Effectiveness of Displaying Energy Consumption Data in Residential Buildings: To Know Is to Change

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ABSTRACT

The authors have proposed a method of reducing the energy consumption in residential buildings by providing household members with information on energy consumption in their own houses. An on-line interactive "energy consumption information system" that displays power consumption of up to 16 different appliance, and power consumption of the whole house was installed in 9 homes. Moreover, a remodeled system that displays city gas consumption of the whole house, and room temperature in addition to power consumption was constructed and was installed in 10 additional homes. The intent was to motivate energy-saving activities and raise energy-saving consciousness. The effects on energy consumption have been analyzed in detail based on the monitored energy data before and after the installation of the system, which have shown a reduction in household energy demands.

This paper describes the amount of energy savings actually achieved by setting up the display system. It then proceeds to describe how these savings were achieved by the residents, i.e., what kinds of energy saving activities were induced by looking into the visualized energy consumption data. In addition, we look at how the comfort of the residents changed, i.e., how the space heating periods and the room temperatures were different.

Introduction

This study focused on residents' awareness of energy conservation and on the potential to reducing energy demand through energy saving activities. The method introduced here is to induce energy savings by providing household members with information on actual domestic energy consumption. A number of studies have been conducted with regards to this. For example, Egan investigated the relationship between different display formats and the reaction of informants to each (Egan 1999). McClelland carried out an study by employing an electronic device to show consumers electricity information (McClelland 1979). Dobson and Griffin developed Residential Electricity Cost Speedometer software and installed it into the PCs of 25 homes (Dobson 1992). Newborough analyzed the effectiveness of an appliance-specific display showing the energy consumption for cooking (Mnsouri 1999)(Wood 2003a), and classified the features necessary for displaying energy information (Wood 2003b). Brandon analyzed the most effective energy saving technique among several feedback methods using, for example, computers, leaflets, etc (Brandon 1997)(Brandon 1999).

The authors have developed an on-line Energy Consumption Information System (hereafter referred to as ECOIS I) that provided residents with information on end-use electric power consumption, and installed the system into nine houses in a suburb of Kyoto, Japan (Ueno 2003)(Ueno 2006). In addition, the authors constructed a remodeled on-line Energy Consumption Information System (hereafter referred to as ECOIS II) that provided residents with information on city gas consumption and room temperature in addition to electric power consumption. The ECOIS II was installed in 10 houses in a city near Osaka (Ueno 2005a)(Ueno 2005b).

The purposes of this study were to analyze 1) how consumers change their behavior toward energy conservation and how power consumption changes after installation of ECOIS I and II, 2) whether there are any energy saving effects of ECOIS I and II, and 3) how the comfort and other benefits of the residents changed.

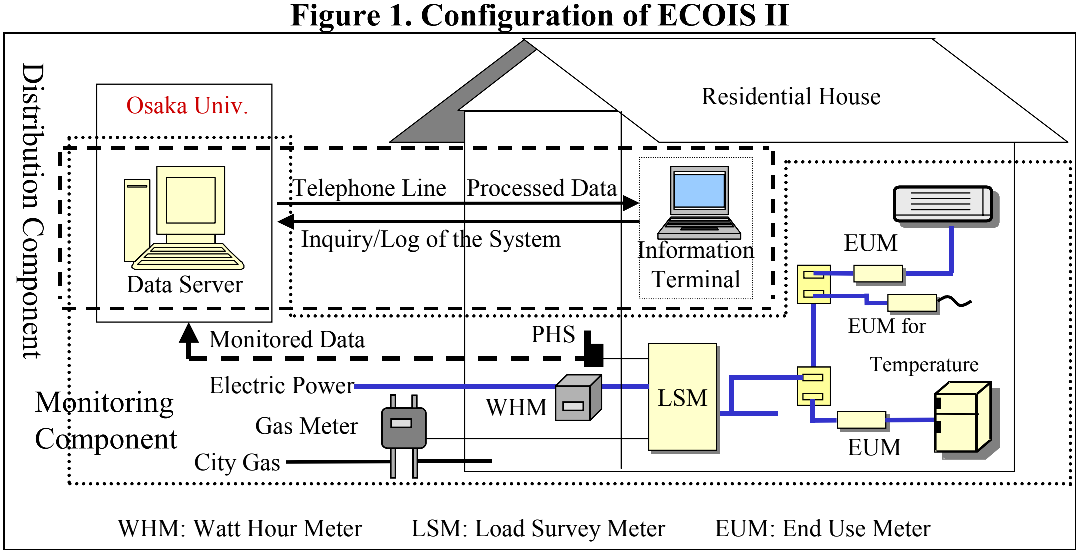
Construction and Experiments of Energy Consumption Information Systems

The Monitoring and Information System

Figure 1 shows the configuration of ECOIS II, which consists of monitoring and distribution components. The monitoring component includes a Load Survey Meter (LSM) that measures electric power consumption and city gas consumption for the entire house, a type of End-Use Meter (EUM) that measures electric power consumption for each home appliance and another type of EUM that measures room temperature. There is maximum of 18 EUMs for power consumption and one EUM for room temperature in each house. Power consumption, city gas consumption, and room temperature are measured at intervals of 30 minutes. The measured power and temperature data by EUM are sent to the LSM through distribution lines in a house, and the city gas data are sent to the LSM through an exclusive line. Data are then collected through Personal Handy-Phone System (PHS) network every night by a computer in the authors' laboratory at Osaka University.

