Motivate Environmentally Sustainable Thermostat-Use through Goal-Setting, Just-In-Time Recommendations, and Behavior Reflection

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ABSTRACT

Rising power demands resulting from technological advancements is an increasingly important global issue. One way to tackle this problem is to motivate individual behavior change, for which the ubiquity of mobile phones offer an ideal platform to influence consumption behavior of users. In this paper we explore the possibilities for using timely recommendations, goal-setting, immediate feedback, and visualization of past consumption behavior in order to motivate people to reduce power consumption resulting from heating/cooling devices. We describe a mobile application which gives the user direct access to the thermostat and provides feedback everyday on how sustainable the user was on the previous day. In addition to this feedback, it gives recommendations to improve the behavior and also offers a behavior overview. The contributions of this paper include a working system for remote control over the thermostat and a goal-setting, recommendation, and feedback application designed to influence a user's behavior.

Categories and Subject Descriptors

H5.m. [**Information interfaces and presentation**]: e.g., HCI

Keywords

Eco-feedback, Sustainability, Environmental HCI

General Terms

Design, Human Factors

1. INTRODUCTION

Technological advancements over the past few decades have allowed us to live more comfortable lives at the cost of consuming increased amounts of energy. Devices like refrigerators, air conditioning units, or home entertainment systems provide quality of life improvements at the cost of placing strain on limited global resources. As recognition and awareness of this trend have grown, there have been increasing calls for citizens to use resources responsibly. Investigations into how energy is consumed in homes provide valuable suggestions for how this goal can be achieved and indicate that temperature regulation systems (such as furnaces and air conditioners) are a key target. They are reported to be responsible for nearly 25% of the consumption in an average American household [7].

Despite the high-energy consumption (and costs) incurred by these systems, studies indicate that there are problems with devices intended to increase their efficiency. For instance, programmable thermostats are capable of decreasing the energy use of a temperature regulation system by relaxing the maintained temperatures during particular time periods, such as when homes are empty during the workday. However, 14% of users are reported to not own such a system and, of those that do possess one, over 40% do not use it [8]. Widespread misconceptions also exist regarding suitable home temperatures. For instance, a 2007 interview study [5] reported that 41% of interviewees believed that room temperatures should be lower in summer than in winter. The authors concluded this results in overly cool rooms in summer wasting a lot of power.

These findings also suggest that, generally, people have poor awareness of how their consumption choices and behavior affects the environment. Sensing technologies capable of capturing a user's activity can be combined with digital displays of consumption (e.g., websites, ambient displays, mobile devices) to address this issue and raise awareness of the impact of particular choices. Such systems and devices, which are intended to inform users about the current state of their consumption and their impact on the environment, are known as "eco-feedback technology" [3]. Eco-feedback technology can be used to motivate users to change their long-term behavior.

Research in psychology can inform the development of systems that change a user's behavior. In a recent survey paper, He et al. [4] discussed a wide range of psychological literature and developed a "motivational framework based on

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the Transtheoretical (or Stages of Behavior Change) Model". One of their conclusions was that behavior change happens in stages and that each stage should be supported by qualitatively different kinds of feedback.

An earlier review of environmental psychology papers performed by Abrahamse et al. [1] evaluated the effectiveness of two intervention strategies - antecedent and consequence strategies. They described antecedent intervention to "influence one or more determinants prior to the performance of behavior" and considered four techniques: commitment, goal setting, information, and modeling. One of the conclusions they drew was that presenting the user with one of these interventions alone is not sufficient, but for example combining them with other techniques such as feedback proved effective in influencing behavior. Consequence strategies on the other hand are based on the assumption that providing users with positive or negative consequences will influence behavior. They analyzed how different forms of feedback (e.g., continuous, daily, weekly, monthly, or comparative) and the presence of real world rewards influence behavior.They concluded that individual feedback combined with comparative feedback provided also energy reduction in the long run. Rewards on the other hand had only a short-term effect according to their analysis. This strongly suggests that making users aware of their consumption behaviors is an effective method for encouraging their reduction. This is the approach adopted in this work.

