DESIGNING A BETTER ENERGY CONSUMPTION INDICATOR INTERFACE FOR THE HOME

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THESIS

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Abstract

Traditionally, research in energy conservation has fallen within the domains of environmental science and psychology. However, as a field, HCI has the potential to contribute new and innovative methods for energy conservation through the use of persuasive interfaces and enhanced computer-based feedback. One such area in which HCI can contribute to energy conservation is in interfaces for residential energy consumption indicators, or ECIs. We performed a survey of over 40 studies in environmental science and psychology on the effects of energy consumption feedback in the home. From this analysis, we created a theoretical framework in the form of seven design heuristics to provide guidance for the next generation of ECIs. We then implemented a fully functional prototype of an ECI interface that satisfies these heuristics, and performed an initial pilot study to better understand its effectiveness at changing consumption behavior.

Acknowledgements

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Chapter 1: Introduction

1.1 Background

In its 2007 Summary for Policy Makers, the Intergovernmental Panel on Climate Change (IPCC) reports that "warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level." The IPCC also states that "most of the observed increase in globally averaged temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations." Furthermore, the IPCC believes that if carbon emissions continue at the current pace, future global climate changes will likely be even larger than those being observed now [7]. This points to a clear need for energy conservation to reduce greenhouse gas emissions.

Traditionally, research in energy conservation has fallen within the domains of environmental science and psychology. However, as a field, HCI has much to offer. Wood and Newborough put it best: "To promote energy-conscious behaviour effectively throughout the population requires a better understanding of the interface between people and the equipment they use" [64].

HCI research is well suited to helping solve this problem; in fact, some HCI researchers have already begun the effort to develop new, innovative approaches to conservation. Tiffany Holmes's new work on Eco-Visualization combines art and technology to help reduce energy consumption in public buildings [30], and Jen Mankoff proposes to leverage the power of online social networks to encourage energy conservation behavior [40]. Such approaches demonstrate the unique perspective that HCI can bring to this problem.

However, there is more that can be done. As energy usage continues to rise and fears over the consequences of global warming increase, we believe further HCI research will be needed in order to develop additional innovative energy conservation solutions. To that end, this thesis looks at one area in which HCI can contribute to energy conservation: interfaces for energy consumption indicators, or ECIs (also known as "smart meters") [64]. ECIs give feedback, often in real time, about the amount of energy being used in a given space.

1.2 Why ECIs?

Research suggests that people are ignorant of how much energy they are using and how much energy various appliances use [8, 41]. A quote from interviews performed by Dobbyn and Thomas captures this phenomenon: "We can't be using that much…It's just the two of us in this two-bed flat. I am out all day …and we are on income support. I just don't know how the bills are so high… I think there is something wrong with them" [16]. ECIs are designed to remedy this problem. They reveal energy consumption behavior in the hopes that people will learn through feedback when they are needlessly using energy and will decrease their usage accordingly.

While the concept behind ECIs is reasonable, the effectiveness of the devices is limited by poor execution. Specifically, we believe the interfaces of most ECIs do not adhere to HCI principles and are deficient in their current forms. Furthermore, by applying concepts from existing psychological and environmental science literature, we can provide heuristics for what should be included in these interfaces to maximize their potential for changing people's energy consumption behavior.

The ECIs that we have chosen to focus on in this thesis are those designed for the home. Such devices provide residents with feedback on energy usage for the entire house or for specific individual appliances. By focusing on the home, we must ensure that these interfaces are designed so that the average resident will have no trouble reading and understanding them; a familiar human-computer interface problem. Despite this challenge, there are several compelling reasons, outlined below, as to why targeting the home is important and can have an impact on reducing overall energy consumption.

1.3 Why the Home?

Residential energy use accounts for a significant portion of overall U.S. energy use. According to the United States Energy Information Administration [1], U.S. energy-related CO2 emissions in 2006 were estimated at nearly 5.9 billion metric tons. The four major end-use sectors (residential, commercial, industrial, and transportation) accounted for 1.2, 1.05, 1.67, and 1.97 billion metric tons respectively. Hence, residential use contributed to 20% of the country's energy-related carbon emissions. Furthermore, residential consumption has increased by 240 million metric tons since 1990, representing 25% growth. Concerns over environmental effects from rising carbon emissions has researchers and policy makers looking for ways to slow this kind of growth, and targeting residents provides one such opportunity.

