interior units are usually installed on walls near ceilings. The exterior units are typically installed on roofs, outside walls, catwalks or anywhere else where they can be accommodated. These systems generally do not have a fresh air inlet — they heat, cool and dehumidify recirculated indoor air. Although manufacturers are experimenting with ducted systems, separate interior units are ordinarily required for each air-conditioned room. Interior air is drawn through a heat exchanger

*The term kotatsu may refer to the heat source alone, or to the entire arrangement of heater, table and futon. The kotatsu is a social as well as a utilitarian arrangement. To own a kotatsu means that one has a device that can be used by a group of persons, particularly the family. To really 'use' a kotatsu is a group venture. Therefore, when one compliments the quality and size of another's kotatsu, the speaker is, in part, expressing approval of the idea of the preservation of a social bond, specifically the family — an institution that in Japan, as in the US, finds itself in transition.

*In 1987, 64% of US households had air conditioners [4].



(a)



(b)

Fig. 2. (a). Typical interior unit. (b) Typical exterior unit.

(a)

(b)

Fig. 3. Exterior units on urban apartment building.

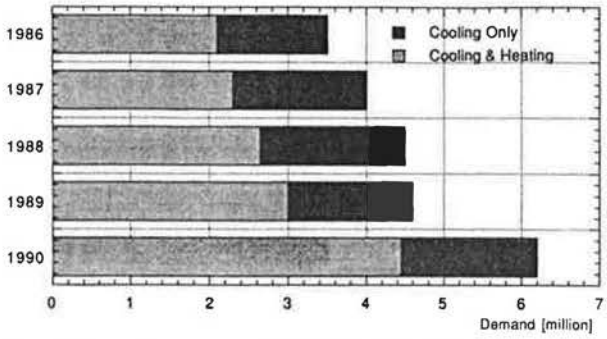


Fig. 4. Annual purchase of cooling-only vs. combination units.

and blows from an outlet of the interior unit as cool or warm 'wind'*.

Multi-function systems

A heat pump system can be operated either as a cooling or heating device by changing the relationship between the compressor, condenser, and evaporator. In many US residential air-conditioning applications, either a room-sized unit or a central air conditioner is added to dwellings that are already heated by permanently installed natural gas, fuel oil or electric resistance heating systems. Many models of Japanese air conditioners, on the other hand, are offered by manufacturers as multi-purpose machines that can heat as well as cool and dehumidify**. By combining these three functions, considerable flexibility is incorporated into a single compact design. Figure 4 shows that Japanese consumers are increasingly opting for the multi-function machines. However, because other heating equipment is also widely available to Japanese households, it may be that these heat pump systems are mainly used for cooling (both air-chilling and dehumidifying) – an hypothesis that we consider more fully below. Japanese consumers ordinarily refer to the machine as a 'room cooler' or adopt the American terminology of 'air conditioner'.

*This translation most accurately renders the Japanese technical terms, which refer to 'wind', 'wind velocity', and 'wind direction' in discussing phenomena that an American engineer would refer to as 'air movement' or 'air handling'. The 'wind' terms follow from an orientation to the system from the point of view of the user, and describe the product of the air conditioner: directionally controllable moving cool air. The comparable term on US air-conditioner controls ("fan speed") refers to the machine rather than its output. 'Wind' also communicates the Japanese understanding that these machines are devices than can be made to replicate a naturally occurring phenomenon (the wind), while the analogous English term ('air', e.g., 'conditioned air') connotes a static indoor environment.

**Separate dehumidifying machines are available in certain parts of the US. They are owned by about 20% of the households in the Midwest Census Region, for example [4].

Variable-speed compressor and fan control

Innovative internal control circuits that allow motors to operate at a wide range of speeds are increasingly common in Japanese heat pumps. Solid-state inverters alter the frequency of the incoming 60-cycle current to 30–150 cycles per second. This allows both the compressor and fan motor to be driven at variable speeds, so that air-conditioner output can be matched to cooling load in a continuously variable fashion, e.g., compared to the intermittent operation of US systems. This meshing of function and load produces less frequent cycling, overall quieter operation and elimination of "annoying start-up and shut-down groans... because the compressor is barely turning over at start-up and shut-down" [5]. Variable-speed drives are more energy-efficient than single-speed systems and inverters provide a technical platform upon which a variety of innovations in control and operation (discussed below) can be developed.

