Applied Energy 184 (2016) 523–530

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

One size does not fit all: Establishing the need for targeted eco-feedback

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HIGHLIGHTS

- We examined occupants' responses to an eco-feedback system in a commercial building.
- We analyzed the impact of notifications on the level of engagement of participants.
- We found notification effectiveness to be highly dependent on the type of feedback.
- Occupant response to uniform normative comparison eco-feedback varied substantially.
- This highlights the need for targeted eco-feedback based on consumption patterns.

ARTICLE INFO

Article history:
Received 27 March 2016
Received in revised form 8 October 2016
Accepted 14 October 2016
Available online 24 October 2016

Keywords:
Eco-feedback
Energy efficiency
Historical comparison
Normative comparison
Occupant behavior

ABSTRACT

Despite all improvements in buildings shell, equipment, and design, CO_2 emissions from buildings are increasing. Since occupants spend more than 87% of their time indoors, they are inseparable and significant elements of building system dynamics. Hence, there is a great potential for energy efficiency in buildings using a wide range of programs such as intervention and eco-feedback. Despite the high level of individual differences and intra-class variability of occupants' behaviors, the current state-of-the-art eco-feedback programs treat all the occupants uniformly and do not target and tailor the feedback. Therefore, it leaves an opportunity to increase the efficacy of eco-feedback systems through the designing of tailored and targeted programs. In this paper, we conducted a comprehensive analysis and tested hypotheses on occupants' behavioral responses to a normative comparison feedback program, in addition to the impact of notifications on the level of engagement of each group of occupants. We categorized occupants who participated in the normative comparison feedback program into three groups (i.e. low, medium, and high energy consumers) based on their baseline energy consumption, and tested 9 hypotheses. A mixed-effect regression model (MRM) and a paired *t*-test was implemented to evaluate the proposed hypotheses. The hypotheses examine the variability of occupants' responses under the same eco-feedback program, and the effectiveness of notifications on reinforcing occupants' engagement in these programs. The contribution of this paper is two-fold: (1) reporting that the effectiveness of the notifications in eco-feedback programs are initially highly dependent on the type and the nature of the program, and then the interval and the content of the notification, and (2) demonstrating the variability of occupants' behavioral responses under the same normative comparison eco-feedback program. These findings indicate the need for a shift in focus toward targeted and tailored feedback programs which treat occupants based on their characteristics. Moreover, they highlight the need for eco-feedback design, development, testing and implementation research that acknowledges and addresses differences in occupant responses to feedback.

1. Introduction

The building sector is accountable for almost 40% of energy-use in the US [1]. Despite all improvements in building shell, equipment, and design, there is still room for further improvement of building energy consumption. As major energy-use sources, such as HVAC and lighting systems, become more efficient, the share

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http://dx.doi.org/10.1016/j.apenergy.2016.10.036
0306-2619/

of miscellaneous energy consumption (e.g. plug loads) which are commonly controlled by building occupants increase. Thus, it calls for investigating potential occupant-based energy saving opportunities in buildings. Since occupants spend more than 87% of their time indoors [2], buildings can benefit from a wide range of programs such as intervention and eco-feedback.

Although occupants can be a potential contributing component of building energy efficiency, due to high intra-class variability, complexity, and uncertainty of their behaviors, finding an appropriate motivation, estimating their potential energy savings, and sustaining changes in behavior are challenging. The behavior targeted in such energy efficiency programs is environmentally significant behavior [3]. More precisely, a subcategory of environmentally significant behaviors referred to as private-sphere environmentalism behavior. This subcategory is defined as a type of behavior in the private sphere that is focused on purchase, use, and disposal of personal and household products and equipment which have environmental impact [3]. In the past decade, a fair body of literature has been shaped around this topic with the primary focus on residential occupants' energy efficiency, and only a secondary focus on the commercial sector. Despite the significant progress being made in the field of occupant energy efficiency across building types, existing developed programs treat occupants uniformly. Yet, we know that motivations, demographics, habits, working conditions, and many other characteristics of the occupants are considerably different. This discrepancy between the variability of occupants' characteristics and the fact that they are treated uniformly is the point of departure for this paper. We examine the variability of occupants' responses to a uniform eco-feedback study.