Beyond the sizable growth of energy use in the home, there are other factors that make targeting households attractive. Residents typically have more control over the energy they use than they would in their offices or workplaces. Therefore, changing micro-level variables like motivation and attitudes [6] may have more of an effect on changing behavior in this setting. Workers in office or cubicle environments may not have as many opportunities to practice energy saving behavior due to corporate policies or the presence of others, even if they have the proper desire and motivation (e.g., turning off the lights in a multi-person office during lunch time would not be feasible if one person is still working and requires them).

Furthermore, the home itself is often a source of comfort and pride for individuals, more so then their work environments. Saving energy in the home may enhance this sense of pride [58] and further encourage good energy consumption behavior.

1.4 Existing ECIs

Existing ECIs can be placed into three categories: general ECIs, which display an aggregated total of how much energy is being used; device-specific ECIs, which display energy usage for individual devices or appliances; and combination ECIs, which display both aggregated and device-specific data.

1.4.1 General ECIs

The most basic form of a general ECI is the energy meter already installed in most homes (Figure 1A). While it can provide real time feedback, it is far from the ideal home interface. Often it is located outside, which makes it impractical for everyday

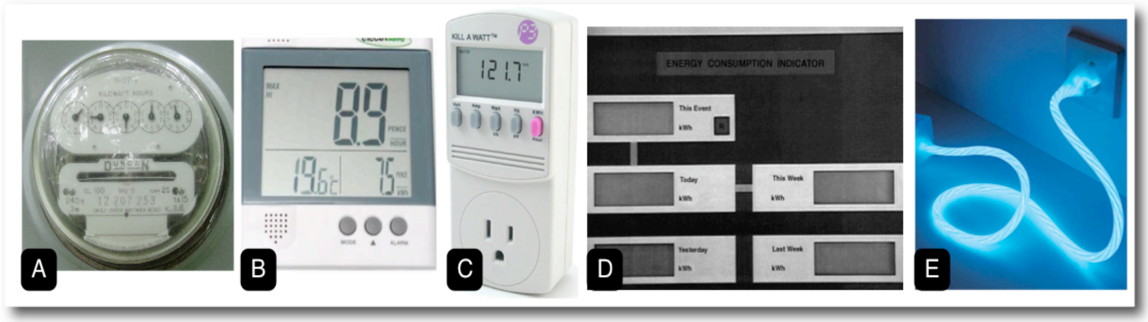


Figure 1. A) Typical home energy monitor. B) Electrisave. C) Kill A Watt. D) Wood and Newborough's electric cooker ECI. E) Power Aware Cord.

viewing. It is also designed to be read by specialists, not everyday end-users, and hence can be difficult to understand.

Several of these shortcomings have been addressed in products such as Centameter [13] and Electrisave [20]. These are portable energy monitors designed to be placed in the home and be read by average residents (Figure 1B). They provide a simple numeric readout of energy used or how much money is currently being spent on energy. However, the small, low-resolution displays and minimal readouts limit the potential of these devices.

1.4.2 Device-specific ECIs

The Kill A Watt [36] and Watts Up? [60] devices allow users to plug in various appliances to get instant feedback on how much energy individual appliances are using (Figure 1C). However, they too have primitive displays and only allow for one device to be plugged in at a time.

Wood and Newborough [64] designed an ECI for a field study performed on electricity consumption used during cooking (Figure 1D). This ECI not only presented real time feedback on the energy used by the electric cooker, but also provided historical feedback which allowed for comparisons to the previous week's usage. While the historical comparison provided more information than a typical energy meter, the display was limited in that it was designed only for a single specialized appliance.

Some of the more creative device-specific ECIs include the Power Aware Cord [5] and Erratic Appliances [2]. The Power Aware Cord glows brighter the more electricity is being used (Figure 1E). The Erratic Appliances begin behaving unpredictably as the amount of energy used increases. While these are interesting ideas, they likely have more appeal as art pieces than devices for most mainstream homes.

1.4.3 Combination ECIs

Combination ECIs are rare, and those that have been built have so far been restricted to the research laboratory. In a 1992 study, Dobson and Griffin [17] designed an ECI for the PC which displayed total energy consumption in addition to disaggregated information broken down by appliance. It also provided a historical comparison.