Intelligent control systems

Some of the most impressive design innovations in Japanese air-conditioning systems are found in their sophisticated controls. Recall that the interior units have a plain grille face, with no visible controls. Their high interior placement, combined with advances in consumer electronics, account for the fact that most of these systems are now equipped with hand-held remote controllers that use infrared or inaudible sound waves. As in the case of early video cassette recorders, Japanese air-conditioner controllers were once connected to the interior units by wires. We will first consider control and monitoring options found on typical Japanese remote controllers. Second, we describe several advanced features available on some of the newest systems. Finally, we consider how Japanese designers have accommodated consumers' presumed (yet contradictory) demands for household systems that offer *both* greater direct user control and greater automatic operation. Figure 5 presents a typical controller design.

Common control options

Main switch (Work/Stop)

This control is essentially an "on/off" toggle that residents push to start their air conditioners, and push again to stop. It is not necessarily a "power" switch, because some other controls may override it. For example, a "timer" button could be operated when the main switch is at "stop."

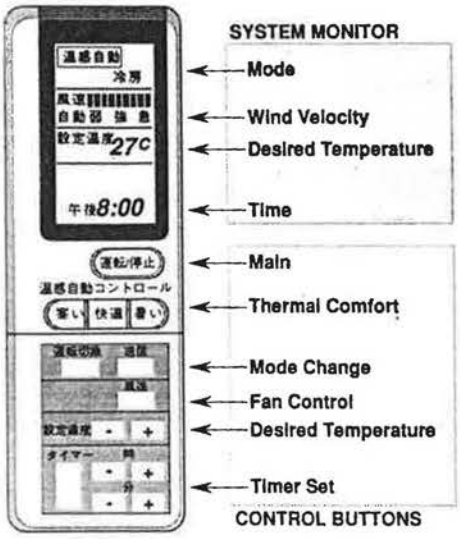


Fig. 5. Remote control unit.

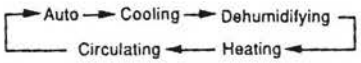


Fig. 6. Mode change sequence.

Mode-changing switch

Because many heat pump systems can cool, dehumidify, or heat, they are often equipped with a switch to change operation modes. This switch is called "Operation Change." The newest systems have only one button to control this mode-change function. Residents select operation modes by repeatedly pushing this button to cycle through the modes as shown in Fig. 6.

Temperature

Heat pump systems are equipped with a thermostat and an associated control. The button used to set the desired temperature is labeled "room air temperature set." Newer control panels have two buttons and a digital display to indicate desired room temperature, with one button labeled "up" and the other "down," like the channel and volume controls on television and VCR remote controllers. An older type of thermostat has a slider along a scale marked in degrees for desired temperature.

Wind velocity control

This is similar to a control labeled "fan" or "fan speed" on US units. The Japanese control directs attention to the quality of the air exiting the wall unit by labeling it "Wind Velocity" or "Wind Volume." Each of these terms conveys one of the characteristics of changes in the breeze (i.e., greater air speed and larger volumes of air) produced when the fan speed is increased. Wind velocity can be changed by 3–7 steps, depending on controller

design. This control also frequently has an "Automatic" fan control mode, which allows the machine to adjust its wind velocity to changes in the cooling load.

Wind direction

Most units are equipped with a deflecting vane or flap to direct outlet airflow. When the resident pushes the button labeled "Wind Direction Control," the angle of a flap at the air outlet changes. The flap angle can also be controlled automatically if residents select the "Wind Direction Auto" option. In this 'automatic' mode, if the unit is heating, the flap angle is set horizontally when the wind from the outlet is not yet warm. As it warms, the flap angle automatically changes so that the wind blows 45° to 75° downward, toward residents. In cooling and dehumidifying modes, the flap automatically swings continuously between horizontal and 45° downward, distributing wind throughout the room and approximating the gusts of a breeze. Some newer systems can sense the location(s) of persons in the room, directing the wind accordingly.

