



A window into occupant-driven energy outcomes: Leveraging sub-metering infrastructure to examine psychosocial factors driving long-term outcomes of short-term competition-based energy interventions



Kyle Konis^{a,*}, Michael Orosz^{b,1}, Nicole Sintov^{b,c}

^a University of Southern California, School of Architecture, WAH 204, Los Angeles, CA 90089-0291, USA

^b USC Information Sciences Institute, 4676 Admiralty Way # 1001, Marina del Rey, CA 90292, USA

^c Arnold Schwarzenegger Institute of State and Global Policy, USC Sol Price School of Public Policy, Los Angeles, CA 90089, USA

ARTICLE INFO

Article history:

Received 7 September 2015

Received in revised form 4 January 2016

Accepted 5 January 2016

Available online 7 January 2016

Keywords:

Campus building energy competitions

Energy feedback

Demand response

Psychosocial factors

Building electricity sub-metering

ABSTRACT

Competition-based “energy saving” interventions are increasingly promoted as an effective strategy for reducing energy consumption in buildings with large occupant controlled electrical loads. However, the factors that drive energy savings in such interventions are not well understood, nor are the impacts of short-term competitions on long-term energy performance. A total of 39 8-occupant suites in a freshman residence hall were instrumented with “smart” electric meters, which recorded circuit-level electricity consumption at 15-min intervals. During a three-week Fall 2014 competition, suites competed to reduce their overall electricity demand and achieved a 6.4% reduction in whole-building demand overall and a 12% reduction during hours of peak demand (from 12:00 to 19:00), despite peak seasonal temperatures and all-time record electricity demand. Analysis incorporating weather-normalized HVAC demand after the competition showed a significant “rebound” for a large portion of the suites (19), however 12 suites made further reductions, and the remainder maintained demand at the competition level. We compared energy data with self-reported survey data and identified self-efficacy beliefs, pro-environmental behaviors, and sense of affiliation with other residents of the hall as key factors distinguishing the suites with the greatest and most persistent reductions in demand from suites that maintained or increased demand.

© 2016 Elsevier B.V. All rights reserved.

1. Introduction

In buildings where occupant-controlled electrical loads account for a large portion of whole-building demand, it is well known that improvements in building performance are dependent on systems which can effectively influence the participation and actions of occupants. Sociotechnical systems that visually present personalized energy feedback to occupants in real time are increasingly promoted as an effective technology for addressing this challenge by enabling competition-based “energy saving” interventions [10]. However, the factors that drive energy savings in such interventions are not well understood, nor are the impacts of such short-term interventions on long-term building energy

performance. The objectives of the present study are to (1) examine long-term changes following a brief behavioral intervention to reduce energy use in a residential building; (2) investigate underlying psychosocial processes of change involved in the management of unregulated loads; and (3) explore the potential for demand response among unregulated loads.

1.1. Significance

Rising carbon dioxide (CO₂) emissions among the U.S. residential and commercial sector are projected through 2040, equating to 2150.4 million metric tons of CO₂ [29–31]. To mitigate this predicted growth and its corresponding environmental and public health consequences, it is critical to manage energy demand. To achieve the 80% statewide greenhouse gas reduction target by 2050 mandated by California Executive Order S-3-05, the existing building stock must become 40% more energy efficient and all new construction must reach zero-net-energy by 2030 [8]. This objective can be facilitated using Demand Response (DR) capable

* Corresponding author. Tel.: +1 213 740 2723.

E-mail addresses: kkonis@usc.edu (K. Konis), mdorosz@isi.edu (M. Orosz), sintov@usc.edu (N. Sintov).

¹ Tel.: +1 310 448 8266.

buildings in which building management system (BMSs) control regulated loads. However, other building types, in which unregulated loads account for large portions of the total building load, present a significant challenge. Thus, although building infrastructure upgrades offer one approach for reducing building energy use, hardware upgrades alone cannot guarantee energy savings.

Occupant behavior, such as how frequently and intensively occupants choose to use air conditioners and other appliances, also impacts building energy consumption, and offers opportunities for savings. These opportunities are not trivial, with behavior change approaches resulting in savings comparable to technology-focused building retrofits [15]. Additionally, energy efficiency programs deployed in the U.S. from 2009 to 2012 cost 50–67% less per kWh than other power resources, including renewable energy, suggesting that such programs may serve as a financially viable resource [19]. Modifying occupant behavior therefore represents a key opportunity for building energy management.

Recent work has leveraged behavioral science to better understand the theoretical underpinnings of energy use behavior [28], explore the effectiveness of interventions aimed at reducing energy and other resource use [1,2], propose models of sustainable energy technology acceptance [15] and better understand consumer adoption and optimal use of emerging smart grid technologies [25]. There is ample evidence to suggest that behavioral approaches can result in considerable energy savings, but less is known about how people change, or what the long-term impacts of these approaches are.