The distribution component includes a laboratory-based computer which distributes data to the information terminal in each house via E-mail. The logs of operation of the information terminal and responses of the consumers to the energy tips are sent to the distribution server every morning. Here, operation of the information terminal involves pressing buttons on the screen of a terminal, namely, a laptop computer, by the customer. In the system of ECOIS I, only the electric power of each appliance (maximum 16 appliances) and whole house were measured: city gas consumption and room temperature were not measured.

Figure 1. Configuration of ECOIS II



Design of the Information Terminal

Figure 2 shows the display on the information terminal with an example of the graphs that can be drawn on the screen. Although various display methods can be considered effective for providing energy consumption information, conciseness seems to have a big influence on the overall effectiveness of the display methods. Hence, the composition of the display needs to be designed carefully. The following were taken into consideration during the design stage of the ECOIS display:

1. Simple access to the detailed data. A number of buttons are located on a single display picture, and only a mouse is required in order to access various functions and more detailed data. The main graph area is located at the center of the picture, while windows displaying energy saving tips and information on electricity charges are located below and to the right of the main graph area, respectively. Table 1 shows the various graphs that can be displayed in ECOIS II. (The area surrounded by dotted line means the graphs can also be displayed in ECOIS I.) Note that the measured power consumption and city gas consumption data are displayed in terms of Japanese Yen so that residents can understand it easily.
2. Provision of useful information for residents to save energy. While displaying a graph of each appliance, energy-saving tips are displayed on the message window. Each piece of advice urges the customer press one of following three response buttons: [Yes], [I will try] and [Neither].
3. Capability of recording operation of the information terminal. Information about the interest of each consumer in the energy consumption of each appliance and how these interests change over time is very important. Hence, operation of all buttons and the responses to each tip were recorded, allowing analysis of the awareness of consumers about energy consumption and energy saving potential.

Here, there is a button on the screen to show kerosene consumption of the appliances. However, no monitored households used kerosene in this experiment. Therefore, kerosene consumption is not shown on the screen.

ECOIS I Experiment

The ECOIS I experiment was carried out in a suburban area of Kyoto, Japan. Monitoring of nine detached houses commenced in Feb, 2000 and information terminals were installed two years later, in Jan, 2002. Each household included a married couple with 1-3 children and 132 m2 (or 1,421 ft2) average floor space.

To evaluate the effect of ECOIS I installation on power consumption, consumption was recorded during two periods, defined as “period I” and “period II”. To evaluate power consumption before and after installation impartially, the evaluation periods were limited to weekdays only. Period I was defined as the 40 weekdays before installation of ECOIS I, and Period II was the 40 weekdays after installation. “Weekdays” means any day except Saturday, Sunday, national holidays, or the end and beginning of the year. A questionnaire survey was used to check that no changes in the number of household members, for example, as a result of a business trip or hospitalization, or changes in the use of rooms occurred. The average outdoor ambient temperatures in period I and period II were 6.4 °C (or 43.5 °F) and 6.8 °C (or 44.2 °F), respectively.

Figure 2. Display Picture on the Information Terminal of ECOIS II (Translated into English)