Timer

Residents can set the desired time to start or to stop air-conditioning with this button. Two types of timer systems merit mention. The first is a countdown timer that requires residents to calculate the number of hours remaining until the unit should turn itself on or off. The second is a quartz clock system (similar to microwave ovens and video recorders) that enables residents to preset the time for their air-conditioning systems to turn on or off. Timers are of value in cooling a room before the resident arrives home from work or shopping. They can also turn the machines off after residents have gone to sleep. This 'strategic' use of air-conditioning could be contrasted with the 'static temperature' approach assumed in US system design, in which users are assumed to desire uniform temperatures at all times, perhaps with a setback (or setup) option for sleep periods or times when residents are not ordinarily at home.

A few Japanese systems are able to monitor themselves, determining the time when they should begin to heat or cool. They do this by periodically measuring the room temperature and comparing that information with user-programmed desired room temperature and usual arrival time data and information on the machine's own cooling performance parameters. The system is able to calculate the running time required to reach the desired temperature, and to turn itself on at a time calculated, so that the room reaches the desired temperature by the time the residents return.

Displays

Remote controls commonly display a variety of information about current indoor environmental conditions and heat pump system performance. While varying by manufacturer and model, this information ordinarily includes indications of: (1) operating mode (heat, cool, dehumidify, etc.), (2) room temperature, (3) current time, and (4) wind velocity setting.

Advanced control options

In an effort to add competitive features that will appeal to a highly saturated home-appliance market, Japanese manufacturers have equipped some of the newest residential air conditioners with additional functions and control options. As in the case of the self-monitoring timer systems, many of these features are intended to make system operation more automatic, requiring less intervention and control by users. The options cover a diverse range, with some simplifying common control actions, some actually defining comfort for users, and some even introducing randomness into the system's operation. We describe three particularly interesting innovations that are fundamentally unlike anything found outside Japan.

Thermal comfort feedback

Since 1986, several models of residential air conditioner made by one manufacturer are equipped with a "Thermal Comfort" switch (see Fig. 5). This switch enables the air conditioner to perceive residents' evaluations of experienced air temperature, and to use that information as the input for feedback control*.

This switch consists of three buttons labelled "(A) I feel cold," "(B) I feel comfortable," and "(C) I feel hot." When button A is pushed, the desired temperature will be set automatically 1 or 2 °C higher than room temperature at the time. The reverse occurs when button C is pushed. When button B is pushed, conditions at the time will be

*This description attempts to accurately render the Japanese usage. Our literal translation, that the device 'perceives' the user's reactions, could easily be replaced by a construction like: "this switch enables users to program the system." But that description would fundamentally misconstrue what both the humans and the machine are doing as well as the designers' intentions in creating this human/machine system. See the following discussion.

recorded in the system's memory. These buttons constitute a thermostat system in which the "I'm comfortable" button (B) sets the thermostat at the present room temperature as if the user had observed the room temperature and then set the thermostat at that level. The other two buttons function to incrementally adjust the set point upwards and downwards until no further adjustment is necessary*.

This system differs from the conventional thermostat-setting interaction of user and heat pump system in at least two fundamental ways. First, it takes the question of *temperature* out of the user's domain of interest all together. He or she no longer need be even incidentally aware of what the indoor temperature is, or what the machine's target temperature setting may be. Second, in designing a machine that 'perceives' the user's psycho-physical states, a new human–machine relation has been constructed. This machine is not merely an instrument of the user, but rather features a 'not-very-intelligent' (but 'intelligent-enough') memory that does more than just store intentionally programmed user preferences. Instead, the machine accumulates information sensed through its interactions with the user. This makes it a very limited robotic servant who, having learned the resident's habits (like servants everywhere), works diligently to enforce them. By lodging this sort of intelligence in a simple logic circuit, the requirement of premeditated human control is eliminated altogether from the human/machine system. Among other ramifications, this relationship removes such user choices as whether to add or remove clothing versus adjusting the space-conditioning, and how to balance saving money against being slightly uncomfortable. It also makes the implicit assumption that comfort can be established from air temperature, without knowledge of clothing, activity, or time of day.

Pre-programmed socio-physical performance standards

In heat pump systems equipped with this second type of control option, system operations are governed by protocols pre-recorded by the manufacturer. These protocols presume a kind of normal behavior to be occurring in each room, and adapt the system to that presumed behavior. This control scheme allows residents to choose from a menu of preset temperature and wind velocity conditions believed to be appropriate to particular sorts of residents. For example, one such system has three buttons named: *Danran* (for living room), *Manabi* (for children's room or study room) and *Yawaragi* (for elderly people's room). Each setting assumes a different temperature level for each person/activity combination and for each mode of operation (heating, dehumidifying and cooling). These temperature settings are presented in Table 1. The *Manabi* setting automatically varies the temperature randomly at regular intervals, based upon a theory that beneficial physiological (and presumably mental) effects result from mild environmental stimulation. To some, this "science knows best" approach may seem somewhat authoritarian.

