# A New Environmental Control System Responsive to the Preferences of All Building Occupants


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We have created an indoor environment control system that can collect the temperature preferences of every person in the environment and modify the HVAC settings appropriately. In this paper we describe the installation of the system in an office building, analyze occupants' use of it, and present the results of questionnaires. Over 90 % of occupants found this system of air conditioning to be acceptable. Since the number of conflicting temperature reports (I feel hot / I feel cold) by an occupant within 30 minutes of an initial report was very small, we conclude that the occupants accepted our method (later comes has the priority) of responding to temperature preferences.


## 1. Introduction

The degree of environmental satisfaction affects the productivity of office workers. The higher the degree of satisfaction with the environment, the higher the work performance and the less fatigue. In addition, a higher degree of satisfaction has been reported, even under the same temperature conditions, when people can adjust the environment by themselves [1] [2] [3]. However, if everyone is allowed to set the temperature to improve their own degree of satisfaction, an appropriate temperature may not be set because of individual preferences for an extremely low temperature, for example, leading to the discomfort of other people and wasted energy.

In order to solve these problems, building occupants can be allowed to report their temperature sensations along the lines of "I feel hot" or "I feel cold" instead of setting a desired room temperature. We have developed a new environmental control system that sets and controls the indoor temperature with the aim of satisfying everyone's temperature preferences. This system is called "temperature sensation air conditioning."

## 2. Overview of System

First, the system configuration and basic operation of the system are described.

### 2.1 System configuration

The system design is based on a cloud-computing tenant services function already provided by Azbil Corporation. We developed a prototype of a dedicated input device in the form of a card for this application.

#### 2.1.1 Cloud-based tenant services

Azbil's cloud-based tenant services include functions such as inputting the temperature setting for the air conditioning and setting a schedule from a web browser screen. Using the temperature sensation air conditioning, occupants can select a function that allows them to enter their subjective feeling of the temperature instead of using a temperature setting function. In other words, building occupants enter their feelings on a web browser screen (fig. 1) by indicating "I feel hot" (AC please!) or "I feel cold" (Heat please!) instead of a conventional temperature setting.

Fig. 1.  Dashboard of the tenant services function

In the cloud-based system, a server, which processes the reports from the occupants, is located in the cloud (fig. 2). As input devices, in addition to ordinary PCs, smartphones are envisioned, with a specially designed screen (fig. 3).