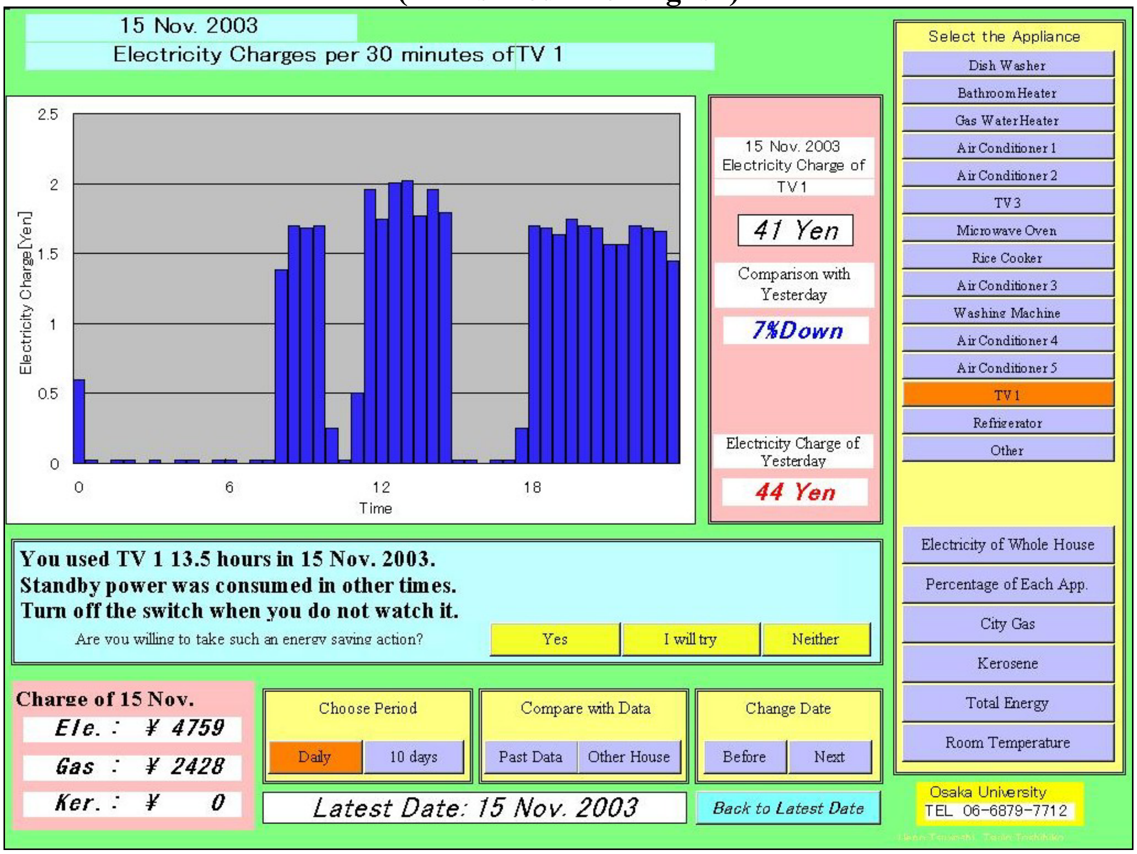


Table 1. The Buttons and Corresponding Graphs of ECOIS II

		Buttons below the main graph area			
		Daily	10 days	Comparison with past data	Comparison with other houses
Buttons on the right-hand side of the main graph area	Electricity charge of the appliances	Hourly electricity charge over a day	Daily electricity charge over a 10-day period	Daily electricity charge, present and past	Own house and other houses
	Electricity charge of whole house	Hourly electricity charge over a day	Daily electricity charge over a 10-day period	Daily electricity charge, present and past	Own house and other houses
	Percentage of the electricity consumption charge	Percentage of power expense of each appliance	Daily percentage of power expense over a 10-day period	---	---
	City gas charge of whole house	Hourly city gas charge over a day	Daily city gas charge over a 10-day period	Daily city gas charge, present and past	Own house and other houses
	Kerosene charge of whole house	Hourly kerosene charge over a day	Daily kerosene charge over a 10-day period	Daily kerosene charge, present and past	Own house and other houses
	Total energy charge of whole house	Hourly total energy charge over a day	Daily total energy charge over a 10-day period	Daily total energy charge, present and past	Own house and other houses
	Temperature at living room	Hourly room temperature over a day	Daily average room temperature over a 10-day period	present and past	Own house and other houses

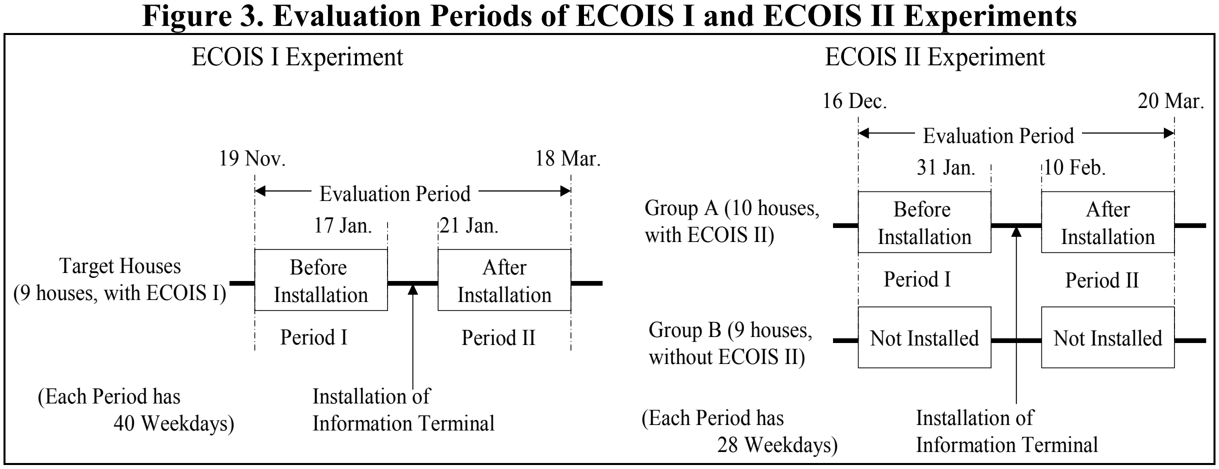
ECOIS II Experiment

Monitoring was commenced in Dec, 2002 at 19 detached houses in a newly developed town in the suburb of Osaka and information terminals were installed in a sub-sample of 10 homes one year later, in Feb, 2003. Energy consumption in the other nine houses was measured as a control, in order to identify the effect of ECOIS II. Hereafter, group A means the households with an information terminal, and group B means the households without an information terminal. Each household included a married couple with 1-3 children (and one house included an aged woman) and the average floor space of group A and group B were 141 m2 (or 1,518 ft2) and 139 m2 (or 1,496 m2), respectively. Although the information about levels of education, incomes, and occupations were not specifically investigated, there were no obvious differences between group A and group B in their socio-economic profile. The experiment continued until Nov. 2003.