TABLE 1. Preprogrammed temperatures (°C)

	Heating	Dehumidifying	Cooling
Danran	22	24	27
Manabi†	20	24	26
Yawaragi	24	26	28

†The temperature is automatically changed in 0.5 degree increments every 30 min after the first hour's operation.

While also decreasing users' awareness of temperature levels and reducing their control over the system, the implications of this control option are quite different from those of the first system discussed. If we assume that thermal preferences differ from person to person, widespread adoption of that three-button comfort system would produce an idiosyncratic range of thermostat settings, temperature levels and resulting energy consumption patterns. Institutionalizing the second ('preset') system would have the opposite effect. Identical settings and temperatures would be observed in rooms dedicated to the particular person/activity combinations encoded in the machine. This is a homogenizing or normalizing system, rather than an individualizing one.

Natural wind systems: the reproduction of measured and logic-generated wind patterns

The same deep regard for nature and things natural that has produced the Japanese garden, bonsai sculpture, flower arranging, watercolor artistry and intricate joinery has also influenced Japanese house form and technology. While urbanized Japan is dramatically different from the agrarian society that spawned a nature-centered culture, the ideal Japanese house remains integrally related to the natural world [3]. And, unlike Western understandings of the relationship of machines to nature and culture, Japanese technology is not necessarily designed to wrest materials from a recalcitrant nature or to

*The newest systems also have a button labelled "sticky" to enable residents to supply information regarding their perceptions and humidity preferences.

dominate a hostile natural world*. It should not be considered odd then (as it might in the US) for Japanese manufacturers to offer machines that emulate natural phenomena within the dwelling itself. This is precisely what has been done in the case of some residential heat pump systems and portable cooling fans. It is possible, for example, to purchase machines that produce 'breezes' which 'gust' in natural patterns – a logical extension of a technology whose primary product is 'wind', and one that is often advertised using natural images**. The Japanese air conditioner as routinely represented by manufacturers, and to some extent accepted by users, is a surrogate for natural winds.

One company offers a machine that reproduces the wind patterns recorded at a well-known resort located near Tokyo. Other systems offer wind patterns generated by an algorithm which assumes that natural phenomena vary in a linear relationship of intensity, frequency and duration such that more intense gusts are less frequent and of shorter duration than are gentler gusts. With this logic encoded in control circuitry, the fan speed is varied to produce seemingly natural breezes inside the dwelling. This natural wind emulation is, to our knowledge, found in technology nowhere else in the world.

As in the case of the first two automatic control options, this feature also distances the user from the device. In the case of artificial breeze, however, the machine is not merely an interactant with the user or guarantor of normalcy, as in the first two cases; rather, it possesses a sort of unpredictable autonomy. It runs according to programs and self-generating control patterns that users can only control by enabling or disabling the option. Its windy product, however, seems to offer a pleasant unpredictability whose closest relative may be the winds produced by oscillating table fans.

Direct control vs. automatic operation

Should increasingly elaborated and sophisticated heat pump machines offer users greater *user control* over system functions, or should increased control be lodged in the *machine*, freeing the user from the need to continually issue commands or engage in repetitive adjustments? The heating and cooling thermostat is the simplest common automatic control. It allows users to select a preferred temperature level and then takes over responsibility for regulating indoor temperatures. What could be simpler or more convenient? Researchers writing in this volume and elsewhere have recurrently noted, however, that users tend to override their thermostats, sometimes even treating them as heating or cooling switches rather than as automatic devices [9–11]. On the other hand, consumers also seem to see the automatic features of video recorders, televisions, microwaves and heat pump machines as adding value (convenience or social status) to their lives and homes. This problem of contradictory demand for control and 'automaticity' is not unique to the Japanese, nor even to heat pump systems. It recurs in the design of many consumer technologies (e.g., automobiles, VCRs, microwave ovens). Furthermore, consumer willingness to pay additional amounts for complex control options doesn't necessarily mean that they use or understand those features. In fact, complex controls and information displays frequently are confusing to consumers [12]. Later in the paper we present similar evidence of user confusion in the case of Japanese heat pump systems.