In this paper, we build on a previous study [4] conducted in a 6 story commercial building located in Denver, CO, to examine the effect of occupants' energy saving responses to a real-time eco-feedback program launched at their work place. The occupants' energy consumption were monitored at a workstation-level using wireless smart meters and they were provided with normative and historical comparison feedback based on their randomly assigned study group. We ranked and divided the occupants that participated in a normative comparison group into three categories (i.e. high, medium, and low energy consumers) and implemented a mixed-effect regression model (MRM) approach to test multiple hypotheses regarding the variability of behavioral responses received from occupants who participated in a normative comparison feedback program. Furthermore, the level of engagement (i.e. logins to the system after receiving a notification) of occupants in each group was tested using a paired *t*-test in order to investigate the effectiveness of notifications sent throughout the study.

2. Related work

There is a vast body of knowledge focused on occupants' energy efficiency in buildings. The majority of these efforts have been focused on residential buildings. Among a wide range of occupant-based energy efficiency programs, eco-feedback systems have been demonstrated to be among the more effective approaches. Thus, in this section, we provide a comprehensive literature review on the variety of eco-feedback programs implemented in commercial and residential buildings. First, we address the studies conducted in the residential sector with all psychological, computational, and design elements taken into account. Then, we review commercial building eco-feedback studies and discuss the existing gaps of knowledge in each area.

Eco-feedback studies in residential buildings can be categorized based on various characteristics. In this study, we have chosen to distinguish the studies based on their feedback resolution, psychological motivators, feedback methods, and the length of the experiments. Eco-feedback programs incorporate a wide range of feedback methods starting with the most conventional paper-based approaches [5,6], to advanced computer-based feedback [7–11], and in-home display units [12–16]. The frequency and resolution of feedback is usually correlated with the level of technology incorporated in each program; however, one literature review conducted on eco-feedback systems [17] found frequent feedback along with digital presentation to be among the most important elements of such systems. Allcott [5] conducted a comprehensive analysis on a massive dataset captured through Opower Inc. and reported that among monthly, bi-monthly, and quarterly feedback provided to occupants, quarterly feedback was the most effective frequency considering the cost-benefit analysis of the program. While the body of research is in favor of more frequent feedback provided to occupants, the cost-effectiveness analysis favors less frequent feedback.

Feedback studies in residential buildings have been conducted in a wide range of lengths and sample sizes. Naturally, the longer the length of the study and the larger the sample size, the more reliable the results. Thus, the studies can be divided broadly into two categories: short-term and long-term. Based on the literature, the short-term effect of eco-feedback studies are relatively stronger than the long-term effect, meaning that the energy savings are higher and occupants are more engaged in the beginning of the program [18]. In terms of occupants' engagement in the program measured by the number of logins to the online platforms, visiting in-home displays, and also responding to the notifications sent out during the study, the general trend supports the decay of engagement over time [19]. However, studies have shown that the engagement and savings diminish to an extent and reach a plateau at some point [18]. Moreover, it has been established that the number of visits to eco-feedback platforms are statistically correlated to the level of energy savings over time [7].

There are various psychological motivators implemented in the aforementioned studies to motivate occupants to sustainably save energy. Social norms [5,10,20–23], historical comparison [11,13,24–26], goal setting [12,27,28], and many other approaches have been implemented in studies to evaluate the effectiveness of each on inducing energy savings. The social norm (e.g. normative comparison) has been shown to be among the most effective approaches [6]. Despite the limited efforts on targeting utilities' customers [29,30] and understanding the underlying correlations between occupants' behavior and their energy consumption [31,32], these programs (e.g. normative comparison, historical comparison, etc.) treat all occupants uniformly regardless of their characteristics, demographic information, and habits, which may lead to weak response from a substantial group of occupants who are not motivated by a non-differentiated eco-feedback program. Unfortunately, the effect of non-differentiated feedback has not been employed to improve the engagement and motivation of all occupants in eco-feedback studies. A tailored and targeted energy efficiency program may enhance the efficacy of such programs. The literature measures the efficacy of the energy feedback studies with the primary scale of percentage of energy savings compared to the baseline, and a secondary scale of the level of engagement of occupants in the program [33,34]. The level of engagement is measured based on the number of logins and the amount of time occupants spend in energy feedback platforms understanding their energy consumption patterns and learning how to reduce their energy consumption.

Commercial sector eco-feedback programs differ from residential sector programs for several reasons. In the commercial sector (especially office buildings), the majority of occupants do not have direct financial incentives to save energy in the building [35]. Moreover, in office buildings, productivity is a major concern of