As in the ECOIS I experiment, consumption in two periods referred to as “Period I” and “Period II” were compared to evaluate the effect of ECOIS II installation on energy consumption. In this case, the 28 weekdays before installation of ECOIS II was defined as "period I", and the 28 weekdays after installation was defined as "period II ". The energy consumption of houses in group A and group B was compared for each period. The average outdoor ambient temperatures at period I and period II were 5.1 °C (or 41.2 °F) and 6.8 °C (or 44.2 °F), respectively.

Figure 3 shows the evaluation periods of ECOIS I and ECOIS II experiments.

Figure 3. Evaluation Periods of ECOIS I and ECOIS II Experiments



Changes in Energy Consumption and Comfort of Residents

Frequency of Responses

Figure 4 shows the total number of operations (button pressing) and responses to energy-saving tips per day averaged over the households in group A during the ECOIS II experiment. It is clear that the total number of operations was very large immediately after installation, after that the number of operations decreased gradually. However, the residents kept pressing buttons on the screen of the information terminal long after the installation. The responses to tips also decreased gradually after installation. Table 2 shows the number of operations of buttons for selecting graphs over the experimental period. The numbers of [electricity charge of the appliances], [electricity charge of whole house], and [city gas charge of whole house] operations were large among the buttons on the right-hand side. According to the log of the system, the residents often pressed from higher buttons to lower buttons in sequence. The number of [daily] operations were the largest, then comes [10 days], [comparison with other houses], and [comparison with past data] in the buttons below the main graph area for all right-hand side buttons. Most residents reported in a questionnaire survey that they were interested in the graphs of [comparison with other houses] because these graphs induced the competitive spirit of the residents.

Figure 4. Number of Operations by the Residents (ECOIS II)

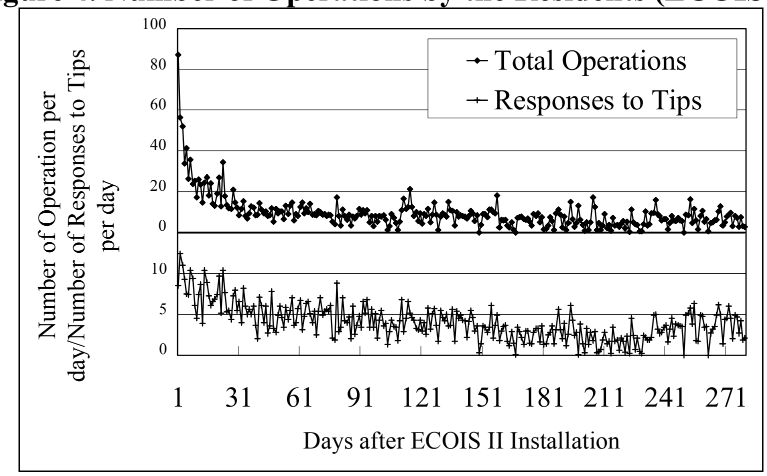


Table 2. Number of Operations Averaged over 10 Houses during the ECOIS II Experiment

		Buttons below the main graph area			
		Daily	10 days	Comparison with past data	Comparison with other houses
Buttons on the right-hand side of the main graph area	Electricity charge of the appliances	101.2	66.4	3.5	7
	Electricity charge of whole house	69	62	10.1	36.5
	Percentage of the electricity consumption charge	55.1	30.1	---	---
	City gas charge of whole house	52.9	38.8	2.7	29
	Kerosene charge of whole house	---	---	---	---
	Total energy charge of whole house	39.8	39.4	7.2	21
	Temperature at living room	38.4	37.6	5.4	11.3

Changes in Energy Consumption of Whole House

In this section, the changes in power consumption (ECOIS I) and whole house energy consumption (ECOIS II) are described as a result of the energy saving activities of the residents.

ECOIS I experiment. Figure 5 shows the relationship between the ambient temperature and the daily power consumption of each house averaged over eight households (energy consumption of household no. 9 was not measured due to a photovoltaic system). Energy consumption in period II is lower when these plots are compared with each other for similar temperatures in period I.

The energy consumption averaged over eight households was reduced 1,325 Wh/day and the reduction rate [1 - energy consumption during period II/ energy consumption during period I] was 9%. Generally, the power consumption of the whole household increases with the fall in ambient temperature in winter; hence, it is thought that the true effect was more than this value.

ECOIS II experiment. Figure 6 and 7 show the relationship between the ambient temperature and the daily power and city gas consumption averaged over households in group A and group B, respectively. Energy consumption in period II of group A is lower when these plots are compared with each other for similar outdoor temperatures. On the other hand, energy consumption in period II of group B remained in the same range as in period I. The whole house power consumption, averaged over ten households in group A, was reduced by 5,150 Wh/day (18%) and the city gas consumption of that group was reduced 4,875 Wh/day (9%). The whole house power consumption, averaged over nine households in group B, was reduced by 891 Wh/day (5%) and the city gas consumption increased 179 Wh/day (0%).

