Experimental Study on Display of Energy-Related Information in Smart Homes Using Virtual Reality

Kodai Ito and Michiko Ohkura

Shibaura Institute of Technology, 3-7-5, Toyosu, Koto-ku, Tokyo,135-8548, Japan
{l09009,ohkura}@shibaura-it.ac.jp

Abstract. Environmental pollution and electrical power shortages are serious issues, especially in Japan recently. Since private households are clearly constitute one of the main energy consumers today, positive effects on the environment can be expected if home energy consumption is reduced. Accordingly, our research purpose is to develop a prototype smart home that can offer "smart" quality of life, QOL, to its residents and reduce both CO_2 emissions and energy consumption. An important issue toward achieving this aim is how to show energy-related information to the home's residents.

As a first step, we perform a preliminary experiment on reducing the numbers of candidates of locations and contents of energy-related information. Next, we perform another experiment to clarify the locations and contents of energy-related information expected to be in demand for display in actual smart homes.

Keywords: Smart home, energy saving, user interface, information presentation.

1 Introduction

Environmental pollution and electric power shortages are serious issues, especially in Japan recently. Since private households are clearly constitute one of the main energy consumers today [1], positive effects on the environment can be expected if home energy consumption is reduced [2]. However, the deployment of automation technologies in the home offers several attractive benefits, among them most prominently increased energy (or even resource) efficiency, improved residential comfort, and the peace of mind of the residents. Accordingly, our research purpose is to develop a prototype smart home that can offer "smart" quality of life, QOL, to its residents and reduce both CO2 emissions and energy consumption. An important issue toward achieving this aim is how to show energy-related information to the home's residents. We conducted interviews and a questionnaire related to the QOL of smart home, and based on the results, we performed experiments to clarify where and how to display energy-related information in a smart home.

N. Streitz and C. Stephanidis (Eds.): DAPI/HCII 2013, LNCS 8028, pp. 294–301, 2013.

2 Results of Interviews and a Questionnaire on QOL of Smart Homes

Our platform consists of two smart homes built in Saitama City in Japan [3]. A family consisting of a father, mother and daughter lives in one of them, and the other is open to visitors (Fig. 1). Based on the results of interviews with the family members and the results of a questionnaire given to the visitors, we found a strong demand to know energy-related information in real time.

Fig. 1. Photograph of smart home open to visitors

3 Preliminary Experiment

3.1 Method

A very important characteristic in a smart home is how easy it is for the residents to check energy-related information. Therefore, the locations and the contents of displayed information should be determined appropriately. However, there are very many possible candidates of such locations and contents. Therefore, we decided to perform a preliminary experiment to reduce the numbers of candidates and thus select the display locations and the contents of energy-related information for the next, main experiment. For the preliminary experiment, we created a virtual reality (VR) space modeled on the CAD data of the smart home open to visitors. The candidates of location are as follows:

1. TV monitor
2. Table in living room
3. Wall next to refrigerator
4. Wall in living room.

Participants were asked to choose at most eight of the following candidates of energy-related information for each location:

A. Amount of electricity generated by solar power
B. Amounts of electricity and heat generated by cogeneration
C. Amount of total electricity generated
D. Amount of commercial electric power consumed
E. Overall power consumption
F. Percentage of power consumption covered by home generation of electricity
G. Heating and lighting costs
H. Electric power-selling rate
I. Remaining home battery level
J. CO_2 emissions reductions
K. Temperature of hot-water supply system
L. Remaining EV car battery level

The VR space was projected to the screen, and the information displayed was changed based on the demands of the participants. Figure 2 shows examples of VR spaces, and Fig. 3 shows a system configuration. After finishing selection of the contents for all locations, the following questions were asked in our questionnaire:

- Do you need a display of each location?
- Are there any places that you want to display other than these candidates?
- Are there any contents that you want to display other than these candidates?