In the very near future combination ECIs will start to become available to consumers for the first time. Starting in 2008, the UK plans to begin testing combination ECIs in households [3]. Designed by More Associates, these prototype monitors can display real time cumulative (MorePower Single) or disaggregated (MorePower Multi) feedback on energy use. These monitors are discussed further in [4].

1.5 Addressing Existing Shortcomings

From an HCI perspective, the existing ECI interfaces have some clear shortcomings. Most of them simply display numbers with little or no contextual information about what the numbers actually mean. Graphics are used minimally, if at all. The tiny black and white, low-resolution screens result in displays that are generally unappealing in look-and-feel.

We could easily make these interfaces more attractive by utilizing color and high-resolution bitmapped graphical displays. In doing so, we are also no longer limited to displaying a single number or simple gauge. This opens up multiple possibilities for new interface directions. Yet it is not immediately apparent what will make for a more effective ECI interface. We therefore need a more detailed framework from which we can evaluate the shortcomings of existing interfaces and provide heuristics for what should be included in the next generation of ECIs. The first question we must concern ourselves with, then, is how to generate this framework.

To answer this, we turn to literature outside of computer science. There has been a considerable amount of research performed in psychology and environmental science on the effectiveness of various strategies aimed at reducing energy consumption in the home. Utilizing this research to generate our framework has several key advantages.

First, this research provides us with a large body of work; we can examine the findings of over 40 research reports and studies, utilizing the guidance of three major review papers from psychology and environmental science [6, 14, 64]. Many of these studies consist of home interventions, where psychologists observed the effects of energy saving strategies on real households. While there are variations in the findings of each, by looking at them collectively we will see that there are several clear energy-saving concepts that emerge. Our confidence in these concepts is increased due to the fact that they have been observed in varying cases and contexts over several decades of research.

Second, we can use the concepts gleaned from this research to set up a measure of the theoretical effectiveness of different interfaces, which we can use as the basis for future empirical evaluations. By first measuring the interfaces against the theories from the psychological literature, we are able to create a strong hypothesis for which interfaces will be effective and in what ways they can be improved. We will then be able to effectively test these hypothesis in ensuing observational studies.

Chapter 2: Literature Survey

In order to generate our framework from existing work, we first provide a survey of the psychological and environmental science literature. We describe the strategies used in various home interventions and the behaviors they targeted. We then report on the effectiveness of each of these strategies, and the lessons we can take away.

2.1 Efficiency and Curtailment Behaviors

The fundamental goal of a household ECI is to change residents' behaviors so that residents will use less energy. There are two distinct behaviors that we can target in order to accomplish this: efficiency behaviors and curtailment behaviors [6, 22]. Efficiency behaviors are those that are typically performed once and have a permanent energy-saving effect: e.g., buying an energy-efficient appliance. Curtailment behaviors, on the other hand, are ongoing, repetitive efforts: e.g., turning the lights off when leaving for work or sleeping the computer at night.

Abrahamse, et. al note that most studies are aimed towards curtailment behaviors [6]. Due to their permanency, however, efficiency behaviors may offer greater possibilities for energy savings than curtailment behaviors [22, 37]. Nevertheless, curtailment behaviors are still important due to the possibility of the rebound effect [10]. The rebound effect occurs when a resident uses a new energy-efficient appliance more often than before, precisely due to its efficiency. The end result is no overall net change in energy use.

2.2 Antecedent and Consequence Strategies

There are many strategies that can be considered to influence the above behaviors, but they generally fall into two categories: antecedent and consequence [18]. Antecedent strategies are those designed to precede a behavior. Antecedent strategies for energy conservation include [6]:

- *Information.* Providing residents with information and/or tips on how to best save energy. Examples include public information campaigns, workshops, and energy audits.

- *Goal setting.* Getting residents to set a goal for energy they want to save over a given time period. Goals can range from easy (2-5% savings) to difficult (20% savings).

- *Commitment.* Asking residents to commit, either publicly or privately, to energy-conservation measures. Commitments can be written or spoken and are often combined with an energy saving goal.

Consequence strategies are those that follow a behavior. Consequence strategies for energy conservation include [6, 64]:

- *Feedback.* Showing residents how much energy they are using. This can take the form of a simple monthly energy bill or an elaborate digital energy feedback display.

- *Reward.* Giving residents a reward for good energy saving behavior.

