WattBot: A Residential Electricity Monitoring and Feedback System

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Abstract
Electricity production emits carbon dioxide and other gases into the atmosphere, adversely influences global climate change, depletes limited natural resources, and negatively impacts the lives of those who live near power plants. We designed a residential electricity monitoring and feedback system called WattBot, that allows users to track their home energy usage and encourages them to reduce consumption. Our solution is an application for the Apple iPhone and iPod touch that receives data from a wireless hub, allowing users to view, compare and analyze their electricity usage over time.

Keywords
Sustainability, energy use, interaction design, persuasive computing, visualization, feedback

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

Introduction
Defining the Problem
Coal is a readily available resource in and around the state of Indiana. The pollutants emitted from power plants in the region directly affect local residents, and

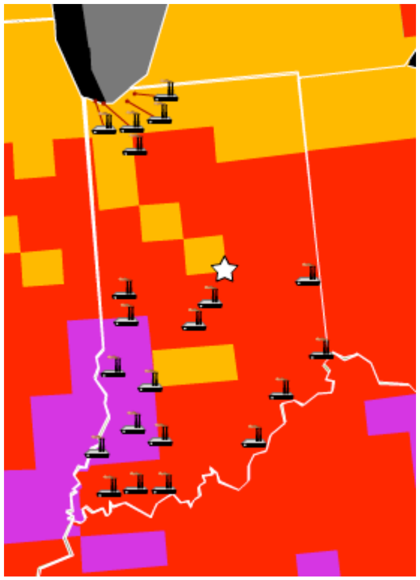

Figure 1 Locations of coal-fired power plants in Indiana [5]

these emissions contribute to global climate change [17]. Coal-fired power plants generate 32% of the carbon dioxide emissions in the United States, more than any other source including surface transportation [16]. In addition, emissions are projected to increase over the next 22 years in response to a 19% increase in electricity demand [9]. Coal power plants emit sulfur dioxide, nitrogen oxides and mercury, causing acid rain, contributing to smog, and polluting lakes, waterways and sources of drinking water [11, 17]. While Indiana ranks twelfth nationally in retail sales of electricity megawatt hours, it ranks second in sulfur dioxide emissions, third in nitrogen oxide emissions, and fourth in carbon dioxide emissions [11].

There are currently 38 public utility power plants in Indiana. Coal fuels 24 of these, including the ten largest power plants in the state. Coal-fueled plants account for almost 96% of the electricity generated in Indiana, which is twice the national average [11, 12]. Nearly 4.5 million people live within a 30-mile radius of at least one of these coal-fired power plants [4, 5].

The Solution Starts At Home

The residential sector consumes more than 30 percent of the electricity in Indiana. If this sector reduced its electricity consumption by 10% it would reduce carbon dioxide emissions by approximately 3.6 million metric tons per year, equal to the average annual emissions of 700,000 passenger vehicles. In addition, this modest reduction in usage would save over $265 million a year in utility costs, which amounts to approximately $100 for every household in Indiana [11, 14, 15, 23].

Energy Usage is Invisible

The costs associated with electricity production are largely invisible to the average homeowner, and there is a pressing need to bring environmental costs to the forefront of individual consciousness [18]. Feedback regarding energy usage is vague and infrequent, and typically limited to a monthly electrical bill. Monetary costs have a limited effect on behavior, influencing the person who pays the bill while bearing little influence on the other members of the household [3].

Consumers require real-time feedback to influence their behavior and reduce energy demand [3, 6]. A display that offers feedback on household electricity usage will help people make more deliberate decisions about their energy consumption habits, and will encourage them to use less electricity [6]. Residential energy consumption can be substantially reduced if homeowners make small behavioral changes in response to information about their energy usage [10, 20].

Exploration

Sustainability Focus Group

Indiana University convened the *Task Force on Campus Sustainability* in 2007 to study issues related to environmental sustainability, and to formulate recommendations for University policy. Early in our design process we invited members of this task force to participate in an exploratory focus group, and their input helped influence our design direction.

One of the primary topics discussed during the focus group was how to effectively persuade people to engage in sustainable practices. By providing people with information about the effects of their behavior, a system can encourage more responsible decision-

Standby power devices continue to use electricity when they are plugged in, even when they are turned off.

