Development of a Home Indoor and Outdoor Environment Visualization System

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ABSTRACT

In recent years, HEMS (Home Energy Management Systems) have garnered attention as an energy-saving measure, and are being adopted in an increasing number of cases in smart houses and smart apartment complexes. As the name indicates, their main focus is energy management functions such as operation/control of appliances, and measurement/display of electric power. On the other hand, adjustment/maintenance of the indoor environment is an important factor for comfortable living in the home, but it is extremely unusual for indoor environment characteristics such as temperature and humidity to be displayed. Therefore, the authors' laboratory has previously developed an "indoor and outdoor environment visualization system" as a means of raising interest in the indoor thermal environment, and promoting use of passive technology suited to the skills of the resident and the season. Energy-saving effects and effectiveness in improving the indoor environment have also been confirmed through trial operation in housing complexes.

As the next step in development, for this report the authors improved the versatility of the equipment by packaging devices more compactly, and developed a system with additional innovations in sensing items and information transmission techniques to take into account factors of health and safety. The utility of the system was verified, and issues identified. In the means for transmitting information, small LED light which color and blinking changes with indoor environment was incorporated. From the results of test installation of this kit in a number of houses, passive activities were promoted and the effects of improvement of indoor environment were confirmed.

Keywords: *energy saving, indoor environment quality, HEMS*

1. INTRODUCTION

In recent years, HEMS (Home Energy Management Systems) have garnered attention as an energy-saving measure, and are being adopted in an increasing number of cases in smart houses and smart apartment complexes in Japan. Japanese government aims to put HEMS into every home in Japan until 2030. As the name indicates, their main focus is energy management functions such as operation/ control of appliances, and measurement/display of electric power. On the other hand, adjustment/maintenance of the indoor environment is an important factor for comfortable living in the home, but it is extremely unusual for indoor environment characteristics such as temperature and humidity to be displayed. Therefore, the authors' laboratory has previously developed an "indoor and outdoor environment visualization system" as a means of raising interest in the indoor thermal environment, and promoting use of passive technology suited to the skills of the resident and the season. Energy-saving effects and effectiveness in improving the indoor environment have also been confirmed through trial operation in housing complexes.

As the next step in development, for this report the authors improved the versatility of the equipment by packaging devices more compactly, and developed a system with additional innovations in sensing items and information transmission techniques to take into account factors of health and safety. In this research, the result of a subject experiment using that visualization system kit were reported.

2. OVERVIEW OF INDOOR/ OUTDOOR ENVIRONMENT VISUALIZATION SYSTEM KIT

Based on the results of previous operation experiments using a prototype system, the authors developed an indoor environment visualization kit that can be easily installed in existing homes. The main concepts are indicated below.

- Improved awareness of the indoor/ outdoor environment (Measurement items and screen innovation)
- Health and safety warnings (Heat stroke alerts, etc.)
- Convenience of installation (Can also be installed in existing homes)
- Power-saving design (Long-term drive using batteries)
- Simplification of data gathering (Use of Internet line in each home)
- Screen for comparison between homes (Continuation of interest)

Figure 1 shows the configuration diagram of the system. It was decided to adopt the following measurement items for the prototype kit: (1) Indoor temperature/ humidity and globe temperature, (2) Wall/ floor surface temperature (radiation temperature), (3) Carbon dioxide concentration (+ temperature/ humidity), (4) Dust concentration, (5) Outside air temperature/ humidity, and (6) Electric power consumption (main + 2 branches). It was decided to adopt specifications making it possible to ascertain the indoor vertical distribution of temperature by installing the sensor terminals for (1) – (3) at three different heights (high, medium, low). (1) – (4) are installed in a typical room (living room), and in addition one more sensor terminal for (1) was prepared for installation in any desired room by the resident. Measurement of the thermal environment is conducted every 30 seconds, and measurement of electric power every minute. In addition, the view count is collected for each page.

The indoor environment and electric power consumption are sent from each wireless base unit to a web server via the in-home Internet line, and the data is processed into easy-to-view graphs and the like. These can then be viewed from a smartphone or PC. An existing product was used as the power consumption measurement device. Compact boards (Arduino) were used for the sensor terminals newly developed and fabricated this time, and ZigBee communication was used as the communication standard with the system's base unit (Raspberry Pie). Power-saving design was carried out for each board, and dry cell drive was adopted in the sensor terminals for (1) and (5).

