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Energy-saving effect of automatic home energy report utilizing home energy management system data in Japan

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ABSTRACT

This study assesses the effects of sending home energy reports utilizing the Home Energy Management System (HEMS) data to more than 1600 households in Japan. The treatment effect was verified using a panel data regression random effects model comparing the electricity consumption of a treatment group to which the report was sent with that of a control group that was not sent. The report was effective in winter and led to a 3.4% reduction in electricity consumption compared to the previous year in the average household. A further reduction of 5.4% for the households with higher electricity consumption for whom a significant reduction of 11.4% in the use of space heating was also observed. Although the treatment effect was not significant in summer for the average household, larger households reduced consumption by an overall average of 2%, with reductions of 6.8% and 7% in terms of space cooling and hot water use, respectively, from the previous month. In contrast, smaller households increased their space cooling consumption by more than 10% on average, which might be considered an undesirable boomerang effect. The accumulative treatment effect in a detached house group was also confirmed. Additionally, an accumulative two-year winter consumption reduction of 7.5% demonstrated the effectiveness of continual intervention.

1. Introduction

Global electricity consumption continues to rise at a high pace, with residential electricity use representing 31% of electricity consumption in OECD countries in 2012 [1]. Households consumed 29% of the total electricity used in Japan in 2013, and this household electricity consumption has increased by 56% from 1990 to 2013 [2]. In June 2015, the Japanese government announced a new energy conservation target to be reached by all sectors by 2030, including a requirement that the residential sector reduce energy and electricity use by 27% and 19%, respectively, from 2013 levels [3]. Achieving this aggressive target is expected to be accomplished through the improvement of insulation levels in dwellings, the diffusion of efficient appliances and lighting, introduction of home energy management systems (HEMS), and the implementation of public awareness/educational activities. The introduction of HEMS, which involves the monitoring and control of residential energy use, to all 50 million households by 2030 is expected to be a target of the program. As of 2015, it is estimated that 200,000 HEMS have been introduced to individual homes in Japan, a trend that has been accelerated through government support in the form of subsidies issued following the 2011 earthquake. HEMS can provide high-resolution data on electricity consumption broken down by variables, including overall space heating, space cooling, and water heating, and other factors, compared to a general in-home display system. However, the utilization of HEMS data is still very limited. The goal of this study was to develop a method for tailored feedback based on the household electricity consumption reports utilizing HEMS data and quantitatively evaluate the effectiveness of such reports.

2. Literature review

Several intervention programs have been instituted with the goal of encouraging households in order to reduce their energy demand [4–10]. Abrahamse et al. reviewed 38 studies conducted between 1977 and 2004 and categorized them as involving either antecedent or consequence strategies to promote household energy conservation [4]. The former strategy involves the use of

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Nomenclature

y_{it}	Average electricity consumption for household i for month t [kWh/day]
α	Constants
x_1	Dummy variable indicating treatment households (households sent report = 1, otherwise = 0)
x_{2t}	Dummy variable indicating the month after the report was sent (after treatment = 1, otherwise = 0)
β_1	Regression coefficient for dummy variable for treatment household
β_2	Treatment effect (Regression coefficient for sending the report)
$\boldsymbol{W}_{it}$	Control variables matrix
γ_{it}	Regression coefficient for control variables matrix
ε_{it}	Error terms (c_i: Random effects error term, u_{it}: Other error terms)

factors, such as commitment, goal setting, information, and home auditing, whereas the latter involves feedback and rewards. Of these, information feedback and energy audit programs are addressed in this study.

