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Feedback on electricity usage for home energy management: A social experiment in a local village of cold region

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HIGHLIGHTS

- This paper purposed to reduce total electricity consumption of households in a cold area, Japan.
- We implemented an information provision system to install four households for one year.
- The system provided the information of electricity consumption 15 min interval via websites.
- We considered temperature effects to electricity demand and made a benchmark for evaluation.
- Consequently, a tendency of reduction of electricity consumption could be seen in two households.

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ABSTRACT

To mitigate global warming, it is essential for households to reduce CO_2 emissions. Saving electricity is one solution for the reduction. To promote this reduction, saving electricity by households should be considered because household consumption is growing rapidly. In this paper, we developed a system for metering electricity consumption and providing it to households as feedback on electricity usage. Previous studies on how to promote household energy savings found that feedback in real-time on electricity usage could be effective. Our system provided two types of information through web pages, (1) nearly real-time electricity consumption information, and (2) action lists for how to save energy. To test the effectiveness of these types of information, the system was installed in four households in an extremely cold district in Hokkaido, Japan for 378 days. During 30 days, data on electricity consumption was collected and stored. In the following month, a web page, which visualized nearly real-time electricity consumption, was opened to each household. After the experiment, an Internet-based questionnaire survey was conducted. The results obtained suggest that environmental awareness was an important aspect for inducing electricity saving behavior.

1. Introduction

To mitigate the phenomenon of global climate change, it is essential to reduce CO_2 emissions, which involves reducing electricity usage. Since domestic electricity consumption is rapidly increasing in Japan [1], energy efficiency measures have been used over a number of decades to reduce CO_2 emissions. We developed an Internet-based system for metering and visualization of electricity consumption, in order to promote reduction of household electricity consumption and elicit behavioral change for saving energy. Many studies that have utilized visualization systems for energy saving found that providing nearly real-time electricity consumption data, which is a feedback on electricity usage, and telling participants how to take actions for saving energy were effective [2]. We utilized feedback on electricity usage in our system. First, our system monitored nearly real-time electricity consumption using a metering system, which transferred data via the Internet to an online database. Second, we provided a web page, which provided feedback on electricity usage.

To test this system's effectiveness, we conducted an experiment with four households in a local village called Teshikaga-cho, in Hokkaido, Japan (Its town office is located at E144° 45′, N43° 48′). Temperatures in Teshikaga-cho from 2010 to 2012 were

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Table 1
Teshikaga-cho's average temperatures (°C) from 2010 to 2012 [3].

Degree	Winter			Interphase			Summer			Interphase		Winter
	January	February	March	April	May	June	July	August	September	October	November	December
2010	−6.4	−7.4	−3.5	1.8	7.3	15.2	18	21	15.8	8.9	2.8	−2.2
2011	−8.1	−6	−3.1	3.3	6.4	13.2	17.8	19.1	16.4	8.8	2.9	−5.8
2012	−8	−9.9	−4.2	2.6	8.4	11.7	17	18.9	18.3	9.7	2.9	−5.5

shown in Table 1. As illustrated in this table, Teshikaga-cho was a very cold resign and demand management in such a cold district had not been conducted in previous Japanese projects; now had its possibility been clarified. This was the originality of our experiment.

In the first phase, nearly real-time electricity consumption data were collected. In the second phase, a private web page was established for each household, showing the households' electricity consumption information. Following the experiment, we used the electricity consumption data and an Internet-based questionnaire survey to confirm the factors that affected the household's electricity saving behavior, with focus on environmental awareness.

2. Related works and our hypothesis

This section summarized relevant studies on the visualization of electricity consumption data. Previous studies can be divided into two categories.

The first category related to methods for collecting data on electricity usage by devices and Internet communication technology (ICT) [4–6]. The main purpose of these studies was to develop an efficient system for monitoring domestic electricity usage by using highly functional smart meters or smart taps, including collection and storage of data into a database. Another purpose was to develop a framework for combining the electricity network and the ICT network into a smart grid.

The other category was researches that employed visualization web pages or applications to change participant's behavior towards gaining energy savings. Another purpose of such studies was to determine which interventions could enhance energy-saving behaviors. Previous studies expecpredicted that gas and water energy would be used to a great extent because of their low environmental impacts [7,8]. After the introduction of the personal computer (PC) to households, many studies had moved from paper-based to Internet-based methods [9–11].

Our system focused on providing electricity consumption data over 15-min intervals; we provided the amounts of real-time electricity consumption and the number of W used per 15 min. This type of approach provided feedback on electricity usage [12].

3. System description

This section described the system used to monitor, collect, and visualize electricity consumption data.

3.1. Monitoring, collecting, and storing power consumption data

Our system used smart meters to collect nearly real-time data on household electricity consumption. Compared with standard electricity consumption meters, smart meters enable the optimization of customer demand and utility provider supply. The electricity usage information recorded by smart meters was typically used to calculate consumption charges; however, in this experiment, it was used to collect the data on electricity consumption and transmit this data via the Internet to a central database. Fig. 1 showed a

Fig. 1. Picture of a smart meter installed in a household.

smart meter installed in one household. Each smart meter was connected to a switchboard and gateway.

In this system, the gateway was a small device that changed the communication protocol from the original protocol to a unified protocol, IEEE1888. The gateway was connected to a modem in the household to connect it with the Internet. We adopted the unified IEEE1888 network protocol for data acquisition via the Internet. IEEE1888 was an IEEE standard protocol for ubiquitous green community control with interoperability, e.g., unified data format, storage system, security system, and providing sample codes [13]. It already existed as a method for integrating ICT with smart meters [14,15]; however, our metering system had significant merits compared to them. Our metering system's novelty was in the use of the international standardized communication protocol, IEEE1888. This protocol has versatility for developing a HEMS (Home Energy Management System) and a BEMS (Building Energy Management System) systems. In this experiment, we used the same type of smart meters; however, various types might be used in other situations, as IEEE1888 unifies the data format even when different smart meters are used. Fig. 2 shows a system overview. The data is collected at 1-min intervals, stored, and accumulated. One of our previous works [16] showed that this system had high accuracy for collecting electricity data. In order to use this system, participants must have Internet access in their houses.