1.2. Residential energy conservation efforts

A large body of research has investigated the impact of behavioral interventions on reducing energy consumption, particularly in residential buildings [2]. Briefly, based on the principles of operant learning theory, the approaches can be divided into two main categories: antecedents and consequences [27]. Antecedents are stimuli presented prior to the performance of a target behavior that serve as cues or facilitators of that behavior. Examples include information, prompts, modeling, and commitments/goal setting. Consequences are administered following a behavior, and the most common strategies used in residential energy reduction efforts include rewards and several types of feedback. A review of this literature is outside the scope of this paper, but these approaches have received considerable empirical support for their effectiveness in producing energy savings [2].

Creating new opportunities for modifying occupant energy use behaviors, “smart meters” collect high-resolution (e.g., 15-min interval) usage data that can be shared with occupants in near real-time via various user-friendly platforms such as mobile devices and kiosks. This granular energy feedback can better enable building occupants to link their behaviors to their usage data and can motivate conservation. Advancing these efforts, findings suggest that building social tools into the delivery of energy feedback, for instance, socio-technical feedback systems that convey normative feedback [10], offers considerable promise in efforts to improve energy efficiency [1,20,22,23].

1.3. Demand response

Reducing overall consumption is one important goal, and maintaining a reliable power supply is a second, equally important, objective. Even relatively brief lapses in power reliability have significant economic impacts. Estimates for annual economic losses from power interruptions include €150 billion among European Union businesses and \$80 billion in the United States [17]. Because energy demand varies by time of day, U.S. utilities are making efforts to curtail peak loads by managing demand, such as

investing \$700 million annually in DR strategies (i.e., voluntary, time-delimited power usage curtailment events) to reduce peak load [30] as opposed to the traditional strategy of supplying additional generation, usually from higher-polluting energy sources [7]. Although DR forecasting models predict when, where, and how much energy will be used, solving the key problem of managing peak demand requires programs that encourage building occupants to make behavioral changes. There are two primary types of DR programs: (1) voluntary curtailment, which involves appealing to building occupants to temporarily curtail consumption by changing behavior in real time in response to alerts; or (2) direct control, in which occupants permit utilities to remotely control home equipment such as air conditioning units or thermostats. Voluntary curtailment programs typically use prompts and appeals to attempt to persuade occupants to curtail usage. Toward this end, utility-consumer connectivity must be enhanced. Programs must shift from a one-way, utility-to-consumer approach to a more interactive relationship, meeting consumers' needs to maximize program acceptance and enrollment levels.

1.4. Energy reduction interventions in university buildings

University campuses are important targets for energy management efforts for numerous reasons. First, they tend to be large energy consumers, with a considerable amount of energy consumed in residential buildings (e.g., [22]). Second, dormitories provide an excellent controlled setting for studying the efficacy of behavioral interventions because layouts are generally similar in size and basic electric infrastructure (e.g., [4]). Next, college students may be ideal candidates for behavioral interventions. Many students are making major life transitions, including relocating from childhood homes and forming new daily routines. Introducing new behavioral patterns during this time can increase the likelihood of establishing and maintaining new habits [34].

A handful of peer-reviewed studies have evaluated the effectiveness of electricity reduction interventions that applied combinations of the aforementioned intervention strategies to university housing occupants. Savings during interventions ranged from 8 to 19% based on different combinations of strategies [4,5,18,21]. Only two studies examined long-term post-intervention impacts. Although they observed reduced levels of consumption up to 1-year follow-up, further research on this topic is warranted [18].

1.5. Building energy competitions

In recent years, many campuses have packaged combinations of intervention strategies as part of energy reduction competitions. Facilitated by socio-technical feedback systems, Campus Conservation Nationals (CCN) has recently been established as an annual challenge in which colleges across North America compete to reduce energy and water consumption over several weeks [9]. Although these competitions appear to be effective in motivating energy reductions, with 109 campuses saving a combined total of 2.2 million kWh electricity in 2014, the majority of projects have not undergone peer review, leaving unanswered questions about their impacts. However, Senbel and colleagues [24] leveraged an ongoing CCN competition across six college campuses in British Columbia to study the combined impact of commitments, prompts, socio-technical feedback, civic engagement tasks, and individual- and group-level virtual incentives. During the 3-week test period, electricity use in the test dormitory, which housed approximately 1800 students (approximately 11% formally participated in the competition), dropped by 16%, and remained at a reduced level over the remaining five months of the academic year (7% below baseline).

Download English Version:

<https://daneshyari.com/en/article/6730474>

Download Persian Version:

<https://daneshyari.com/article/6730474>

[Daneshyari.com](https://daneshyari.com)