- *Commendation/Criticism.* Passing judgment on residents based on how well they conserve. Commendation differs from a reward in that no physical goods are exchanged; only praise is used.

2.3 Effectiveness of Strategies on Energy Saving Behavior

Multiple studies have utilized each of these strategies in various forms. While the ultimate effectiveness of each strategy will depend on the specific form it takes and the details of its implementation, there are nevertheless general trends that we can observe regarding the usefulness of the strategies in each category, as we discuss below. A summary of this information is presented in Table 1.

2.3.1 Antecedent

The effectiveness of antecedent strategies has been mixed. Commitment [34, 48] and goal setting [9, 43] have both been shown to be effective in changing energy consumption behavior. Generic information on how to save energy, however, has generally only been effective in changing knowledge but not in changing actual behavior [23, 32, 39]. Yet, more specific information (e.g., from energy audits) has resulted in energy savings of up to 20% [24, 25, 46, 62]. Furthermore, information displayed at the point in which an energy consumption decision is made has proven useful. Placing informative signs near a light switch can reduce lighting usage up to 60% [15]. Unfortunately, strategies involving information alone are often subject to the fallback effect [61, 64], in which energy savings decrease over time as the newness of change wears off [28].

2.3.2 Consequence

Consequence strategies in general have shown positive results. Multiple studies have shown the effectiveness of providing feedback on energy consumption [11, 12, 29, 31, 44, 53, 57, 64]. Feedback that is both immediate [58] and detailed [27, 61] is most desirable by residents. Interestingly, comparative feedback (comparing usage with others) is not necessarily more effective than regular feedback in the household [19, 26, 47]. Rather, historical feedback (comparing current usage to past usage) seems to be preferred by residents and tends to be more effective [50]. This may in part be due to the fact that residents don't believe they are being compared with the correct group [14].

Using criticism to leverage cognitive dissonance has also been shown to be a successful consequence strategy [33]. Cognitive dissonance occurs when people's actions do not match with their stated goals or beliefs, creating an internal conflict (for more on cognitive dissonance, see [21]). Rewards, on the other hand, are effective initially, but they typically do not have long lasting effects [45, 54].

Perhaps more interestingly, commendation has been shown to help reduce energy consumption [52], even through something as simple as a smiley face. Schultz et. al. performed an intervention in which they gave households feedback on energy usage comparing them to others in their neighborhood [51]. They found that when normal descriptive feedback was provided, households gravitated towards the mean; that is, households below the average tended to raise their consumption, whereas households above the average lowered their consumption. However, when a positive injunctive message along with a smiley emoticon was added to households with low consumption, they no longer increased their usage to match the mean (see Figure 2).

2.4 Synergies

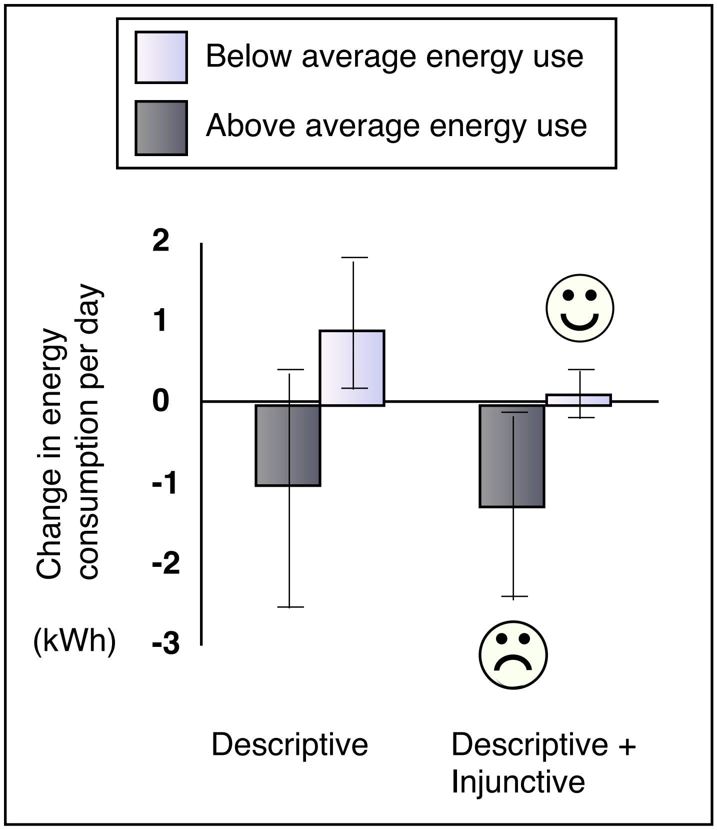


Figure 2. Image adapted from Schultz et. al [51]. When shown a smiley emoticon along with an injunctive message, residents no longer gravitated toward the mean; high consumers reduced their use, and low consumers remained low.