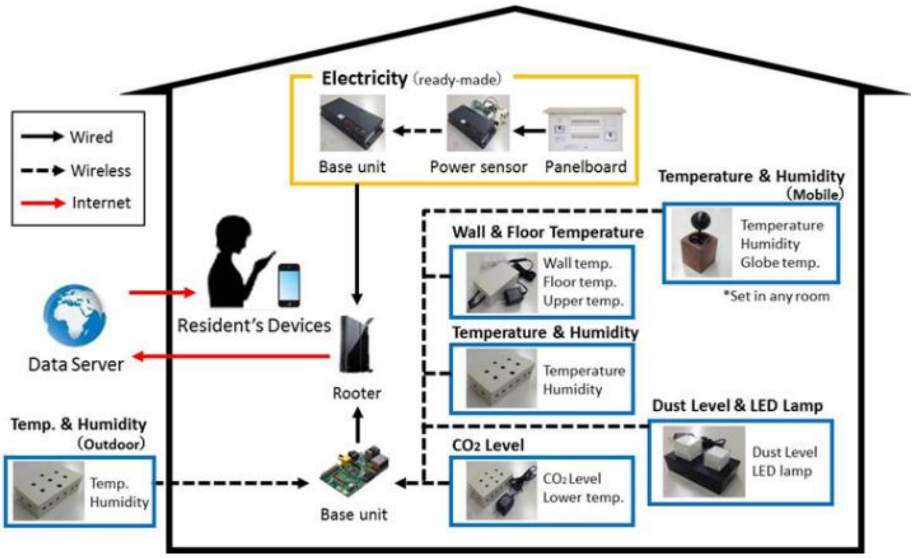

Figure 1: Configuration diagram of the system

Figure 2 shows the functions of the "LED lamp indicator" which is a major distinguishing feature of this system. This indicator provides a real-time display of the measured indoor/outdoor temperature information using the color level of an LED lamp. This allows the user to intuitively ascertain the indoor/outdoor thermal environment even without looking at a smartphone or other device. In addition, the system has a function to enable display of various alerts for ventilation, heat stroke and dryness using a flashing LED display when measurements of temperature/humidity, CO_2 concentration or other values exceed a fixed threshold. Internally, the system has a built-in dust concentration sensor.

Figure 3 shows a sample screen from the "Uchi-Repo" viewing site. The home screen displays the weather forecast for 3 days starting today and real-time values for measurement data, and the system is designed so that information on the indoor environment can be understood at a glance. At the room temperature screen, graphs are displayed of the indoor temperature, window/floor surface temperature, vertical distribution of temperature, and outside air temperature, and at the humidity screen, graphs are displayed of the indoor humidity and outdoor humidity. This enables indoor/outdoor comparison, comparison of times series for 1 week from the current day, and so forth. Time series graphs are also displayed for CO_2 concentration and electric power consumption. Also, using the comparison screen, it is possible to compare the indoor environment and electric power consumption with other households, and to ascertain the whether the indoor environment in the home is good or bad, and where power usage is high or low. The system is designed so that an LED flashes simultaneously when sensor measurements exceed fixed thresholds, and warnings on ventilation, heat stroke, and dryness are displayed on the home screen of the "Uchi-Repo" site. This helps promote quick response. To ascertain differences in the sense of heat/cold in each household, a function is also provided to enable reporting of the current degree of comfort.

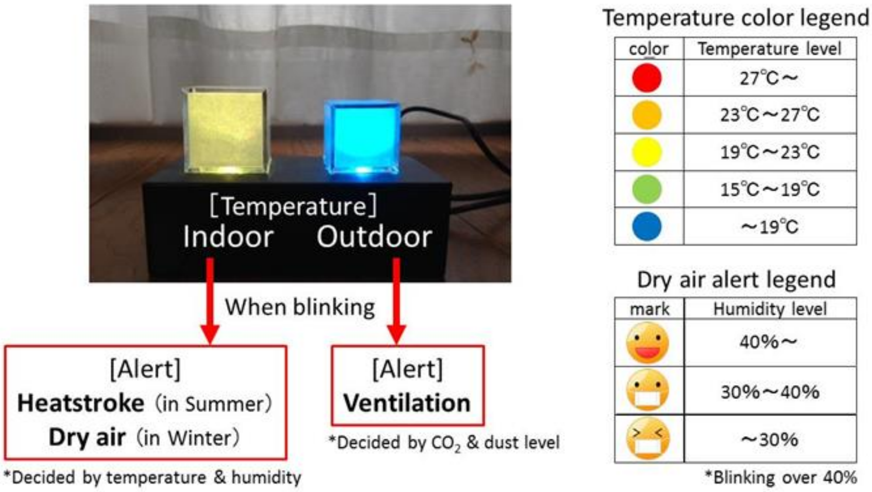

Figure 2: Functions of the "LED lamp indicator"