The reduction rate of energy consumption averaged over the ten houses in group A was 12%. It should be noted here also that the energy consumption in winter depends heavily on ambient temperature and hence the actual effect would be less than 12%. The energy consumptions of the two groups A and group B differ from each other, as it can be seen from Figs. 6 and 7. For example, the average electric power consumption of Group A and Group B in period I were 28.9 kWh/day and 18.9 kWh/day, respectively. It was difficult to distinguish these differences at the time of selection of households for ECOIS II installation and the authors believe that this difference would not obscure the evidence on the effectiveness of installing ECOIS II.

Figure 5. Relationship between the Ambient Temperature and Daily Energy Consumption Averaged over the Households in ECOIS I experiment

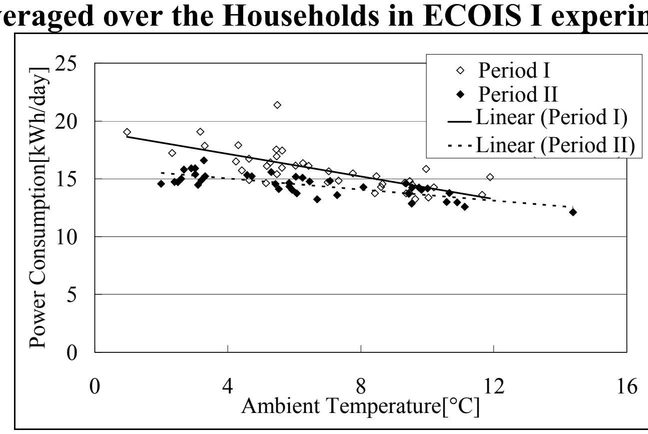


Figure 6. Relationship between the Ambient Temperature and Daily Energy Consumption Averaged over the Households in Group A in ECOIS II Experiment

(a) Power consumption of whole house (b) City gas consumption of whole house

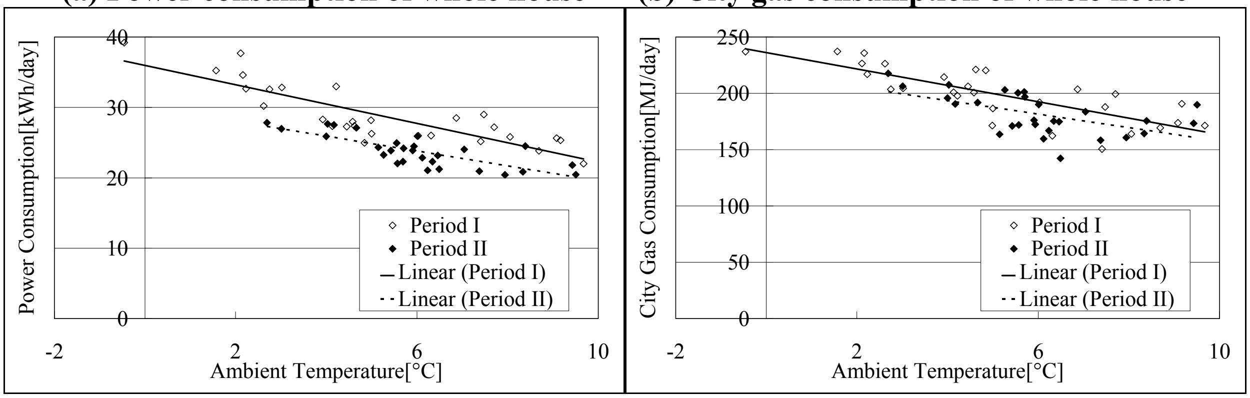
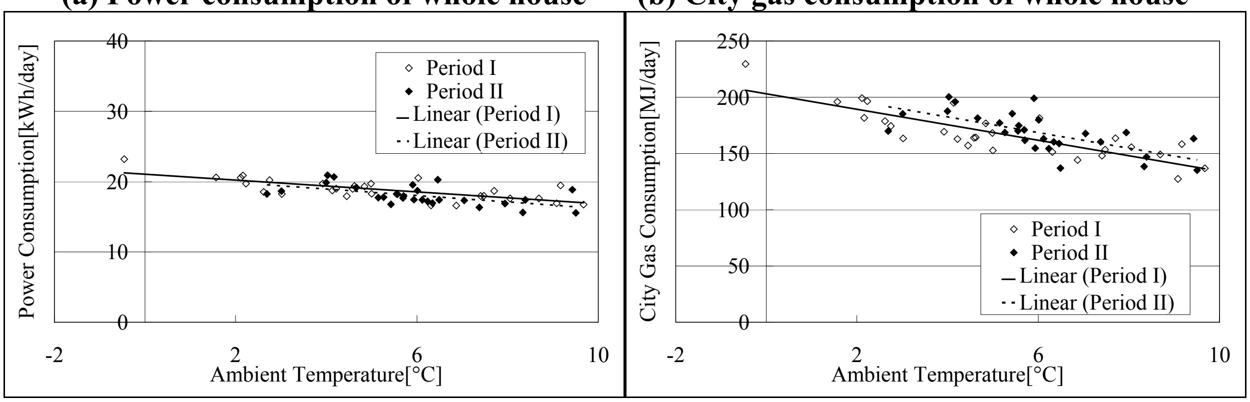