While many different strategies for reducing home energy consumption have been shown to be effective, even more important are the synergies that exist between them [14]. Combining strategies in both the antecedent and consequence categories can be more effective than attempting to only use strategies within a single category.

For instance, while information alone tends to be ineffective, combining it with feedback proved effective [28]. Furthermore, combining goal setting with feedback led to a 13% reduction in energy use in one study, with lasting effects [63]. And combining all three (feedback, goal setting, and information) led to a 15% reduction in one study [59] and a 20% reduction in another [9]. Furthermore, the literature shows evidence of synergies between different types of feedback [14]. Therefore, providing multiple forms of feedback (e.g., historical and real-time) seems to be more useful than including just one type.

Yet there is a danger of information overload when combining disparate strategies. In a four month field study, Wood and Newborough found that electronic feedback combined with a packet of energy saving tips did not lead to greater energy

Antecedent Strategies	
Commitment	Effective in changing behavior
Goal Setting	Effective in changing behavior
Generic Information	Changes knowledge but not behavior
Tailored Information	Effective in changing behavior
Consequence Strategies	
Normal Feedback	Effective in changing behavior; immediate, detailed feedback desirable
Comparative Feedback	Distrusted by residents; ineffective
Historical Feedback	Effective in changing behavior; preferred by residents
Rewards	Short-term behavior change
Commendation	Effective in changing behavior
Criticism	Effective when leveraging cognitive dissonance

Table 1. Summary of the effectiveness of various intervention strategies on changing residential energy consumption behavior.

savings than electronic feedback alone [64]. The authors attributed this to overwhelming the residents with too much information at once.

2.5 Community

The effectiveness of comparative feedback with the community has so far been limited. This is partly due to the fact that residents tend to mistrust who they are being compared with [50]. In addition, these comparisons are often hampered by visuals which are difficult to interpret [19]. Furthermore, these comparisons have often occurred during the monthly billing cycle rather than in real time.

There is potential to utilize the Internet to greatly enhance community comparisons. Mankoff first proposed leveraging rapidly growing social networks like Facebook and MySpace to facilitate this comparison [40]. Such approaches could enable users to compare themselves not just with other users in their neighborhood or nearby regions, but potentially users all over the world. In addition, comparisons could be even more effective if they occurred within a group of strong ties. The added social guilt and peer pressure that comes from a close circle of friends could yield more effective comparative feedback than simple monthly comparisons with strangers.

2.6 Discussion

From this large body of research, there are two major concepts that emerge as critical for encouraging energy consumption behavior.

2.6.1 Target Both Efficiency and Curtailment Behavior

Efficiency behaviors should be targeted in order to take advantage of the greatest potential energy savings benefits. The goal of any energy saving strategy should not simply be to reveal to residents the amount of excess energy they may be using on a day-to-day basis, but also to show them ways in which they can become more efficient without changing their normal energy use patterns.

However, curtailment behaviors still need equal emphasis, not only due to the significant energy savings they can provide, but also to avoid the rebound effect. In addition, for consumers who may not have the means or ability to practice efficiency behaviors (e.g., if they don't have the income to purchase new energy efficient appliances) then curtailment is the only option. This gives all residents the opportunity to contribute to energy conservation.

2.6.2 Utilize Multiple Antecedent and Consequence Strategies

While many individual strategies were effective in reducing home energy consumption, the evidence of synergies existing between the antecedent and consequence strategies suggest that more than one strategy is needed. Utilizing as many strategies as possible should increase the chances that the interface will be effective in changing residents' behavior.

However, it is important that these strategies be integrated tightly so that the resident is not overwhelmed with too much disparate information. Only essential pieces of information should be revealed as necessary, with further detail made easily discoverable as needed.

Chapter 3: Design

3.1 Design Heuristics

We now present our framework for evaluating ECI interfaces. This framework is synthesized from the concepts extracted from our survey on psychological and environmental science literature in addition to lessons applied from general HCI principles.