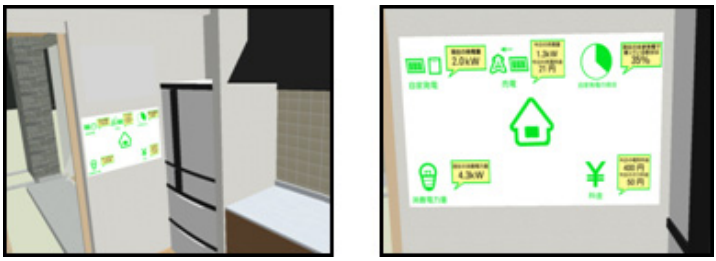

Fig. 2. Example of VR spaces

3.2 Results and Discussion

A preliminary experiment was performed using 12 staff members of our university as subjects.

Figure 3 shows results of preferences for locations of energy-related information. The table in the living room was judged unnecessary. Therefore, we employed the three locations other than the table in the living room.

Figure 4 shows the results for contents. Overall power consumption (E) was judged necessary at every location, but other selected contents varied from location to location. In particular, there was a large difference between Wall next to refrigerator and Wall in living room. This is because usually only the housewife looks at the Wall next to refrigerator. On the other hand, every person visiting this house often looks at

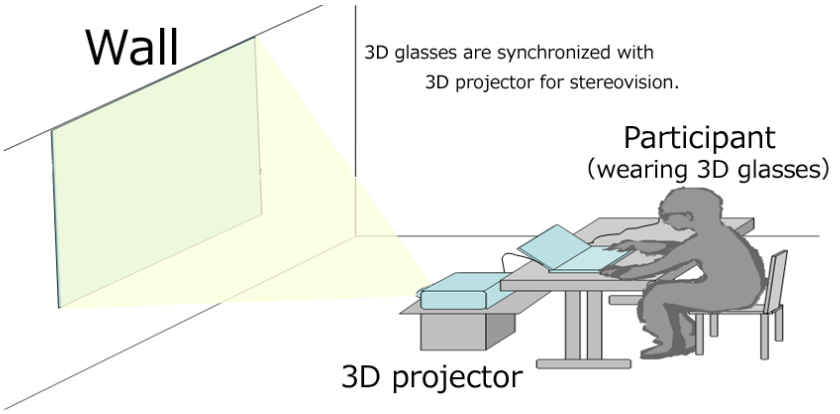

Fig. 3. System configuration of preliminary experiment

the Wall in living room. Therefore, we can conclude that necessary information differs depending on the place and that all candidates of information candidates necessary in some places. Accordingly, we employed all candidates of energy-related information in the next experiment.