Figure 7. Relationship between the Ambient Temperature and Daily Energy Consumption Averaged over the Households in Group B in ECOIS II Experiment

(a) Power consumption of whole house (b) City gas consumption of whole house



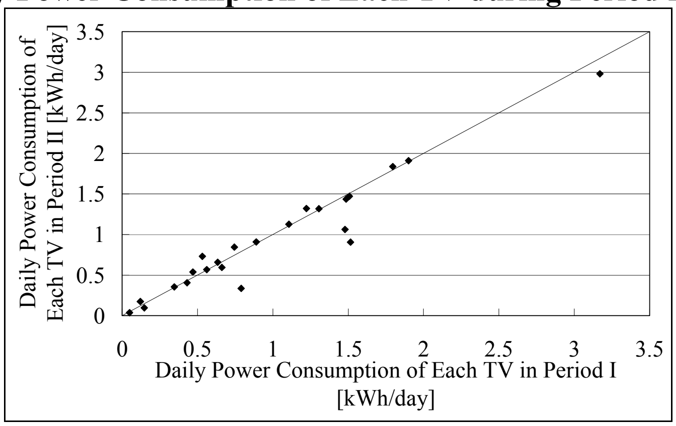
Energy Saving Activities for TVs

Figure 8 shows the relationship between daily power consumption of each TV in period I and period II. Power consumptions of 23 appliances were measured in two experiments (ECOIS I and ECOIS II). Power consumption decreased after ECOIS installation (period II) for several appliances. In figure 8, dots below the line represent appliances whose energy consumption were decreased. There were 8 appliances whose power consumptions were reduced over 5%. Power reduction averaged over 23 appliances was 53 Wh/day, and maximum power reduction was 608 Wh/day.

TVs consume electric power not only in operating hours but also standby hours. To reduce the power consumption in operating hours, residents have to reduce the hours of watching TV. On the other hand, to reduce the standby power, residents have to disconnect the appliance from the outlet. In this experiment, reduction rate of standby power consumption was 17.6% averaged over 23 appliances. On the other hand, reduction rate of power consumption in operation was 1.0% averaged over 23 appliances. It seems that residents felt that reducing standby power of TVs was easier than ceasing watching TVs. Therefore reduction rate of the standby power consumption was much larger than that of the power consumption in operation.

However, electric power [W] in operation is much larger than that during standby, therefore daily power reduction in standby power was 31 Wh/day and power reduction in operation was 22 Wh/day.

Figure 8. Daily Power Consumption of Each TV during Period I and Period II

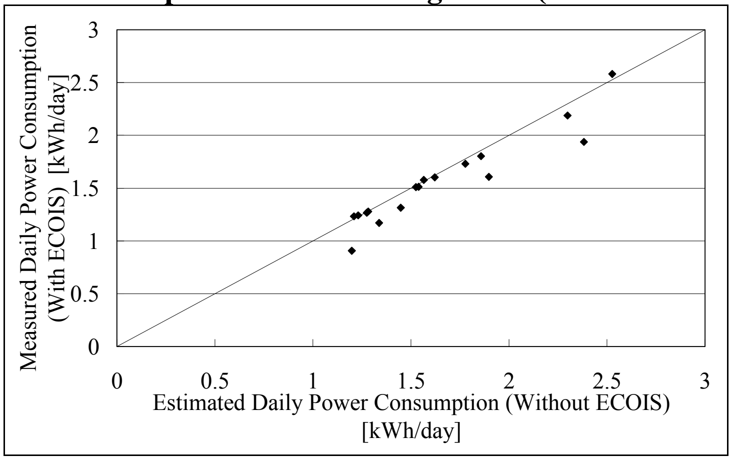


Energy Saving Activities for Refrigerators

The power consumption of 16 refrigerators and one freezer were measured in two experiments. Power consumption of refrigerators and freezers depend the outdoor ambient temperature very much. Therefore we cannot compare the power consumption during period I and period II. We made an equation showing the relationship between measured outdoor ambient temperature and measured power consumption during period I, and estimated the power consumption during period II if ECOIS was not installed. In this section, the estimated value (without ECOIS) and the measured value (with ECOIS) are compared. Figure 9 shows the relationship between the estimated daily power consumption for each appliance and the measured daily power consumption for each appliance. The reduction rate is 5.2% averaged over 17 appliances. Although several residents said they begun to take more care not to leave the refrigerator or freezer door open unnecessarily after installation (period II), a clear change in power consumption as a result was not identified because the effect was very small. However, refrigeration capabilities were adjusted by changing the thermostat settings for five of the appliances after installation by residents, and significant reductions in power consumption were seen. The reduction rate varied 9.2-24.3%, and averaged 16.0% over the five appliances.

Refrigerators and freezers are always automatically operated, and their power consumption is very large. However, significant energy-saving effects can be expected by thermostat adjustments, which is very easy and not necessary to repeat. However, such adjustments should be undertaken considering the contents and circumambient temperature of the refrigerator, since this activity also changes the environment inside the refrigerator.