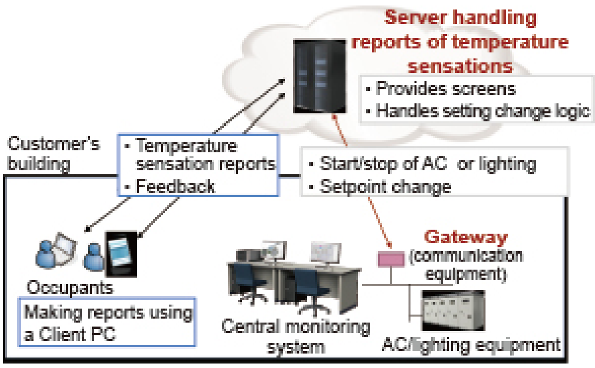



Fig. 2.  Configuration of a cloud-based system

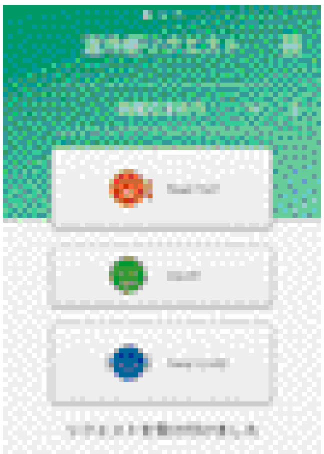


Fig. 3.  Example of screen for the smartphone

### 2.1.2 System using a dedicated input card

Using a PC or smartphone as an input device would result in rather complicated operation, including starting up the browser, logging in to the system, specifying one's location, and pressing the request-sending button. Although it is possible to shorten the operations to some extent by adding a function to identify the location, etc., there are limitations, such as the necessity for login, that cannot be omitted for reasons of security. Accordingly, we developed a prototype of a dedicated input card device that enables one-press action to send a report immediately whenever desired (fig. 4). Requests are transmitted from the card through a receiver using a communication method called BLE.*1 So that individuals can carry the card in a card holder with their employee ID card, etc., it is smaller than a credit card, measuring only 70 × 35 × 3.3 mm. Additionally, it is designed for intuitive operation. For this card-based system, the receiver and the AHU are paired. When a request is transmitted, the settings of the AHU corresponding to the receiver that receives the strongest signal will be changed. In this way, office workers can transmit their temperature sensations to the nearest AHU without being aware of the location of the AHU.

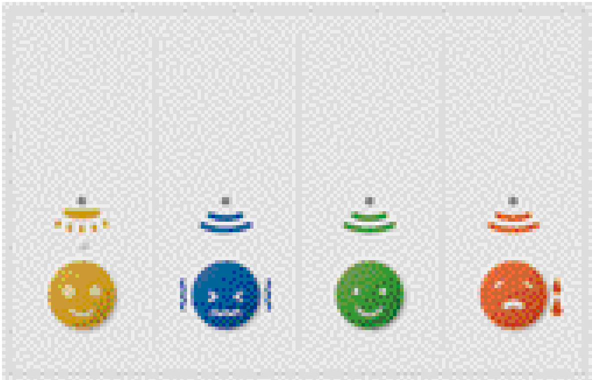


Fig. 4.  Specially designed input card device

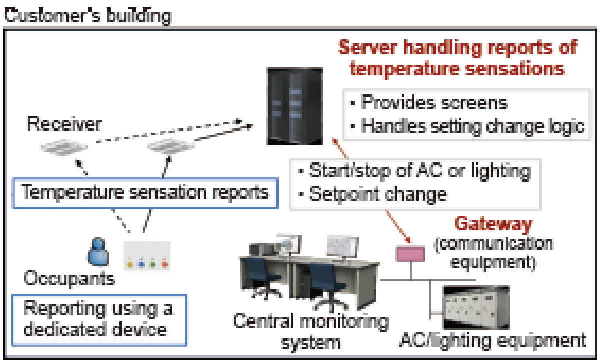



Fig. 5.  System configuration for the input card

In this system, it is necessary to install receivers in the ceiling of the building. Therefore, as shown in figure 5, the server used for computing, including processing of the received signals, should also be installed in the building. If visualization of the results or configuration screens for the users is necessary, data is exchanged with the cloud system. The system provided to customers can be changed according to their desired method of environment control.

*1. BLE (Bluetooth® Low Energy) is a communication method designed to provide lower power consumption and lower cost communication and implementation than Bluetooth.

### 2.2 Environmental control system responsive to everyone's preferences

#### 2.2.1 How preferences are handled

Figure 6 shows the method of changing the temperature setpoint when a user indicates "I feel hot." After the reported feeling is received, the indoor temperature setpoint is greatly decreased temporarily (No. 1 in fig. 6), and then the temperature is set to the predetermined value (3 in fig. 6). By changing the temperature greatly and maximizing the airflow volume, the office workers' reports can be handled immediately.

If two or more people make contradictory "I feel hot" or "I feel cold" reports, the later one has priority. The method of taking a majority vote over a certain period of time is also possible, but in that case immediate response capability would be sacrificed. In the case of VAV*2 air conditioning equipment that adapts this system, since there is no possibility that a particular spot will be hit with extremely hot or cold airflow, it is unlikely that contradictory reports will simultaneously occur in the same air conditioning area. Therefore, priority is given to quick responsiveness, and the priority is given to the latest reports.