We suggest that mobile devices are an ideal platform on which to offer motivation to users and convey benefits incompatible with the functionality of stationary devices. For example, we can use sensors provided by mobile phones (e.g., location sensor, accelerometer, etc.) to infer the user's current activity and predict future ones. This functionality can be used to provide just-in-time feedback about the outcome of actions and provide live recommendations of alternatives.

Integrating all this literature, this paper introduces a mobile application designed to give users feedback about their past behavior, provide timely recommendations to promote behavior change related to temperature regulation power consumption, and to support users in the achievement of the long-term goal of consuming less power in temperature regulation while they are not at home. The application we developed allows users to remotely and conveniently control the thermostat in their apartment using their phone. We believe that the system can be deployed most effectively in the motivations stages of Preparation, Action, and Maintenance identified in the Transtheoretical model described above. The remainder of the paper provides a description of the application and outlines the structure of a study that we intend to run as the next stage of our work.

2. SYSTEM DESCRIPTION

We designed a system to help people reduce power consumption resulting from domestic heating and cooling devices. It informs the user about his behavior by giving an overview over past consumption in the form of a graph. Studies have shown [1] that providing the user with tailored information about their consumption can result in reduced energy consumption. Through timely recommendations on how to save energy, the system aims to help the user's decision-making process to behave more environmentally sustainably. In order to further motivate the user, he is given a savings goal and the application indicates how well this goal was met the day before, the current week, or the current month. We provide the user with the challenging goal of reducing at-home temperature to 65°F, because previous work has shown that more attainable goals, although easier to achieve, have lower rates of success [1].The system is designed to inform the user and motivate him to change his long-term behavior. We intentionally combined goal-setting with feedback techniques and tailored information to increase the chances that people will reduce energy consumption.

Through a mobile phone application, the user is offered remote control over the thermostat. This allows error recovery in case the user forgot to set the thermostat before leaving the house. In addition to supporting manual and programmatic control of the at-home temperature, we also offer automatic control over the thermostat, reducing energy consumption when the user is not at home, and returning the at-home temperature to a desired level when the system predicts the user is returning home. In doing so, the system aims to support the user in setting the right temperatures.

The advantage the system offers a user is not only error recovery through remote control, but also feedback if a behavior was environmentally positive or negative. Aditionally it provides positive reinforcement if the behavior the day before was positive or timely suggestions on how to improve the behavior in case it was not positive.

To support the automated control of the thermostat, we gather continuous location information using a mobile application. Using the current location and past movement data we are able to determine the time a user is predicted to return home. We leverage a robust location prediction algorithm developed by our research group, which aims to predict future destinations based on prior and current movement data ([9]). Using this predicted return time, we can automatically control the thermostat as described above. The location information is not only used for predicting a user's return time, but also to calculate how much power was consumed by heating/cooling devices during the time the user is not at home and while he is at home.

In addition to location information we also collect inside, outside, and the thermostat's temperature setting for the user's apartment. This information is used to provide feedback on the user's behavior and also to give recommendations on how to improve an environmentally negative behavior. To understand a user's reasoning for changing the thermostat's set temperature, we also query the user immediately after a manual change to a higher temperature has occurred.

The system was based on a commercial home automation system from Insteon [6] and a custom mobile phone application written on Google Android. Logically it consists of three main parts: the home automation system, the mobile phone, and a central server. The following two sections will give a short description of the home automation system and then describe the mobile phone application.