Figure 9. Daily Power Consumption of Each Refrigerator (Measured and Estimated Value)



Energy Saving Activities for Electric Rice Cooker and Electric Pot

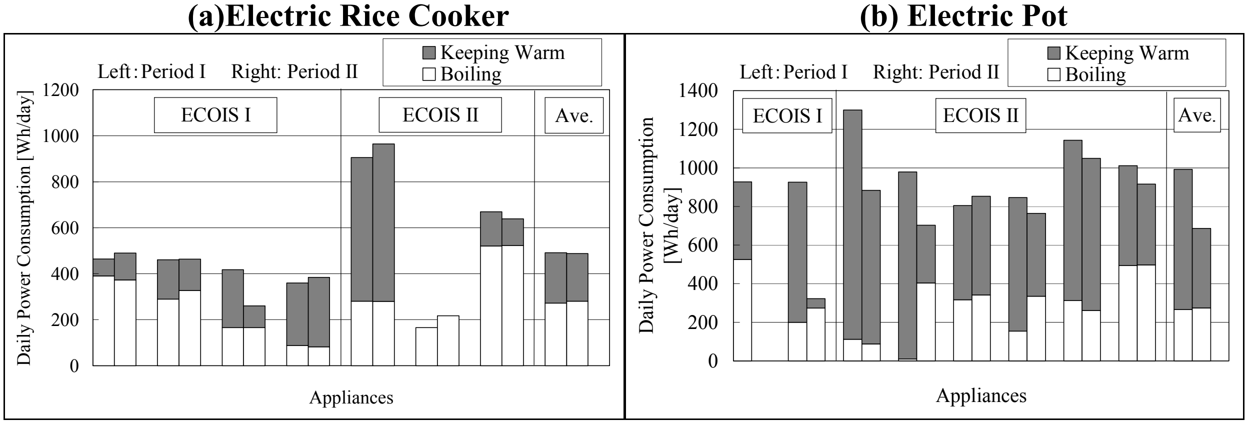
Electric rice cookers are used for boiling rice and keeping it warm. Seven rice cookers were measured in two experiments. One of them were used only for boiling, and not used for warming. Figure 10(a) shows the daily power consumption for boiling and warming of each electric rice cooker during period I and period II. Power consumption of three appliances among them decreased because residents reduced hours for warming. However, the power reductions averaged over the seven appliances were very small.

On the other hand, eight electric pots were measured, and the power consumptions of seven appliances among them were reduced by reducing power consumption for warming. The power reduction for warming varied from 42 to 669 Wh/day (5.1% to 100%). 30.8% of total power consumption was reduced averaged over eight appliances (see figure 10(b)).

The number of electric pots whose power consumption were reduced was larger than that of electric rice cookers. In addition, power reduction per appliance of electric pots was larger than that of electric rice cookers.

Figure 10. Changes in Daily Power Consumption of Appliances in Period I and Period II

(a)Electric Rice Cooker **(b) Electric Pot**



Energy Saving Activities for Space Heating

Energy consumption for space heating is very large in winter. Here, the changes of energy consumption for space heating in living rooms are described. Figure 11 shows the daily energy consumption for space heating in the period I and II for each household in the ECOIS II experiment. (In the ECOIS I experiment, total energy consumption for room heating was not measured.) As mentioned above, only the city gas consumption of the whole house was monitored and the consumption of each end-use, such as cooking, heated water supply and space heating was not measured. In order to estimate the energy consumption for space heating, the city gas consumption of gas fan heaters was estimated using their power consumption and the city gas consumption of whole house. Therefore, figure 11 shows the houses except for three houses that use a city gas floor heating system. Energy consumption for space heating of five houses were reduced. The reduction rate was 17% averaged over 7 houses.

Figure 12(a) shows the averaged room temperature during room heating in each house. And figure 12(b) shows the daily hours spent heating. Averaged room temperature during period I and period II did not differ much (0.25 degree C down). On the other hand, the daily hours spent heating were reduced in many houses. Daily hours spent heating were reduced by 1.2 hours per day averaged over 7 houses. Thus, residents reduced energy consumption for space heating more by reducing hours spent heating than by adjusting room temperature during space heating.

Persistency of the Energy-Saving Activities

Figure 13 shows the daily changes in the amount of time spent disconnected from the outlet for an electric rice cooker and a heated toilet before and after installation of ECOIS I. A remarkable change in the number of non-connected hours was not seen for the electric rice-cooker even after installation, but on the other hand, the hours of disconnection decreased several weeks after installation for the heated toilet.

At first, residents disconnected the heated toilet from the outlet frequently, but then they did so less frequently. This is presumably because the residents thought this energy-saving action was not reasonable. This is an example of an energy-saving activity with large potential load reduction for residents that was tried, but was not persistent.