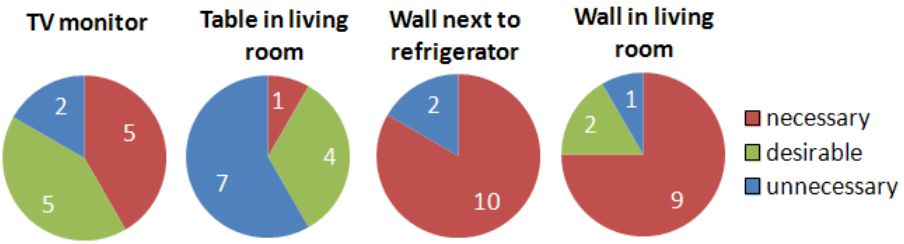

Fig. 4. Results for preferred locations of energy-related information

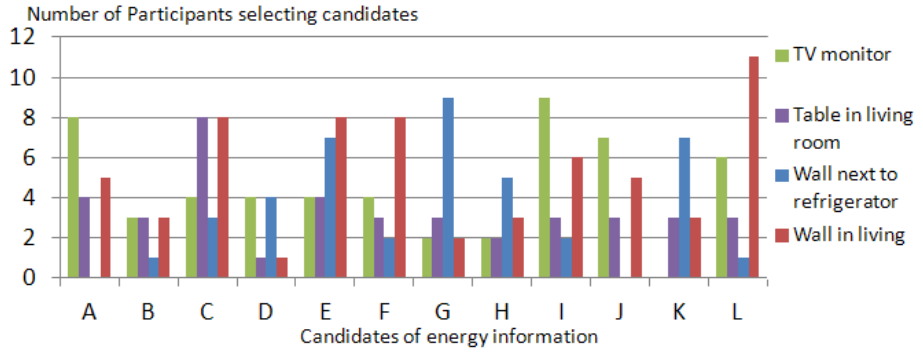

Fig. 5. Results of preferred contents of energy-related information

4 Main Experiment

4.1 Method

Based on the results from the preliminary experiment, we performed a further experiment in the smart home that is open to visitors. The purpose of this experiment was to clarify the locations and the contents of displayed energy-related information demanded in a smart home. In the main experiment, the energy-related information was displayed at or projected to each location in the real smart home. Now, the locations employed were as follows:

1. TV monitor
2. Wall next to refrigerator
3. Wall in living room.

We used the same twelve candidates of energy-related information content as in the preliminary experiment. The information displayed or projected was chosen by participants at each location. Participants could decide the position of the energy-related information at 1-4 or 5-9 in the layout. Figure 6 shows examples of displays, Fig. 7 shows the layout of a display, and Fig.8 shows a scene from the experiment.

After finishing the selection of contents for all location, the following questions were asked:

- Do you need a display at each location?
- Are there any places where you want a display other than these candidates?
- Are there any contents that you want to display other than these candidates?

Fig. 6. Examples of displays

4.2 Results and Discussion

The second experiment was performed using 46 participants, including 43 visitors and 3 residents.

Figure 9 shows the results for preferred locations of energy-related information. All locations were judged necessary, and Wall next to refrigerator in particular was judged necessary most often.

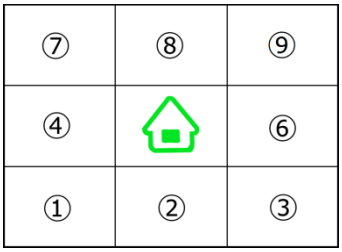

Fig. 7. Display layout

Fig. 8. Experimental scene

Figure 10 shows results for contents in this experiment as well as in the preliminary experiment. All energy-related information in this experiment was judged more important than in the preliminary experiment. This is because participants in this experiment observed the smart home in advance, which caused them to be more interested in energy information than the participants in the preliminary experiment. In addition, Overall power consumption (E), Percentage of power consumption covered by home generation of electricity (F), and Heating and lighting costs (G) were, in particular, judged necessary in this experiment. We found strong demand for the system to display the effects of energy savings.

Figure 11 shows the results for contents at each location. The numbers of participants who chose C, E, I and L were similar at the three locations. On the other hand, the numbers of participants who chose A and J tended to be less at the Wall next to refrigerator. This is because the monitor at the Wall next to refrigerator was smaller than that at the other locations. In addition, the number of participants who chose K was more at the Wall next to refrigerator, because this location is near the kitchen. Therefore, the energy-related information can be divided into two categories: necessary at all locations and necessary at specific locations.