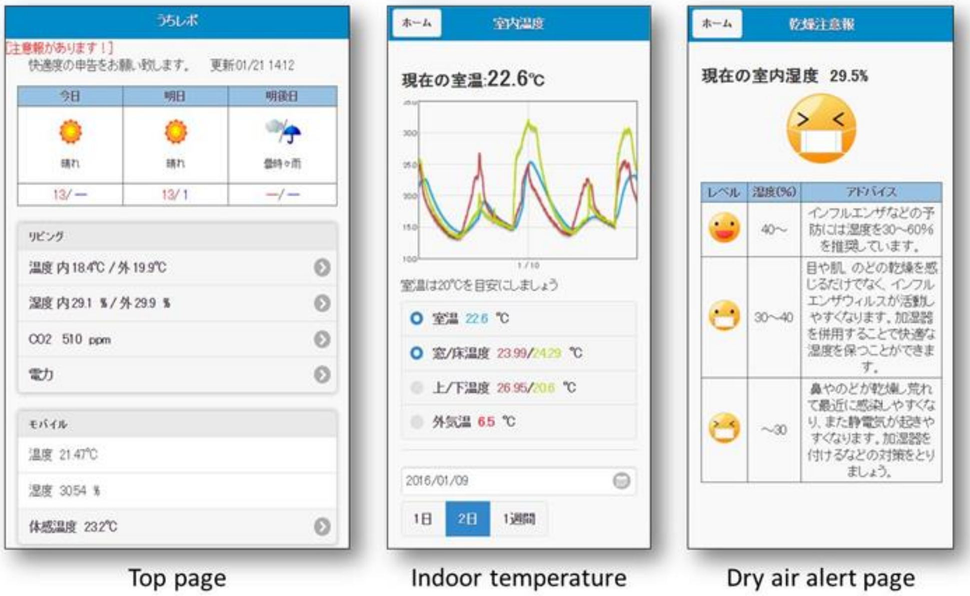

Figure 3: Sample screen from the "Uchi-Repo" viewing site

3. SUBJECT EXPERIMENT USING VISUALIZATION SYSTEM KIT

3.1 Overview of experiment

Table 1 provides an overview of the homes for the subject experiment. Experiments were conducted by installing 4 of the systems improved and developed in the previous section in 4 households. Data was only collected for about 1 week subsequent to installation of the equipment. After that the viewing site "Uchi-Repo" and how to use it were explained, and then data was collected again for 1 week while performing visualization. The experiment period was November 11 – 25, 2015, at the start of winter. After the experiment was finished, a questionnaire survey was administered regarding how the subject usually spends the same period each year, changes in awareness due to system adoption, and views on the system itself.

	Location	Number of residents	House type	Construction type
A	Machida city, Tokyo	5	Detached house	Wood
B	Hiratsuka city, Kanagawa	5	Detached house	Wood
C	Machida city, Tokyo	4	Detached house	Wood
D	Saitama city, Saitama	4	Apartment	RC

Table 1: Overview of the homes for the subject experiment

3.2 System viewing and evaluation

Figure 4 shows screen viewing counts for each day and time band in each household, and Figure 5 shows the viewing percentage for each type of screen. It is evident that there are differences in the view count and percentage depending on the lifestyle, interest and concern of the subject. As can be seen, in homes with a high view count (A and D), viewing is done periodically in the morning in A and in the evening in D. From Homes B and C with a comparatively low view count, comments were obtained on the questionnaire such as "the graph screens are hard to see" and "the information I want to see is hard to understand." In terms of screen types, the percentage for the "home screen" where the full set of real-time data can be viewed is high for all households, and it is presumed that interest is high in current value data on the thermal environment and amount of electric power. The "comparison screen" received the next most views. In this regard, there was a comment that "it is interesting to compare with other households."