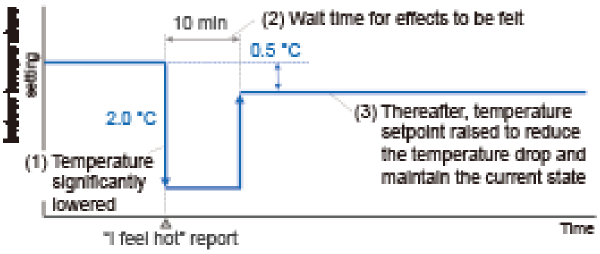



Fig. 6. System behavior for "I feel hot"

#### 2.2.2 Weighing the reports

After meals or when returning to the office from outside, metabolic rate rises and people often feel temporarily hot. If the temperature setpoint is lowered to respond to an "I feel hot" report generated by someone at such a time, it is likely that people will feel cold when their metabolic rate decreases. Therefore, it is necessary to determine whether the reported feeling is temporary or ongoing. If it is temporary, one of the system's functions resets the temperature setpoint to the original value after a certain period of time elapses. There are two methods of determining whether the reported feeling is temporary or ongoing. One uses environmental data and the other uses the period of time when the report is made. These two methods can be used in combination.

A simple example of the decision process using environmental data is shown in figure 7. The decision is based on the discomfort index (temperature-humidity index). In this example, to make the explanation easier to understand, the method will be explained using temperature. First, the threshold temperature to be used for judgment should be set in advance. In a hot environment where the room temperature is higher than the threshold, if someone reports "I feel hot," it will be judged as an ongoing feeling. Conversely, in an environment where the room temperature is already low, a reported "I feel hot" feeling is judged to be the temporary feeling of a specific person.

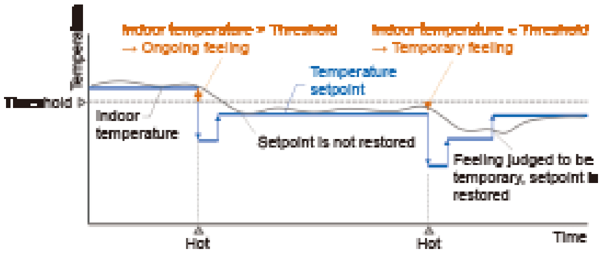
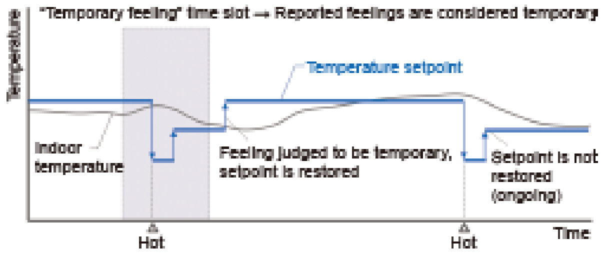



Fig. 7. Judgment of reported hot/cold feeling as ongoing or temporary based on environmental data

A simple example of decision-making based on the period of time is shown in figure 8. A reported feeling during the period of time when metabolic rate changes temporarily due to people's behavior, such as immediately after coming to the office or after lunch, is judged to be a temporary one. The periods of time are set individually for each building by the building administrator.




## 3. Trial Operation

Since August 2015 the system has been in use in building 100 of the company's Fujisawa Technology Center, where the number of occupants is about 1000. The effectiveness of the new system can be evaluated based on the reports made by the occupants and the results of questionnaires.

Fig. 9. Building 100

Table 1. Basic building information

| | |
|---|---|
| Building | Building No. 100, Fujisawa Technology Center, Azbil Corporation |
| Use | Office building |
| Area | 2810 $m^2$ |
| Total floor space | 17918 $m^2$ |
| Occupants | Approx. 1000<br>(the card-type input device is used only by the approx. 200 occupants on the 4th floor) |
| AC method | VAV*2 central air conditioning<br>Approx. 2000 $m^2$, 4 AHUs, 16 VAV zones per floor |

*2. In a variable air volume air conditioning system, indoor temperature is controlled by changing the volume of airflow for each zone.