Residual devices either consume standby power, or use less than one watt of electricity when turned on.

Device	Percent
Air-Conditioning	16.0%
Residual Devices	15.5%
Refrigerator	13.7%
Space Heating	13.4%
Water Heating	9.1%
Lighting	8.8%

Figure 2 Average U.S. household electricity usage by device [10]

Figure 3 Kill A Watt electricity usage monitor [19]

making in regards to consumption and sustainability. They mentioned a recent real-world example where improved access to electricity and water usage information encouraged conservation efforts in Indiana University residence halls. One member of the focus group suggested a simple indoor electricity meter that could be interpreted by regular people, and would inform them of their electricity usage in real time.

The group made it clear that engaging people and increasing awareness were necessary components in permanently altering attitudes and behavior. They emphasized the need for a catalyst to spur people to action, and we began exploring options for designing such a catalyst.

Existing Solutions

We surveyed a number of home energy devices available on the market or under development, and discovered at least twenty solutions designed for managing or monitoring home electricity usage. Many of these solutions, such as Energy, Inc.'s TED-1000 [8], Blue Line Innovations' PowerCost Monitor [2], and DIY Kyoto's Wattson [7], are devices that passively display information, including the number of kilowatt hours your home has used or how many dollars you have spent per month.

Some of the devices, such as Energy Optimizers Ltd.'s Ploggs [13] or SmartLabs Inc.'s INSTEON SmartLinc [21], don't address energy usage directly, but are rather intended for controlling and automating household appliances. The most exciting products, such as the Agilewaves Resources Monitor [1] and the Tendril Residential Energy Ecosystem [22], offer detailed historical graphs and web-based access, but are not yet commercially available.

Bodystorming Exercise

To further our understanding of the energy consumption problem, we each used a Kill A Watt [19] energy usage monitor to measure the electronic devices in our own homes. We recorded the levels of wattage drawn by these devices so we could recognize and compare how much electricity different devices consumed. The Kill A Watt is a playful tool and we quickly realized how easy it was to overlook the continuous trickle of electricity consumed by devices that use standby power. This exercise enhanced our awareness of standby power consumption and informed the design of our prototype.

Our Design Solution

Guided by our primary and secondary research, we began generating sketches and concepts for our energy feedback system. We considered a number of approaches, including specialized electrical outlets, glowing artifacts, and a series of ambient displays. Our goal was to create an electricity usage display that allowed homeowners to track their real-time and historical home energy consumption, while encouraging them to reduce their energy use.

Our solution, WattBot, is an application for the Apple iPhone or iPod touch that communicates with your home electrical system and allows you to view, compare and analyze your electricity usage over time. The key to encouraging people to engage with this information is to make it truly portable, available anywhere in the house at any time. By taking advantage of the mobile and interactive innovations of

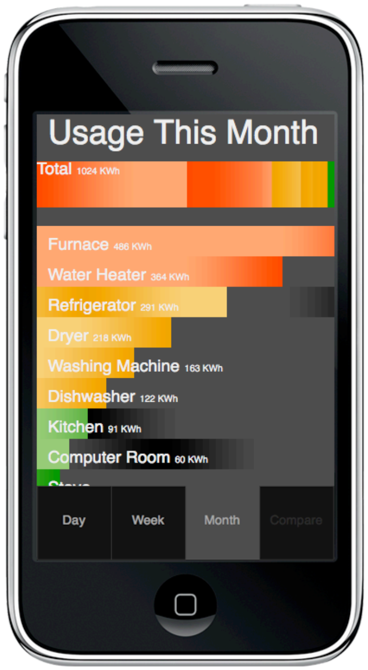

Figure 4 Concept rendering of WattBot application

Figure 5 Circuit breaker box, data collection hub, iPhone

the iPhone we are able to create a compelling experience for our users, expanding the opportunities for our device to influence their behavior.

