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Mobile Application Driven Diffusion of Energy Saving Practices from Non-Residential to Residential Buildings

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ABSTRACT

One of the major barriers to closing the energy efficiency gap is the failure to successfully inform the population about measures to conserve energy. This paper introduces the design of a mobile application developed to improve energy conservation of residential buildings by informing occupants of transferrable energy efficient green features in a green-certified, non-residential building. The application was developed to investigate dissemination of transferable energy saving practices to explore spillover effects from non-residential to residential buildings. Our research aims to capitalize on such spillover effects to narrow the energy efficiency gap.

Keywords: Buildings, diffusion of innovations, energy conservation, energy efficiency, energy saving practices, green features, mobile application, spillover effect

NONMENCLATURE

Abbreviations	
EGF	Energy green features
ESP	Energy-saving practices

1. INTRODUCTION

Energy consumption and the associated greenhouse gas emissions have become a rising concern over the past couple of decades. The United States Environmental Protection Agency prioritizes energy efficiency as a significant portion of the National Action Plan for Energy Efficiency [1] that aims to be a more sustainable and direct pathway towards energy conservation. However, the energy efficiency gap—the difference that exists between actual and optimal energy use [2]—is a substantial barrier which impedes energy conservation efforts. Understanding the energy efficiency gap is the first step towards realizing the need for innovative mechanisms that can reduce this gap. Nevertheless, to achieve energy efficiency, it is important to focus not only on technologies that enable the most optimal use of resources, but also on cultivating energy conservation behavior because the environmental impact of day-to-day choices can balance current energy efficiency efforts.

When implementing energy conservation strategies in buildings, failure to successfully inform occupants about different options and measures to conserve energy (here referred to as energy information gap) is one of the major factors leading to the energy efficiency gap [3]. Moreover, the definition of electricity is often “abstract, invisible, and untouchable” [4] to the general public. Therefore, our research focuses on narrowing the energy efficiency gap by developing a mobile application that can clarify and disseminate energy conservation measures to cultivate occupant energy behavioral changes [5], among the general public and even among those with pro-environmental attitudes [6]. This paper introduces a mobile application designed as an interactive platform that can provide energy green feature (EGF) information and the associated energy-saving practices (ESP) to occupants.

We first present a review of the relevant literature. Then, we present the methodology that includes the theory framework, application development, and mobile application design (front and back-end). We finish with conclusions and future research plans.

2. LITERATURE REVIEW

2.1 Energy Conservation Systems Overview

Previous research has focused on bridging the energy information gap by implementing questionnaires [7], [8] or technology to improve occupant energy-related behavior in commercial or residential buildings. Some technologies used include web-based recommender systems [9], eco-feedback systems [10], [11] mobile applications for increasing energy awareness [12] and web-based conservation tools [13]. This previous research presented evidence of how occupant behavior in buildings drives changes in energy consumption. Sćepanović et al. [14] presented evidence that the physical context (e.g., buildings) can have a direct impact on people and their energy related

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behavior. In other words, the built environment has a potential to impact the energy behavior of its occupants; however, we further argue that this impact has the potential to diffuse from one setting to another, particularly in terms of spillovers across building types.

2.2 Non-residential to Residential Spillover Effects

Despite an abundance of research on occupant energy-saving behavior in commercial or residential buildings, the spillover effect of occupant pro-environmental behaviors from one building type to another is limited. Davis et al. [8] identified a positive correlation between work and home attitudes and behaviors. Others studied the relationship between work and home behaviors [15], [16] examining nuances in relational differences in home and work environments.

Recently, Lin and Azar [17] explored patterns of, and links between, energy conservation at work and at home. This survey-based study—narrowly focused on the likelihood of equivalent behaviors performed at work and at home—found a positive relationship between work and home energy-saving behaviors, providing some evidence of potential positive spillover effects. Here, we focus on targeting the diffusion of energy-saving practices from a non-residential, green-certified building to residential settings through a mobile application. Offering energy-saving information through a mobile application, which has a high adoption rate by the general public [7], has the potential to improve awareness, encourage energy conservation behavior, and generate positive spillover effects across building types. In particular, we focus on providing examples of implemented EGF in a non-residential building that can potentially impact occupants' ESP at home.