### 3.1 Response of occupants

The results of an analysis of occupant questionnaires are shown below. First, figure 10 shows the result of asking whether an air conditioning system requesting the preferences of occupants is better than the conventional one. A large majority of 94 % of the occupants answered that they thought it was better. There were some answers along the lines of “It is good to be able to operate the system according to the feeling on my skin,” or “Since hot or cold feeling depends on the individual, it makes sense to ask individual preferences.” It can be said that the method of controlling the environment in response to individual preferences as done by this system is accepted by building occupants.

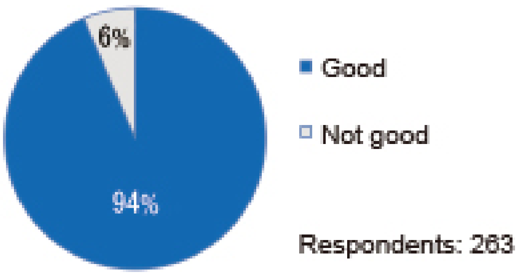



Fig. 10. Air conditioning responsive to individual preferences

For occupants who reported their feeling about the temperature using the system, we asked if the system reacted as expected and if the environment improved. As shown in figure 11, 59 % of the respondents answered that there were cases of improvements. On the other hand, 12 % of the respondents answered that there was no effect. Since the system changes the temperature setpoint depending on the reports, there will be cases where no improvement can be observed, such as when the air conditioning system is already operating at maximum capacity. It is desirable to give occupants feedback on how the system responded to their report.

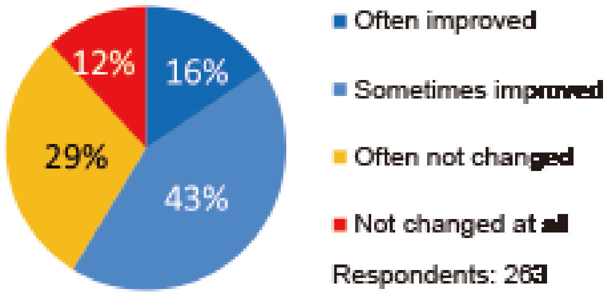



Fig. 11. Responses to reports

Also, figure 12 shows how the respondents felt about responses to reports made by others. The majority (84 %) answered that they did not care or know about the responses, and 9 % answered that they were happy when others reported instead of them. So, adding 84 % and 9 %, over 90 % of the respondents were not bothered by setting changes made by others. Only 3 % of respondents were dissatisfied with the setting changes made by others, so for the most part questionnaire responders who did not actually operate the system accepted the environment without dissatisfaction.

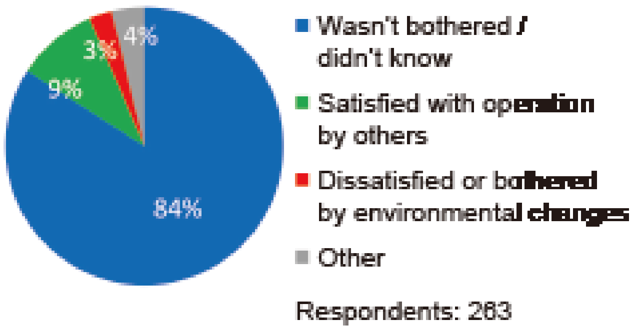



Fig. 12. Reports made by the others

Finally, regarding plans for future operation, we asked occupants whether they preferred air conditioning responsive to reported preferences or the conventional operating method (changing the temperature setpoint using an input device on the wall). In total, 58 % of the respondents preferred the air conditioning responsive to reported preferences, and 8 % preferred the conventional method, so the former opinion was decidedly dominant. The results shown in figure 13 are categorized according to whether or not the questionnaire respondent had operated the system. Of the respondents, 65 % of the persons who had operated the system and 50 % of those who had never operated it view the system positively. Occupants favored it because the system can be controlled based on their preferences or because it can be controlled from their desk.