2.1 Home Automation System

Home automation - the use of small modules to extend appliances with remote control and automation features - is a commercially available technology. The Insteon system used in this work allows the remote regulation of home temperature and also provides support for the calculation of power consumption. Calculating the power consumption of heating or cooling devices (e.g., furnaces or air conditioner) is a complex problem, because it not only depends on the length of time a device is active, but also on a set of complex variables including: the efficiency of the heating/cooling device, the volume of the home space, the current inside and outside temperature, the thickness and material of the walls, the number of walls exposed to outside conditions, and the number and kind of windows in the walls, to name a few issues. Because measuring these data is challenging for individual users the system presented in this paper used a simplified set of calculations using an equation provided by the U.S. Department of Energy:

$$\mathrm{AHC(city)} = \mathrm{C}_{adj} * \left(\frac{hdd_{city}}{hdd_{us}}\right) * (1 + S * (T_{wAvg} - T_{typ}))$$

Legend:

AHC(city)	=	Annual Heating Costs for city
C_{adj}	=	Adjusted consumption (gas furnace) in mBTU
$\mathrm{hdd}_{city/us}$	=	Average number of Heating Degree Days
S	=	Savings per degree of setback temperature in percent
T_{wAvg}	=	Set temperature as weighted average
T_{typ}	=	Typical indoor temperature during heating season

This equation assumes standard values for some of these variables and uses differences between inside and outside temperature and the number of hours the user was at home and away from home to calculate the power consumption. We believe the results of this calculation to be sufficiently indicative of real consumption to serve as effective feedback.

2.2 Mobile Phone Application

The mobile phone application was developed and deployed on T-Mobile G1 phones running Google Android. It consists of several components and is the core of the system described in this paper. Its key function is to collect and transmit its current location to a central server in real time and support the motivational techniques described in the beginning of this chapter. Using the transmitted location it enables us to estimate whether or not a user is at home, or whether they are likely to return home in the near future. Furthermore we are able to calculate the power consumption while the user is at home or out and about in the world. The application provides an interface composed of three main components: a temperature control screen which allows remote control over the home automation system, a graph overview showing past behavior, and a recommendation screen. Each of these components is introduced in the following subsections.

2.3 Temperature Control

This interface component allows users to view and control the current temperature in their homes. This feature was intended to support error recovery (for instance, by allowing correction after forgetting to adjust the temperature settings prior to leaving home) but also to provide a sense of security and control - to reassure users that they remain in control of the system even though it incorporates significant automated elements. Such privacy and lack of control concerns are often raised with novel technology incorporating automation or context sensing control and can result in users developing negative opinions about the systems. By providing a manual override, the system presented in this paper hopes to avoid this problem. In addition to remote control we also ask the user why he increased the temperature in the apartment, because we also strive to understand a user's reasoning it.

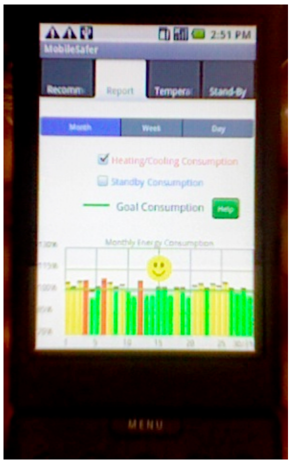

Figure 1: Screenshot of Graph Overview Screen.

2.4 Graph Overview

The graph overview is one of the core feedback mechanisms in the application. As illustrated in **Figure 1**, it offers users a consumption overview split into daily, weekly, and monthly activity. Each sub-graph includes a goal line highlighting the difference between intended and achieved levels of consumption. This is highlighted using a simple red, yellow, and green color scheme. This visualization is designed so that users can see at a glance their performance over days, weeks and months. By including these longer periods of time, the system aims to convey a sense of mounting achievement and provide motivation to continue with and/or improve sustainable behaviors. In order to further support this and provide positive reinforcement, a small smiley face is shown if users achieve green behavior for more than half of the days in a particular week or month. As described in [4], individuals profit from positive reinforcement of their actions, which gives them a feeling of success and competence. The graph system is designed to provide such feedback.