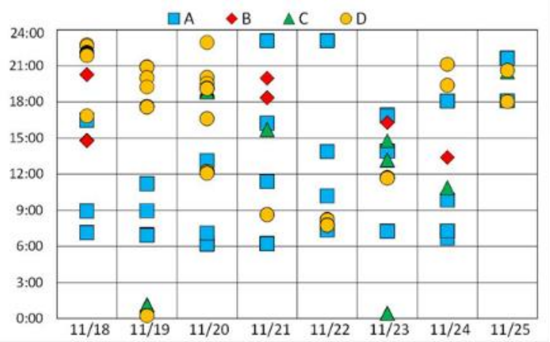

Figure 4: Screen viewing counts for each day and time band

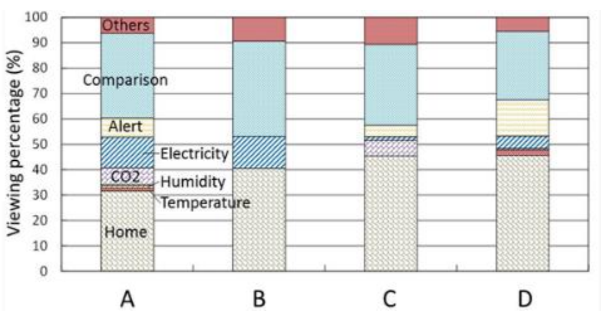

Figure 5: Viewing percentage for each type of screen

3.3 Changes in environment awareness due to visualization

Table 2 shows results regarding the changes in environmental awareness of each household according to the questionnaire. In all households, the item "I began to worry about ventilation" pertained often, and this can be regarded as confirmed by the results of interviews indicating that the subjects periodically engaged in the ventilation behavior of opening/closing doors and windows while looking at the flashing display of the LED lamp. In households where power consumption decreased, it was confirmed that subjects began to worry about use of the TV and other appliances, but it was ascertained that bothersome techniques such as unplugging generally were not translated into action even if they were effective. In addition, among households which responded that they became able to predict the current temperature and humidity, they all responded that information communication using an LED lamp is effective. In addition, there were also comments such as "I confirmed with the LED color that maybe the current room temperature was too cold for children," and "I determined the timing for using heating based on the LED color." This can be regarded as confirming that this sort of visual device has high potential to aid in proper prediction and regulation of the indoor environment.

Classification		Questionnaire list	A	B	C	D	Point
Temperature	a	I began to worry about temperature control.	○	△	△	△	5
	b	I learned to be able to predict current indoor temperature.	○	×	○	○	6
	c	I learned to be able to know my comfortable temperature.	○	△	×	○	5
	d	I could control indoor temperature without heating.	○	×	×	△	3
	e	I began to get sunlight from the window.	△	○	△	○	6
	f	I began to worry about opening and closing curtains.	△	×	△	○	4
Humidity	g	I began to worry about humidity control.	○	×	△	△	4
	h	I learned to be able to predict current indoor humidity.	△	×	○	○	5
	i	I could control indoor humidity without humidifier.	×	×	×	△	1
Ventilation	j	I began to worry about ventilation.	○	×	○	○	6
Indoor climate	k	I began to worry about indoor climate from the outside.	×	△	×	○	3
	l	I began to worry about indoor climate before going out.	△	△	×	△	3
	m	I began to worry about indoor climate before going to bed.	△	△	△	△	4
Electricity	n	I began to worry about using appliances.	○	○	△	○	7
	o	I began to reduce wasteful electricity use.	○	○	△	△	6
	p	I began to turn off the TV when no one is watching.	○	○	○	○	8
	q	I began to disconnect the plug of unused appliances.	△	○	×	△	4
LED lamp	r	I did environment control behavior by LED lamp indicator.	○	×	○	○	6

Table 2: Questionnaire results regarding the changes in environmental awareness

4. EFFECTS OF IMPROVING INDOOR ENVIRONMENT

4.1 Passive techniques

All of the households have a custom of shutting curtains at night and opening curtains to let in light, and no practical actions were seen based on an understanding of the effects of direct gain and heat accumulation. Also, during the period of the experiment, the air temperature was comparatively high, and this may be one reason why passive behaviors were not actively carried out. However, based to the questionnaire results, it can be said that the system provided greater awareness and interest in the indoor environment, such as "I was able to adjust my clothing to suit the temperature by viewing the LED lamp" and "I noticed the difference between my body temperature and the actual temperature."