We present the framework in the form of seven heuristics for what should be included in an ECI interface. H1 and H2 draw on concepts from HCI, while the remainder follow directly from the literature survey: H3 concerns efficiency behavior; H4 and H5 are antecedent strategies; and H6 and H7 are consequence strategies.

H1. Provide a visual display in an easily viewable location.

While this may be an obvious heuristic to some, many existing home energy meters currently fail to provide visuals or an easily viewable display. Instead, most standard meters are hidden away or placed outdoors, and those that aren't still have only a numeric readout of household energy consumption, either in kWh, CO2 loads, or monetary units. Such numeric displays of data cannot have the emotional impact that visuals can provide. Graphical displays can attract the viewer and promote curiosity, while revealing important aspects of the data and encouraging comparisons [56]. Displaying a stream of digits to non-technologically inclined or environmentally conscious resident is likely to have little to no cognitive or emotional impression compared to displaying a salient and meaningful visual of the same information.

H2. Provide context.

For a home energy display to be most useful, relevant contextual meta-information should be presented simultaneously with the main information shown [38]. A display that shows “100 kWh” doesn’t mean anything unless the person viewing it is educated previously to know what that number means within the current context. Without such knowledge, it is difficult to make a judgment and determine if a behavioral change is necessary. Even with a visual display, if the information shown has no relevant context, it will be hard to interpret. Hence, information cannot just be shown to the user without a contextual framework that allows the users to make a judgment on what they are seeing.

H3. Encourage efficiency behavior in addition to curtailment behavior.

This heuristic follows directly from the lessons learned from the literature survey. Current energy monitors are designed to encourage curtailment behavior by revealing usage of various appliances and utilities with the idea that people will recognize when they are using energy unnecessarily and will curb their usage. However, there are typically no recommendations or encouragements to seek out efficiency behaviors. Instead, residents must get this information elsewhere, e.g. from a home energy audit that might suggest home insulation to reduce heating and air conditioning usage.

Integrating this into the display of an ECI could potentially be much more useful, as residents would no longer need to seek out multiple sources of information. This could be accomplished simply by bringing to the resident’s attention devices which are not as efficient as they could be. For instance, the ECI could highlight an inefficient washing machine in the interface and suggest purchasing an Energy Star appliance to reduce energy use by 50%. Furthermore, with the vision of smart networked homes [49] in the near future, we could glean even more information with regard to context and efficiency. For example, the interface could notify the resident that the air-conditioning system is not as efficient as it could be because a window is open.

H4. Provide personalized energy saving tips.

Winett [62], Grady [25], and others have shown that energy audits can be effective in reducing home energy use by up to 20%. A major reason why is because information from energy audits is tailored to the individual households [6], so it provides specific information on what exact steps can be performed for each household to reduce energy. This is crucial because not all households are the same, and some houses may be able to utilize different techniques than others to reduce energy.

Displaying generic information on how to reduce energy use in an interface, therefore, will not be as effective as displaying specific, personalized tips. For instance, displaying the tip “Use compact fluorescent bulbs (CFLs) instead of incandescent bulbs” may be quite helpful for a household that has never used CFLs before, but it would be useless for one that has already replaced all of its incandescent bulbs.

H5. Incorporate goal setting and/or commitment.

We saw previously how feedback can be more effective when combined with goal setting. Hence, by adding the ability to set a goal inside our display (as also suggested by Wood [65] and McCalley [42]) we gain the benefits of the combined antecedent and consequence strategies. Furthermore, we can then design the feedback to show progress as it relates to the goal, which successfully provides context for the feedback information. It also improves motivation, as the resident now has a realistic target that they can reach for. In addition, by getting residents to commit to the goal, we can then use this commitment to create cognitive dissonance if the residents are not on track to meet their goal (see H7).

H6. Provide multiple levels of real-time and historical feedback. Providing multiple levels of detail is an important part of any visual display [56]. One fault of current home energy monitors is that they only give residents a broad overview of a house's usage. This gives a good idea of how much total energy is being used, but it does not allow residents the detail they need to figure out how they can reduce this total number if desired. As Kempton and Neiman state, this is like shopping at a store without being shown prices on the individual items [35]. Residents have no idea which devices are contributing the most to the overall power consumption. Hence, their air conditioners could be taking up 70% of their electricity usage, but there is no way for them to find this out.