2.5 Recommendations

The recommendations screen aims to provide recommendations to users on how to achieve consumption goals through behaving sustainably. Once again, to present a clear visual representation we adopted a simple red, yellow and green color scheme for this UI. The user is shown a green screen when he behaves sustainably the previous day, by turning down the temperature while away from home to at least 60°F and turning down the temperature to 65°F while at home. If the user sets a higher temperature while at home, he is shown a yellow screen. If the temperature is consistently high throughout the day, the system will show him a red screen. For the yellow and red screen we give the user a recommendation on how to achieve sustainable behavior, which is in essence an explanation about why his behavior was not sustainable. We also suggest wearing additional clothing to compensate for cool temperatures at home.

In addition to recommendations and behavior indications we also inform users about the environmental impact of the wasteful behavior of leaving temperature regulation systems active in empty homes. This is done simply by calculating and presenting the number of 60W light bulbs that could have be powered by the wasted energy.

The recommendations screen is the first screen shown to the user upon application startup. Every morning the phone notifies the user about the previous days consumption data by flashing the onboard LED and vibrating. The goal of this feedback is to provide positive reinforcement for sustainable behavior and to inform users about the impact of their behavior on the environment. In this way, we hope to provide an incentive for users to alter unsustainable behaviors. Our application informs users about problematic behaviors, highlights the impact of these behaviors, and gives specific recommendations on how to enact change. By showing this information in the mornings, prior to regular departures to work, we hope to be able influence the user's behavior in a timely and appropriate fashion. Studies have shown [2] that frequently updated feedbacks with multiple feedback options such as comparisons of several days or providing additional information sources like recommendations are most effective.

3. STUDY DESCRIPTION

In order to test the system and evaluate whether or not it can influence a user's behavior and awareness of environmental issues, a field study of the system is planned. This will take place in winter 2010/2011 and will use a group of 20 recruited participants residing in a city which experiences sub-zero temperatures and significant snowfall for several months. The group will be split into 2 sub-groups, with each group initially being in a manual condition where the user has to change the temperature on his own volition or an automatic condition where the system automatically sets the away-from-home temperature The study will be separated into two phases and each phase will go for 4 weeks, with a study length of 8 weeks in total. After 4 weeks the two sub-groups will switch conditions.

Prior to the study, GPS location data will be captured from each user and used to train the location prediction model and to calculate baseline consumption data. In order to measure environmental attitudes and temperature comfort levels both before and after the study participants will be required to fill out a survey every week. The survey is split into two categories, a temperature survey that will be distributed weekly and a survey to measure environmental attitude, locus-of-control, and self-efficacy that will be conducted at the beginning, middle, and end of the study. The temperature comfort survey will give us data on how the subjective comfort of the user changes through use of our system. We believe that a successful application that aims at changing a users environmental behavior also has to consider a user's comfort level. A system that disregards an individual's subjective comfort level could be unsuccessful because the user rejects it. One goal of our system is to change a user's environmental behavior, thus we need a way to evaluate the impact our two versions of the system have on the environmental awareness of the users. Because we also give the user information about his environmental behavior and recommend actions to change environmentally bad behavior, we measure the locus-of-control and self-efficacy of a user at the beginning, middle, and end of the study. This information will tell us if there was a change, for example, from external locus-of-control, the state where outside sources influence events happening in our life's, to internal locus-of-control, the state where the user himself affects events. Measuring self-efficacy will tell us if our system had a self-empowering effect on users, where they increasingly got confident to influence their environmental behavior.

4. SUMMARY

In this paper we first gave an introduction into the problem space of home power consumption and explained some of the problems with the current use of thermostats. Additionally we highlight how research results from psychology can help to influence a user's behavior and reduce power consumption resulting from heating/cooling devices.

We then described a working prototype of a mobile application designed to influence a user's sustainable practices. Our prototype allows remote control and automated control over the thermostat, gives the user a goal to achieve, provides daily feedback on how well this goal was met, recommendations to achieve the goal (or positive reinforcement in case the goal met), and an overview over past consumption behavior. Our immediate next work is to conduct a study of this prototype with 20 people in the fall.

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