Furthermore, this paper also focuses on the diffusion of information from person to person which implies communication of EGF and ESP from the information receiver to others. The latter constitutes the sharing of information with others to expand the potential impact that this energy efficient information has and multiplying the overall energy conservation measures to reduce the energy efficiency gap.

3. METHODS

This paper introduces a mobile application that familiarizes users with EGF in a green-certified non-residential building and the transferable ESP that the occupant can implement at home. Taking the general preference for smartphone energy-saving applications [7] into consideration, a mobile application was selected. Exploiting everyday technology used by occupants (i.e., smartphones) may enhance positive spillover effects.

3.1 Testbed Building

The Kendeda Building at the Georgia Institute of Technology was selected as the testbed building. This is a net-positive building constructed to create a space that can demonstrate that an energy-positive commercial building is feasible in the hot and humid climate of the southeast of the United States. The term energy-positive implies that the building needs to generate more energy than it consumes by employing renewable energy technology and energy efficient features.

3.2 Diffusion of Innovations Theory-based Design

The design of this mobile application is based on the theory of diffusion of innovations. This theory depends on the type of innovation, communication channel, time and the social system [18]. Similarly, the application is designed as a communication channel to provide EGF information to occupants while employing the innovation-decision process from awareness to implementation of ESP [19].

3.3 Application Development

The user interface is designed to bridge the energy information gap by informing occupants of current energy efficient technology (i.e., EGF) applied in the Kendeda Building, but the same framework could be applied to other buildings.

3.3.1 Framework design

The information provided through the mobile application is intended to increase the awareness of occupants, specifically of the technology that reduces the energy burden of the day-to-day activities invested in the Kendeda Building. When occupants learn that the features implemented in non-residential buildings are successful in reducing their impact on climate change, it can potentially influence occupants to take related energy-saving decisions and actions at home. By providing transferable ESP, we expand the occupants' knowledge from non-residential EGF to energy-saving behaviors in the residential sector. Table 1 provides a parallel comparison of the qualitative data of Kendeda Building EGF and residential ESP by function. This constitutes the core framework for the mobile application design.

3.3.2 Mobile application front-end design

Table 1 Energy green features (EGF) vs. Energy-saving practices (ESP) by function

Function	Kendeda EGF	Residential ESP
Renewable Energy Production	PV solar panel array used as the only source of energy	Purchase personalized solar home gadgets to reduce electricity used to charge devices
Reducing HVAC Energy Demand	High volume ceiling fans to reduce temperature set point and achieve occupant comfort	Turn on ceiling fans to raise thermostat setting for cooling about 4°F with no reduction in comfort
	Radiant flooring system: heating and cooling floors for direct occupant comfort	Adjust thermostat setpoints for daytime/nighttime and occupied/ unoccupied settings
	Canopy and automatic blinds provide shade to building	Use blinds and curtains at home to reduce heat and cold intrusion, depending on the season
Reducing Lighting Energy Demand	Skylights and clerestory windows for continuous daylighting in building	Incorporate daylighting to bring sunlight into the home
	Motion-activated energy efficient lights	Purchase energy efficient LED light bulbs

The mobile application design is centered on the social construction of innovation decision making presented in [19]. Therefore, the order in which each frame is presented to the user is specifically designed to present the user with the required information in the innovation decision process [19]. The innovation decision process is based on the prior conditions inherent to each person, i.e., attitudes, beliefs, and previous and existing behaviors. After understanding the user's prior conditions, the decision process depends on the knowledge/awareness of the adopter and the level of persuasion or attractiveness of the innovation. Finally, a decision is made, implemented, and confirmed.

As previous studies have concluded, attitude-tailored information has a higher probability of success [13]. In Figure 1a, we present the first user-interface screen that asks about the occupant's preferences regarding social/health, economical, or environmental feedback. This step is crucial to the framework of the decision process because it tailors the information to what is most important to the user, which increases the probability of adopting the ESP. In addition, our user interface follows a "context-aware recommender system" [20] based on the user's prior conditions to provide tailored information about Kendeda Building EGFs (Figure 1b) and residential ESP (Figure 1c).