By providing disaggregated information in a centralized location, users can take necessary action to reduce the usage of those devices that are contributing most to their energy consumption. In fact, some research has suggested which devices might benefit most from inclusion in such a display (for more details see [66]).

Furthermore, we need to take advantages of the synergies provided from multiple levels of feedback. For instance, providing real-time and cumulative would allow residents not only to see how much energy they are currently using, but also to see how it is accumulating over time. In addition, providing historical feedback would allow residents to compare current usage to their own past usage. This would provide residents with the ability to track the effect that their energy saving measures have over weeks, months, and years.

Multiple layers of feedback could also provide a view from which residents could compare their current and historical energy usage with selected community groups of their choosing. Allowing residents to choose which groups to compare their usage against could help alleviate the problem of mistrust observed in previous studies and make community feedback more useful.

H7. Provide commendation and criticism.

Generally, as interface designers we tend to create non-judgmental interfaces. The home energy interface, however, should be an exception to this rule. Leveraging cognitive dissonance can be a powerful way to encourage residents to meet their goals and commitments for reducing energy consumption [33]. Furthermore, Schultz

Design Heuristics
H1. Provide a visual display in an easily viewable location.
H2. Provide context.
H3. Encourage efficiency behavior in addition to curtailment behavior.
H4. Provide personalized energy saving tips.
H5. Incorporate goal setting and/or commitment.
H6. Provide multiple levels of real-time and historical feedback
H7. Provide commendation and criticism.

Table 2. Summary of the design heuristics.

et. al show us how even simple positive/negative judgments like smiley faces can encourage people to continue their good energy consumption behavior [51]. And [52] suggests that feedback combined with commendation is more effective than simple feedback alone. Therefore, a home energy interface should not shy away from judging users when necessary, as this can potentially increase the interface's effectiveness.

3.2 Evaluating Existing ECI Interfaces

Given these seven heuristics, we now have a framework within which we can examine the theoretical shortcomings of the existing ECI interfaces previously mentioned.

General ECIs satisfy very few if any of the heuristics. Home energy monitors use gauges that are difficult to interpret and are often hidden out of sight (H1). Products like Electrisave are more easily viewable, but they have small numeric displays that don't incorporate visuals. Furthermore, there is no incorporation of antecedent strategies; it is impossible to set a goal or commitment directly on the display (H5), and there is no energy saving information presented, much less tailored (H4). There is only a single level of feedback provided (H6), with no context (H2) and no commendation (H7). There is also no direct encouragement of efficiency behavior (H3).

The same is true of most device-specific ECIs. Kill A Watt and Watts Up? also provide non-visual displays, a single level of feedback with no context or commendation, no antecedent strategies, and no encouragement of efficiency behavior. Wood and Newborough's electric cooker ECI, however, does incorporate a visual display with multiple levels of feedback (today, yesterday, this week, last week). But it still fails to provide support for antecedent strategies, commendation, or encouraging efficiency.

Existing combination ECIs, especially the MorePower Multi, have highly visual displays and multiple levels of real time and historical feedback. However, these displays are not utilized to their full potential. They still do not provide support for antecedent strategies, they fail to provide sufficient context for their feedback, and they don't offer commendation or criticism. Efficiency behavior is encouraged indirectly by showing which specific appliances are using the most energy, but the emphasis in the interface is still on curtailing usage rather than pushing for replacing inefficient devices.

ECI	Heuristics Satisfied
General	
Home energy meters	(none)
Electrisave, Centameter	(none)
Device-specific	
Kill A Watt, Watts Up?	(none)
Power Aware Cord	(none)
Wood and Newborough	H1, H6
Combination	
Dobson and Griffin	H1, H6
MorePower	H1, H6

Table 3. Summary of heuristics satisfied by existing ECI interfaces.

Table 3 summarizes the results of evaluating existing ECI interfaces against our framework. None of the ECIs satisfy all of the design heuristics. In fact, no interface satisfies more than two. This shows there is a clear room for improvement in this space.

3.3 Iterative Prototyping

With the design heuristics in place, we began the process of developing low fidelity interface prototypes that attempted to satisfy heuristics.