Feedback programs involve providing information to households on their energy demand or energy savings in order to affect behavioral change. In the reviewed paper [5], requirements of successful feedback programs were identified, including: frequent and long feedback based on actual consumption; interaction with households; appliance-specific breakdown of usage, including historical or normative comparisons; and understandable and appealing report design. The contents, frequency, and delivery method of feedback affected the outcome of introduction of new devices such as smart meters or internet services. The post-2010 research has involved larger sample sizes and has increased the credibility of the validation of effect of intervention feedback programs, as pointed out in Ref. [10]. For example, in 2010, Schleich et al. sent feedback to 1500 households in Austria through a web portal and by mail and confirmed a 4.5% electricity reduction over 11 months [11]. In their program, information on previous-day electricity consumption patterns, electricity cost, and practical measures to save electricity were provided on a web portal that utilized smart meter data. In addition, written two-page feedback forms were mailed to participants once a month to increase their motivation. Houde et al. assessed real-time feedback sent to 1743 Google employees in 2012 and confirmed a 5.7% reduction of electricity use that was sustained over four weeks [12]. The effectiveness of comparative feedback for similar households was examined using very large household samples in a series of studies by OPower [13]. The energy report sent by OPower reduced energy use by 2% over a sample of 600,000 households, and follow-up research validated the results [14,15].

The use of tailored feedback in the residential sector is generally valid but involves high costs [4,16]. The Japanese environmental ministry is supporting a visiting audit program to reduce residential energy demand [17]; however, larger-scale deployment is expected to be difficult because of barriers including expense, difficulties with dispatching consultants, and low acceptance of intrusive audit measures. By contrast, the above-mentioned methods used by OPower obtained a 2% reduction in energy use [13] and have the versatility to expand to very large numbers of households. Effective feedback systems utilizing HEMS or smart meters will be needed to promote further energy conservation in the residential sector. Rapid introduction of electricity smart meters in households and businesses is currently being promoted in Japan and is expected to be complete by the early 2020s [18]. Although the utilization of smart meters installed in all households for energy audits or demand response will ultimately need to be considered, our study targets automatic energy audits and the production of customized tailored messages using HEMS, which has a higher resolution than smart meters.

Energy reporting using HEMS can achieve a balance between general versatility and targeted specificity. Commercial HEMS systems in Japan have been installed in circuit panels in nearly all new houses, allowing the collection of electricity consumption as cloud data for 8–32 circuits at intervals of one-half to 1 h. HEMS service providers including house builders and appliance manufacturers have developed web sites that customers can use to check their electricity consumption, make simple comparisons between customers, and obtain general energy tips; however, their utilization has remained low.

Our goal is achievement of a cost-effective, diffusible energy reporting system and we investigate the development of energy reports utilizing HEMS data in this paper. We develop an algorithm for automatically generating tailored feedback and confirm the effectiveness of this reporting system. The novelty of this paper is that (i) the home energy report was automatically created using HEMS data which has higher resolution than before, (ii) the effect of the report was quantitatively evaluated by randomized experiment.

The remainder of this paper is organized as follows. Section 3 presents experimental method including the description of participants, contents of home energy report, and evaluation method of the effect. Section 4 provides experimental result and Section 6 concludes on energy conservation methods including use of home energy report.

3. Method

3.1. Participants

We selected households for the treatment and control groups randomly from the households registered in the HEMS database [19]. The database possesses HEMS data obtained from homebuilders, condominium developers, and HEMS data service providers at various resolutions for approximately 2000 households. In addition to electricity consumption data, the database contains survey responses regarding household resident attribute information, including building type, household data, appliance use, electricity contracts, and behavior, which were collected through questionnaires. The database is linked to weather and appliance specification databases to enable analysis of these factors in connection with HEMS data.

We selected treatment and control groups from households who have installed HEMS and cooperate with the experiment. Based on the experiment schedule, households previously accepted were set as the treatment group, and households agreed later were treated as the control group. Differences between the attributes of both groups were controlled by panel data regression random effects model analysis. Households in three sites were selected for an experiment in which home energy reports were sent to a treatment group.

Table 1 shows the major attributes of the sample households.

Sites A and B consisted of detached houses, whereas Site C consisted of apartment buildings. Common characteristics among the three sites included relatively new houses, younger heads of household, and locations in primarily warm climate regions. Compared to average Japanese households, the sample households had larger floor areas and more members and were more likely to be centrally air conditioned. All households in Site A lived in an all-