4.2 Ventilation behavior

Figure 6 shows changes in CO_2 concentration and CO_2 screen viewing on the 18th at Home A and the 23rd at Home C. At Home A, the living room is used for sleeping, and the CO_2 concentration rises to a high level at night. It is presumed that, due to the flashing of the LED lamp every morning, the subjects viewed the CO_2 screen, and this was connected with periodic ventilation behavior. In Home C too, it was confirmed from the questionnaire that the subjects viewed the CO_2 screen and shifted to ventilation behavior when they noticed flashing of the LED lamp.

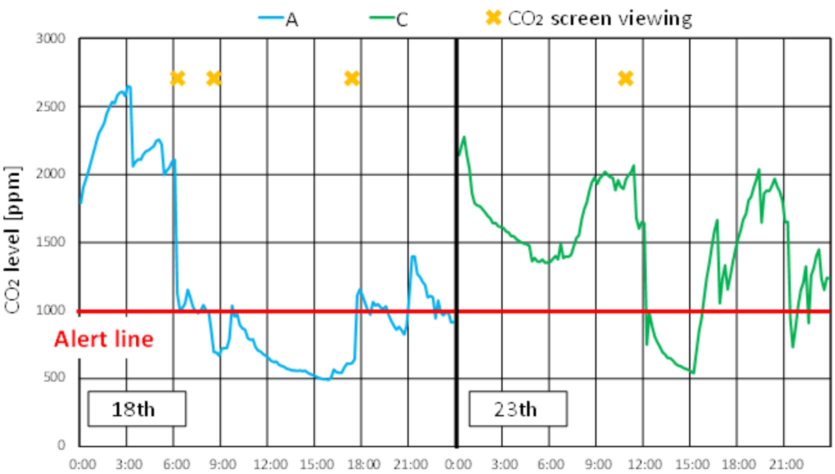

Figure 6: Changes in CO_2 concentration and CO_2 screen viewing

4.3 Energy consumption

Figure 7 shows the daily average of electric power consumption before and after adopting the system at each home. This experiment was done at the beginning of winter, but there was still not much use of heating equipment, and partly for that reason no major overall change was evident. However, in households where the rate of viewing the electric power screen was high (Home A), it was possible to confirm a certain degree of reduction.

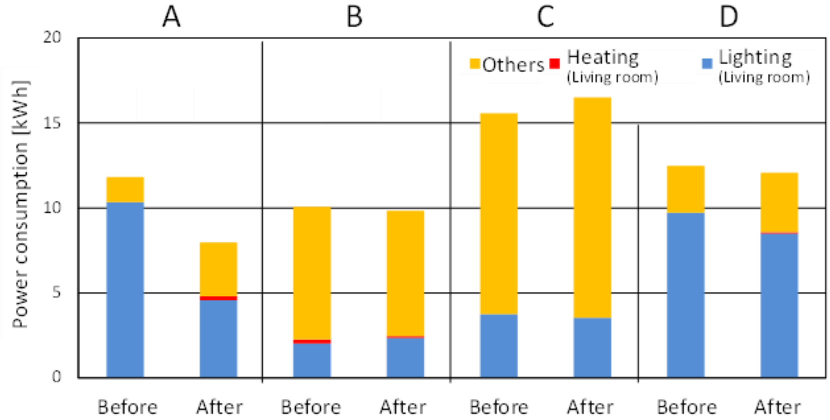

Figure 7: Daily average of electric power consumption before and after adopting the system

5 CONCLUSION

This research is a PILOT project, but the following summarizes the main findings obtained as a result of a subject experiment with the developed kit for visualization of the indoor environment.

- A tendency was evident for use of the system kit to lead to various types of awareness, interest, and concern toward the indoor/ outdoor environment, and cases were seen that were linked with specific passive behavior.
- It was confirmed that the LED lamp indicator promoted routine awareness of the indoor/ outdoor environment in almost all households, and helped to warn about alert items.
- A trend was evident of high interest in the screen comparing with other households.

Going forward, the authors will increase the number of subjects, lengthen the experiment period, conduct detailed verification of the results of improving the environment through communication of information such as warning displays, examine effective comparison screen content, improve to a system and design with less trouble and resistance to installation, and so forth. The author's plan is to proceed with development to make this a system for promoting energy-saving behavior and environment adjustment behavior, and a tool for management of energy consumption, and safety, health and comfort.

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