To increase occupants' knowledge (Figure 1b), the mobile application is used as a persuasion mechanism that provides social/health (blue box), economical (yellow box), or environmental (green box) benefits of each energy-saving practice. Only the type of feedback selected in Figure 1a is presented to the app user in Figure 1b. This mobile application presents ESP from known sources for occupants to decide to make a change and apply ESP at home. It is important to note that the mobile application gives the option to the user to provide residential energy-saving behaviors before any practices are presented to reduce imposing ideas on users (Figure 1b). Therefore, it is the choice of the user to receive any suggestions from the application. The final steps of the decision process are implementation and confirmation of the decision. Future phases of this ongoing research will measure these final steps through weekly surveys that will directly measure the change in attitudes, beliefs, and behaviors of mobile application users tested.

The mobile application framework is an extension of a community-scale energy feedback application [21]. For further details on the baseline of the aforementioned application, please refer to the methodology in [21].

3.3.3 Mobile application back-end design

The current version of the mobile application is developed for iOS devices using XCode IDE (integrated development environment) and Swift 5 programming language. In this section, we focus on the mechanics that allow the mobile application to present the necessary information as required. The overall work on the back end involves differentiating tailored information from the beginning and pairing non-residential EGF with residential ESP.

In the introduction frame (Figure 1a), we add the PickerView object that provides multiple user-interface elements that lay out the prior conditions detailed in section 3.3.2. The interrelations between the UIPickerView selection and the information presented to the user in subsequent frames (e.g., Figure 1b) is coded with an "if" statement in the Swift code editor.

The EGF frame (Figure 1b) that intends to provide Kendeda Building information to the user presents the

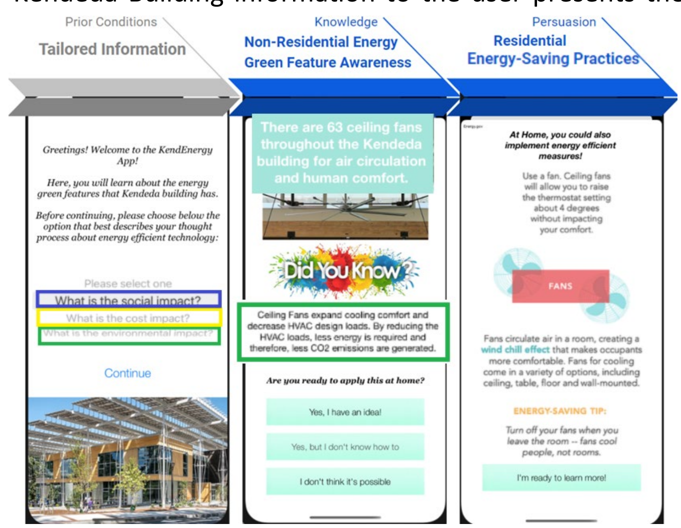

Figure 1 Mobile application framework: (a) Prior conditions, (b) Knowledge, (c) Persuasion.

environmental, economical, or health information depending on the user selection from the Picker View. The EGF information is extracted from the Georgia Tech Energy Report and presented through ImageView objects. All the different EGF are scrutinized and compared (see Table 1) with practices that could be performed at home to promote meaninful spillover effects from non-residential to residential buildings. The ESP frame (Figure 1c) that intends to provide transferable energy efficient practices at home is designed based on public energy efficiency information found in several sources, primarily the U.S. Department of Energy. This frame intends to diffuse this readily available but rarely accessed information, increasing the public's awareness of energy efficiency measures.

Lastly, the application was tested first on the XCode simulator for different iPhone screens to check that all features work as expected. Then, the application was downloaded on an iOS device and the different options from the PickerView tested for accuracy in the sequence of the information presented in each frame.

4. CONCLUSIONS AND FUTURE RESEARCH

The mobile application described in this paper is intended to bridge the energy information gap between energy green features in non-residential buildings and energy-saving practices at home. It applies diffusion of innovations theory in its design to engender and enhance spillover effects across building types. The next phase in the research will be to conduct a human subject study to test for the potential and magnitude of such spillover effects from non-residential to residential buildings. Future research can also expand the application to other device platforms (e.g., Android) and types of buildings.

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