We do not offer specific advice to manufacturers and designers to help them avoid the user control vs. automatic operation dilemma, seeing distinct advantages (and sources of consumer resistance) in both. We do point to three factors that have allowed Japanese designers to elegantly finesse the problem, however. These lie in the fact that:

(1) Japanese heat pump manufacturers enjoy ready access to miniaturized digital logic, promoted by manufacturing groups and state authorities;

(2) Japanese designers are encouraged to innovative in heat pump design in an effort to maintain market share against the incursions of nearby industrial economies;

(3) Japanese consumers have come to expect considerable innovation in consumer durables*.

Therefore, Japanese heat pump control systems have developed to accommodate both increased user control *and* increased automaticity. A good example is the system controller pictured in Fig. 5, which presents a clear performance monitor display and greatly simplified thermostat programming via the prominently featured "I feel hot," "I feel cold," "I'm comfortable now" interaction

*The role of nature in Japanese culture has been widely considered. A brief overview is presented in Wantanabe [6]. The Japanese house as a natural phenomenon is an important theme in Japanese literary tradition (e.g., Yoshida [7]), as well as in contemporary cultural and architectural criticism [2, 8].

**Refreshing images, e.g., cool sylvan glades and waterfalls are frequently used in Japanese air-conditioner advertisements – the images once commonly used in the US to advertise menthol cigarettes.

*US and European manufacturers, for a number of reasons not considered here, do not enjoy these advantages and are further constrained in innovation (in ways that the Japanese are not) by their pre-existing technological commitments, distribution and maintenance systems, the structure of their markets, and by American consumers' cultural expectations.

TABLE 2. Resident characteristics and behavior

Respondent	Age	Sex	Behavior at 10:30
A	23	Female	Watching television 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 television reclining on the floor
E	38	Male	Watching a video movie or television sitting on the sofa
F	29	Male	Watching television reclining on the floor
G	34	Male	Reading a book reclining on the sofa
H	29	Female	Reading a newspaper while listening to the radio
I	37	Male	Being at table
J	41	Female	Watching television sitting on the sofa
K	42	Female	Watching television sitting on the floor
L	42	Male	Watching television reclining on the floor
M	64	Female	Knitting
N	33	Female	Watching television or knitting
O	28	Female	Watching a video movie or television 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 television

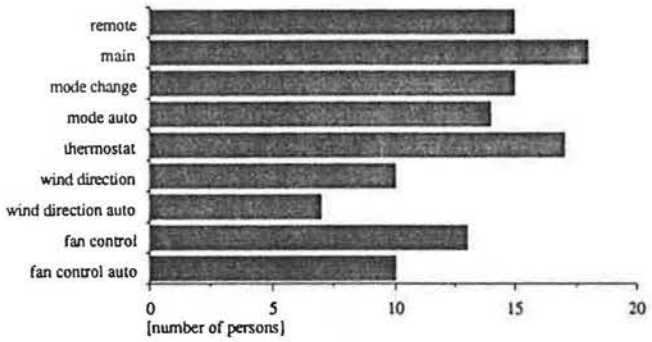


Fig. 8. Controls reported out of the sample of 20.

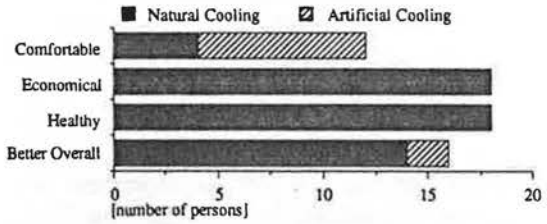


Fig. 9. Preferences for natural vs. artificial cooling.

(90%) believe that natural cooling is better for health than an air-conditioned room, and 70% prefer natural cooling to an air-conditioned room. Three-fourths of the residents believe natural cooling to be more economical, but only 20% said that natural cooling is more comfortable than an air-conditioned room. Respondents seem to believe that natural cooling, in principle, "is a better thing," although they typically do not believe that it is more comfortable than air-conditioning.