Figure 11. Daily Energy Consumption for Room Heating in Living Room of Each House at Period I and Period II (Secondary Energy)

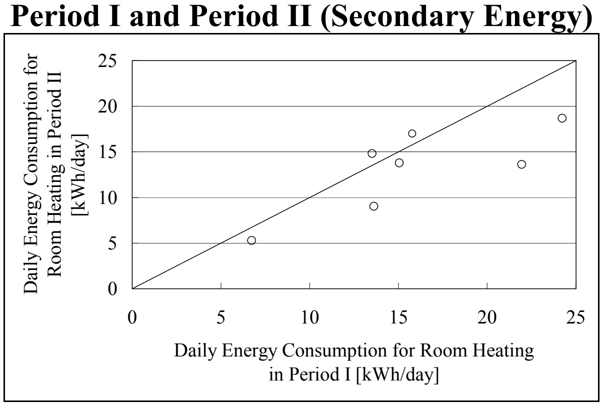


Figure 12. Room Temperature and Hours Spent Heating in Living Room of Each House

(a) Room temperature **(b) Daily hours spent heating**

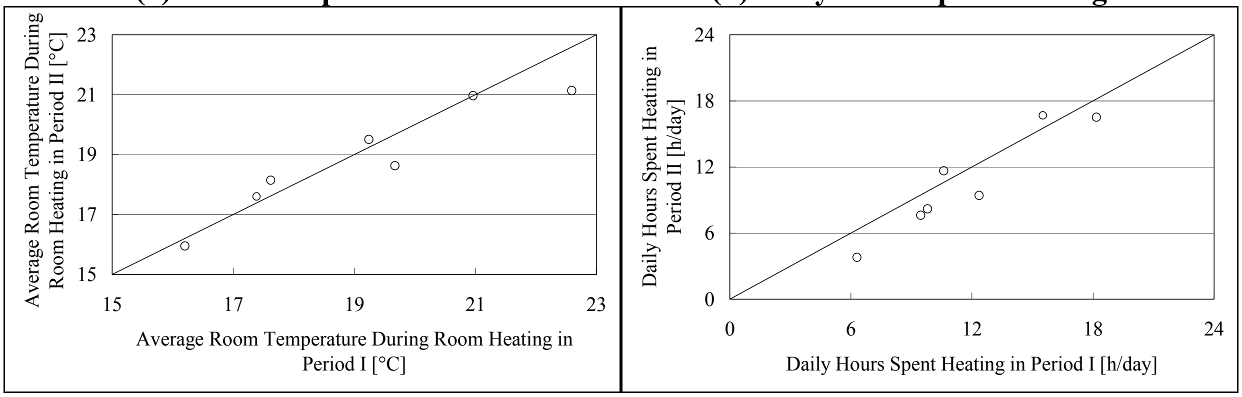
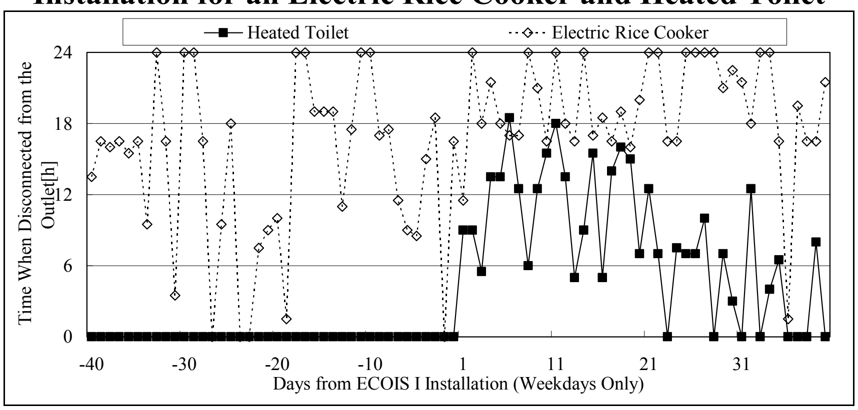


Figure 13. Daily Changes in the Time when Disconnected from the Outlet after ECOIS Installation for an Electric Rice Cooker and Heated Toilet



Conclusion

In this study, two on-line energy consumption information systems for motivating energy saving activities were constructed, and the energy saving effects and activities induced by this system were analyzed based on monitored data. The results are based only on the data from winter, but total energy consumption was reduced notably.

In the ECOIS I experiment, the average reduction in the power consumption of the whole house with installation of the system was estimated at 9% over eight households. And in the ECOIS II experiment, the total power consumption decreased about 18% and the total city gas consumption decreased about 9% averaged over ten houses with ECOIS II. On the other hand, the total power consumption decreased about 5% and the total city gas consumption increased 0.4% averaged over nine houses without ECOIS II. Thus it seems likely that installation of ECOIS II had influence on the energy saving awareness and actions of the customers. Total energy consumption was reduced by 12 % after the installation of the system.

However, we cannot ignore the cost of a reduction of comfort by the energy-saving activities. Reducing energy demand is indeed important, but we observed that the residents do not continue energy-saving activities that reduce their comfort (heated toilets) or desired activities (TV watching). In this experiment, the reduction rate of standby power consumption of TVs was large but that of the power consumption in operation was small. It appears people choose actions to save energy with the smallest cost to their comfort. Therefore, we should consider the balance point between energy-saving value versus the perceived loss of comfort when selecting energy saving methods, and adopt the methods with the highest energy-saving effects and the smallest reductions in comfort.

Acknowledgements

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