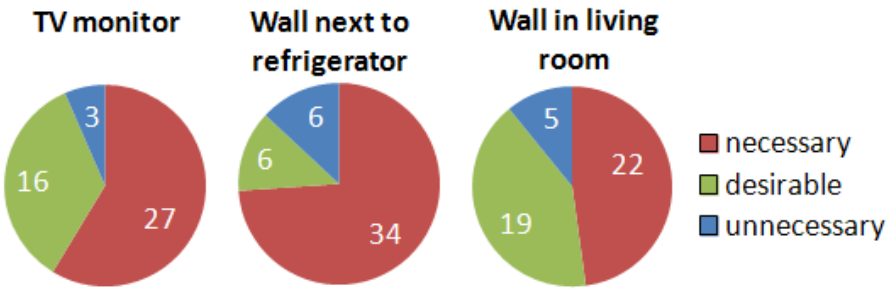

Fig. 9. Results for location of energy-related information

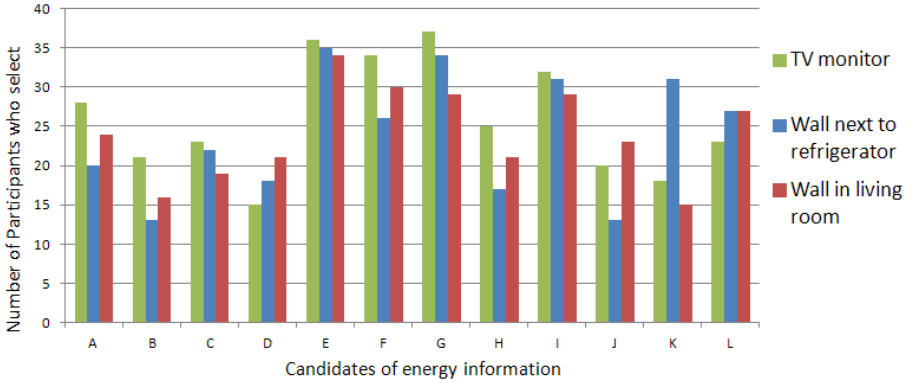

Fig. 10. Results for contents in main and preliminary experiments

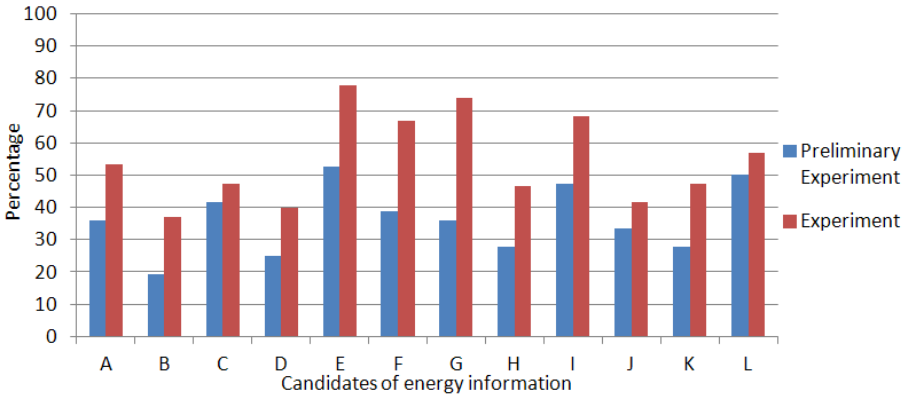

Fig. 11. Results for contents at each location

5 Conclusions

We focus on the QOL in a smart home and aim to clarify where and how to display energy-related information in the smart home.

As a first step, we performed a preliminary experiment on reducing the numbers of candidate locations and contents of energy-related information. Next, we performed a further experiment to clarify the actually preferred locations and contents of displayed energy-related information in a real smart home. Consequently, we obtained the findings listed below.

- All candidate locations are considered necessary, and Wall next to refrigerator is in especially high demand.
- All energy-related information is considered necessary, and the types of information that can give the user an actual feel for energy savings, such as Overall power consumption (E) and Heating and lighting costs (G), are in particular highly demanded.

- The desirable information is different depending on the location; for example, participants want to reduce the number of contents at the locations where the monitor is small, and they require the Temperature of the hot-water supply system (K) if the location is near the kitchen.

Acknowledgments. We express our gratitude to HONDA R&D and Saitama City Office for providing the smart homes for the experiment. In addition, we thank the staff and students of Saitama University and Shibaura Institute of Technology for their participation as volunteers in the experiments.

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