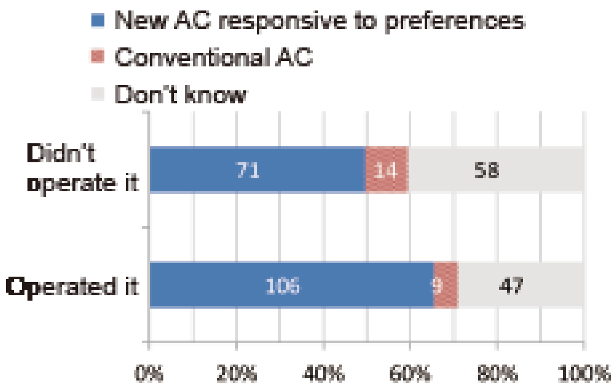



Fig. 13. The new method vs. the conventional method

### 3.2 Trends in reports

The reports from occupants were analyzed. Figure 14 shows the number of reports per month and the average outdoor temperature in terms of the report type (“hot” or “cold”). The data was gathered only from the fourth floor, where card-type input devices were used. There is a tendency for the number of reports to increase in the summer season when the outdoor temperature is high. Overall, it can be seen that there are many “I feel hot” reports. It is understandable that there are differences in the tolerance range for temperatures, because it is easier in the “cold” case than in the “hot” case to cope with the temperature by adjusting the clothing.

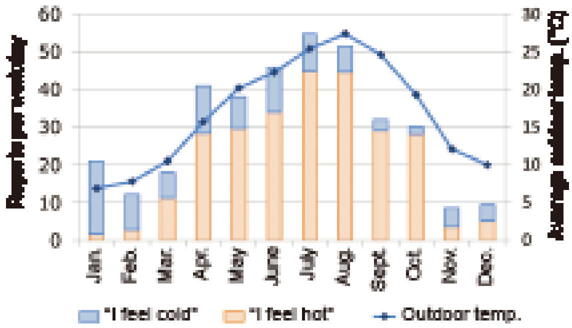



Fig. 14. Trends in the number of reports

As stated above, later reports have priority for changing the temperature setpoint. When the “I feel hot” and “I feel cold” reports occur at the same time due to differences among preferences, the temperature setpoint may not be changed as occupants desire. We investigated the frequency of such cases. As shown in figure 15, within an individual air conditioning area, we checked the ratio of reports (“hot”/“cold”) that were different from the preceding report. For all reports, 88 % or more were the same as the last report, and the percentage of different reports that occurred within 30 minutes of each other was only 3 %. Therefore, it is unlikely that contradictory requests will occur within a short time with a VAV air conditioning system, and it will be rare that the air conditioning system operates against the desires of occupants, even when the priority is given to the later report.

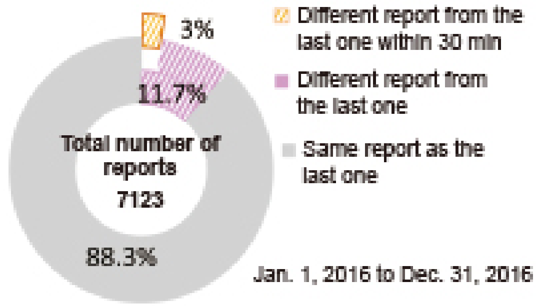



Fig. 15. Occurrence of reports that differed from the previous one

Although the system is designed to appropriately change the temperature setpoint according to occupants’ reports, it is also possible to provide a comfortable environment if the system understands which way the reports are trending and can create an appropriate environment even before a report is made. In order to understand the occurrence of reports and trends in reports, the correlation between the time when the requests occurred and the number of requests was investigated for three periods, summer (June to September), intermediate months (April, May, October, and November), and winter (December to March). Figures 16 to 18 show the results. In building 100, work begins at 8:30 and lunch is from 12:00 to 12:45. The building is located 15 minutes on foot from the train station, and many people come on foot.