These results suggest a conflict in the residents' evaluations between comfort and health, and between comfort and stated preference. The source of some of this apparent inconsistency may lie in respondents' inclinations to report cultural ideal values when asked – in this case the widely understood virtues of the natural over the artificial (a set of values that are also widely shared in the US and Europe) – regardless of what their actual preferences may be. The dilemma posed by the often large differences observed between persons' actual preferences and behaviors, and the normative accounts of idealized preferences and behaviors that they supply to researchers, is a long-standing problem in the social sciences [14]. What's more, it may be the case that people really do not have opinions in many of the areas that researchers expect they do. We often cannot accurately reconstruct our own habit-encoded action, but are often too polite to point this out to researchers, and are perhaps loathe to publicly admit to such defects. It is also the case that cultures commonly harbor conflicting values and imperatives (e.g., self-interest vs. common welfare), as do individuals (e.g., self-protection vs. love of country). In this case, the apparent conflict between the desire for natural cooling and the comforts of artificial cooling has opened the possibility for the introduction of 'more natural' cooling systems, as in the advanced efforts to reproduce natural conditions in the home – innovations that take advantage of developments in solid-state logic and inverter technology to open

up a range of new design possibilities. The nature vs. artifice problem seems to have produced some unique innovations in the case of the Japanese heat pump.

"Do you need air-conditioning?"

Innovation in heat pump design may be welcomed by consumers because they find themselves in urban circumstances and climatic conditions within which they believe they must have air-conditioning. Ninety-five percent of the respondents regard artificial cooling as a necessity. Only one older resident reported that she did not need cooling. She has never used any cooling device, although one is installed in her room. It is also interesting that none of the residents regard their heat pump air-conditioning systems as status symbols, although, as we have noted, the Japanese government classifies these devices as "luxury consumer goods."

"When do you use your air conditioner?"

Residents were asked to report their customary use of the heat pump systems under a variety of circumstances and times of day. Although most respondents contend that their systems are needed and provide superior levels of comfort, they also tended to mention the sorts of limited-use strategies reported in other locales.

"Cooling when you feel hot"

Figure 10 shows the range of actions that residents take to control the indoor climate when they feel hot. Eighty percent of them open a window first, while only 5% turn on their air-conditioning first. Seventy percent start cooling second. Responding to another question, not shown on the Figure, 30% say that they cool their rooms only for visitors or members of the family. These cooling preferences and strategies offer a concrete expression of residents' statements that a natural indoor climate is better than air-conditioning. They suggest a disciplined use of air-conditioning in which machine-cooling is resorted to when other approaches are inadequate.

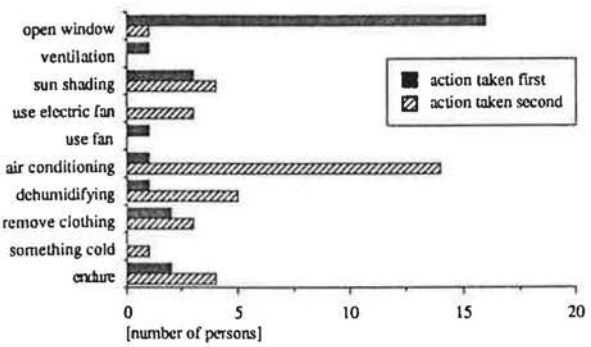


Fig. 10. Cooling strategies reported.

"Cooling when you go to bed"

Only one resident uses the air conditioner while asleep. Forty-five percent reportedly never use their air conditioners at night, while the remaining 40% use timers to shut off the air-conditioning after they are asleep.

"Opening windows before going to bed"

Only 21% of the residents report leaving their windows open during the night. This has been the dominant traditional cooling pattern, and is still widely practiced in rural areas where houses stand at a distance from one another. In urban areas this is much more difficult. About 85% of the residents express concerns about leaving their windows open at night. Forty-five percent of the residents are afraid of peepers or burglars, while another 40% complain of dirty air or noise from outside coming through open windows.

"Cooling when you get up"

Eighty percent of the residents don't use their air conditioner when they get up in the morning. They think that this practice is not particularly healthy and that it is comfortable enough without artificial cooling in the morning.

"How do you control your air conditioner?"