The main screen of the WattBot application shows each individual circuit of the home. The length of the bar represents how much electricity that particular room, device or appliance has used during a given timeframe [Figure 4]. The bars are sorted by usage, so the biggest offenders are always at the top of the list. Each bar is color-coded depending on how much electricity it has consumed. The topmost bar represents the total household usage, with a shaded portion for each device representing its percentage of the total. In exposing these home energy consumption patterns, users will begin to see opportunities for eliminating unnecessary usage and increasing efficiency. We believe that as people become familiar with these visualizations, they will take meaningful steps towards reducing their electricity consumption.

The colored gradient on each bar animates when a device is currently using energy, at a speed determined by the rate at which it is consuming electricity. During usability testing our participants described this visualization as being similar to the spinning motion of an outdoor electricity meter. Through these animations people will be able to wander around their house, identify items that are consuming electricity, and decide whether or not it is worth having that device turned on. This active, real-time feedback would be useful when preparing to leave for work for the day, and especially handy before leaving on vacation.

Collecting Data

In order to gather the electricity usage data necessary to generate these visualizations, our solution focuses on the home's circuit breaker box. Unlike many energy usage devices on the market that only sense the usage for the entire home, WattBot breaks down its data collection by individual circuit, so it can give users a fine-grained understanding of where their electricity is going. This configuration allows the system to single out energy-intensive devices such as air conditioners, furnaces and dryers, which consume so much electricity that they typically need to be on their own circuit.

Attached to each circuit breaker is a small clamp or wire that measures the amount of electricity passing through the circuit. This wire connects to a data collection hub, which is a small device near the breaker box that records and stores the electricity usage for each circuit [Figure 5]. Instead of a display, the data collection hub broadcasts a wireless signal, allowing users to access its visualization and configuration screens through an application on the iPhone.

Affordability

Chetty et al. address the issue of unintentionally creating a "green divide" between consumers who can afford energy-saving technologies and those who cannot [3]. Our approach requires that people have a home wireless network as well as an iPhone or iPod touch, which may make it cost-prohibitive for some households. It is unlikely, however, that homeowners would be willing to invest in a unique mobile device that only reports on energy usage. Thus, it is reasonable and cost-effective for WattBot to leverage these multi-purpose consumer technologies.

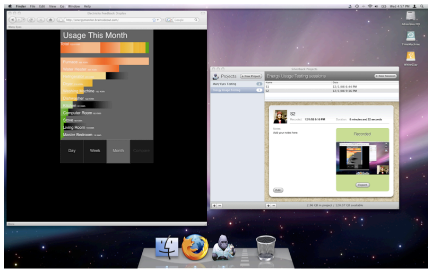

Figure 6 Our WattBot usability testing environment

Prototype available online at http://wattbot.brainsideout.com/

Evaluating The Design

To evaluate our proposed design we created a high-fidelity website prototype of WattBot's energy visualization display [Figure 6]. Using this prototype, we conducted a series of usability studies to gather people's responses to the interface and to uncover any potential problems. When conducting these studies we recorded audio and video to capture the user's facial and verbal reactions, and used a screen recorder to capture the user's actions on the computer.

Our usability participants successfully completed most tasks, which involved navigating through the application and interpreting the meaning behind the visualizations and animation effects. We did discover that the total bar at the top was confusing to users, and that our color scheme was misleading. A few users misinterpreted the warmer-colored bars as representing heat output, not electricity usage.

A number of our usability participants indicated that they wanted to be able to access usage information for previous days, weeks and months. They also informed us that they would enjoy comparing current and historical usage, in order to gauge their performance in conserving electricity.

Future Development

In addition to the changes and suggestions uncovered during our usability testing, we would like to offer a detailed appliance view that displays the usage history for a specific device. Additionally, we would like to make this information available through an application or website that could be accessed on a home computer. We have also considered allowing remote web access through a secured interface, so you could access your home electricity usage from anywhere in the world.

From a sensing point of view we are considering an ecosystem of remote sensing plugs that would be deployed throughout the home. These sensors would give you a fine-grained understanding of how different devices are using electricity, even if they aren't on their own independent circuit. These plugs would communicate wirelessly with the data collection hub, and when combined with remote web access could enable you to remotely control your home appliances. This is an exciting idea, but it does have significant safety and security implications that we would want to carefully consider.

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