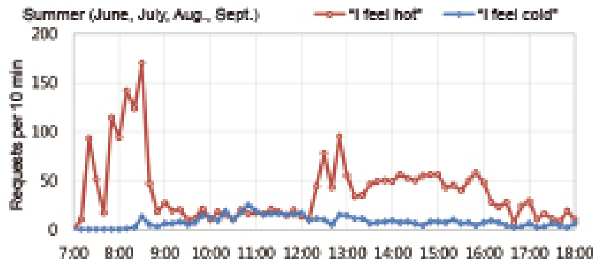



Fig. 16. Time vs. number of requests (summer)

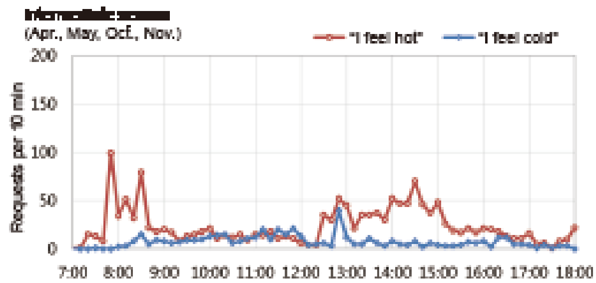



Fig. 17. Time vs. number of requests (intermediate months)

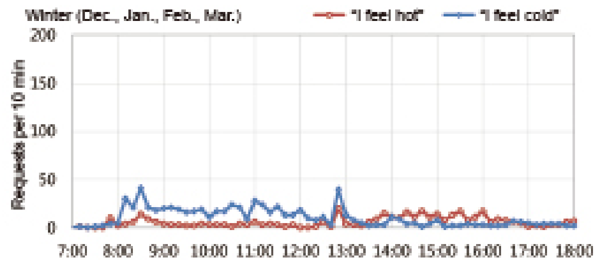



Fig. 18. Time vs. number of requests (winter)

In the summer, there are many “I feel hot” reports around 7:30–8:30 before work begins and after lunchtime. In the intermediate period also there are more reports after people commute and after lunch until 15:00, although to a lesser extent than in the summer. Therefore, setting the indoor temperature lower at the start of work and after lunch, during the period when metabolism goes up, will lead to improvement in the comfort of occupants. In the winter, the number of reports decreases, but there are many “I feel cold” reports in the morning. On the other hand, around 14:00, the number of “I feel hot” report increases. Accordingly, it is better not to raise the indoor temperature too much in the morning.

Although the trends for an entire floor are shown here, we have found also that trends differ for each air conditioning area. In order to create a space that is more comfortable for the occupants, we are planning to provide a systematic control method that considers factors such as unevenness of temperature and differences in outdoor temperature for different air conditioning areas.

## 4. Conclusions

We have implemented, in an existing building, an air conditioning system controlled by the expressed preferences of occupants, developed to improve their environmental satisfaction, and we investigated the occupants’ reactions. Occupant questionnaires found that 94 % of occupants found this system of air conditioning to be acceptable. Regardless of whether or not the occupants actually operated the system, a large number of them preferred it to a conventional system.

Since the number of conflicting temperature reports (“I feel hot” or “I feel cold” by occupants within 30 minutes of the previous request was very small and a high percentage of the reactions to system responses to the reports of others were “It didn’t bother me” / “I didn’t know” or “I’m glad they did it for me,” we conclude that the occupants accepted our method of prioritizing the latest temperature reports.

As a next step, we will develop a mechanism to feed back the results of a report to the individual occupant and to the administrator, and a mechanism that learns from trends in reports in order to provide a comfortable environment prior to receiving reports. Based on the results of one year of system operation, we confirmed that reports of feeling hot tend to increase at the start of work and after lunch in the summer and intermediate seasons, and in the afternoon during the winter.

Since this system of air conditioning that is responsive to the preferences of occupants was well accepted by building occupants, we are confident that it contributes to the improvement of occupants’ comfort. In the future, we intend to continue developing products that contribute to the increased comfort of building occupants, in keeping with the azbil Group philosophy of “human-centered automation.”

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