Figure 11 presents the residents' reported operation of their control switches. When the residents feel warm, although their air conditioner is already operating, 85% of them use the "thermostat" control, lowering its temperature setting. Only 10% report using the "fan control" button. The thermostat control is the more familiar control. A better understanding of these control data will require further study of how Japanese users understand their systems' operations, and of the variety of strategies that they use to control those systems. We have no indication from these data about the extent to which persons adjust their thermostat settings, or

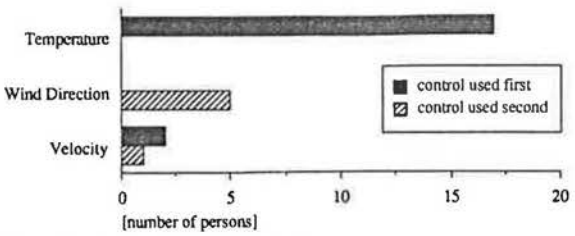


Fig. 11. Control first selected.

whether they attempt to optimize comfort, control, energy efficiency, or any other value.

"What will you do if required to use controls that you do not understand?"

Because controls for Japanese residential heating/air-conditioning systems are so sophisticated, we suspected that residents might not use all of these controls, and that some persons might not understand all of their control options. This was, in fact, the case. Only 25% reported using every control. A suggestive finding is that all of these respondents are male. Thirty percent of the residents use subsets of the controls in ways that they assume to be correct, while 35% said that they would look at the instructions before attempting to change system controls. Without making any claims of representativeness for this sample, it is interesting to note that five of the six residents who exercise limited control of their heat pump systems without reference to written instructions are women, while the seven residents who consult the instructions are evenly divided between men and women. The two elderly residents both say they ask someone else how to adjust the system. Our findings of gender and age effects are inconclusive, but they warrant further investigation. We should not be surprised to find that air-conditioning technologies are implicated in gendered and age-graded cultural systems. Elements of material culture (e.g., various types of clothing, hand tools, machines and other artifacts) have been commonly found to have age- and gender-specific associations across a variety of cultures.

The key findings of this preliminary study, however, are our observations of a wide variation in the use of system controls, evidence of a potentially widespread lack of knowledge of how these systems can be operated (in what we would expect to be a more-sophisticated-than-average sample), and indications of some interesting differences between individual users in their dependence upon, and regard for, written instructions. We have found, and might well expect to find in larger and more representative samples, evidence of limited use of the growing number of features available on heat pump systems.

Conclusions

We have attempted to acquaint non-Japanese technologists and energy researchers with Japanese heat pump air-conditioning systems, especially those with new forms of automatic and intelligent controls. We have also tried to supply some information about the cultural and environmental contexts within which this technology has developed, acknowledging at the same time that unexamined market factors and decisions of manufacturers and pre-existing technology have undoubtedly influenced the development of these systems. We have described the systems and their conventional controls in some detail, and have considered three sets of new automatic features that (1) remove the thermostat from the user's control, (2) establish normative standards for environmental conditions that are selected by designers rather than users, and (3) reproduce natural cooling wind patterns inside the dwelling. These innovations in machine intelligence direct attention to the implications of this technology, including the potential for conflicts between demands for greater user control and more automatic features — demands that have been addressed by supplying users with both sorts of control in a single remote controller.

When the beliefs, technological competencies and cooling behaviors of a small sample of Japanese residents were considered, it was found that these residents valued natural over artificial cooling, but found the latter necessary in urban environments. Still, they reported that they were sparing in their air-conditioner use, opening windows and pursuing other natural cooling strategies before using their heat pump units. While half of those surveyed had heat pump units that could be used as heaters, only about one-third were actually being used for that purpose. A majority reported that they did not understand or use all control options on their machines. When asked how they would adjust their systems in ways that might require them to use unfamiliar controls, about one-third said they would consult printed instructions, while another third said they would attempt to adjust the systems using trial-and-error methods.

While these findings were produced by a small sample, this group of respondents might be expected to be technologically literate and appreciative of the ease and comfort supplied by heat pump cooling. Contrary to those expectations, the respondents expressed a preference for natural cooling, claimed only limited use of their heat pump systems, evidenced a lack of complete understanding of system controls, and were reluctant to consult accompanying literature. Further study of interactions of user, machine and instructions (written and spoken) seems warranted. On the basis of these preliminary findings, however, we would argue that heat pump controls should be designed to be easily understood by users, without requiring them to read detailed instructions. Energy savings might also result if

residents better understood how to efficiently control their systems.

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