3.3.1 Prototype 1

The first prototype was designed around the idea of a spatial map. The interface is meant to be displayed on a full color touch screen in a prominent location in the home where it will be easily visible (e.g., on a wall, or on the kitchen table) (H1). It shows a floor layout of the resident's home with the most energy-intensive utilities and appliances represented as icons in their real-world locations. As the resident turns on appliances, icons transition from translucent to fully colored, so residents can easily see which appliances are on and using energy (continuous realtime feedback). Appliances which are most inefficient are haloed in glowing red, a clue as to which appliances can likely be replaced. Hence, we encourage both curtailment and efficiency behaviors (H3).

As the month progresses, the resident's total energy use is shown in a meter at the bottom of the screen, providing historical feedback in addition to real time (H6). The progress meter is presented within the context of a goal which is inputted by the user at the start of the month (e.g., a goal of 15% savings) (H2, H6). In addition, a projection is given for where the resident will be at the end of the

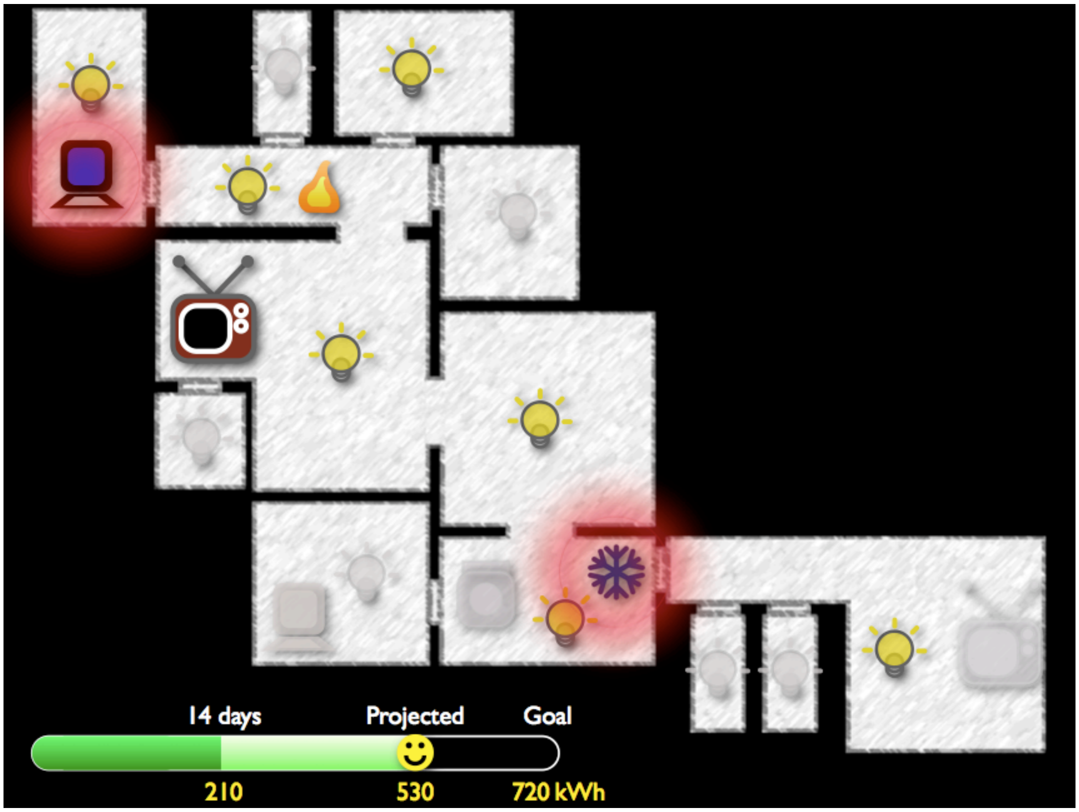


Figure 3. The initial prototype.

month based on current usage. If the resident projects a usage that is less than the goal, a smiley face is displayed, encouraging the resident to keep up the good work. If usage is projected to be more than the resident's goal, a red bar and sad face appears. This satisfies the commendation/criticism heuristic (H7).

To see more information about a certain appliance, the resident can simply tap on it. This brings up the current number of watts that appliance using, suggestions for how to save energy (H4), and the total cumulative energy that this appliance has used for the month.

While this design succeeds in satisfying all of the heuristics, it has several drawbacks. First, while it might work well for small houses with relatively few appliances, it does not scale well to larger houses with many rooms and dozens of

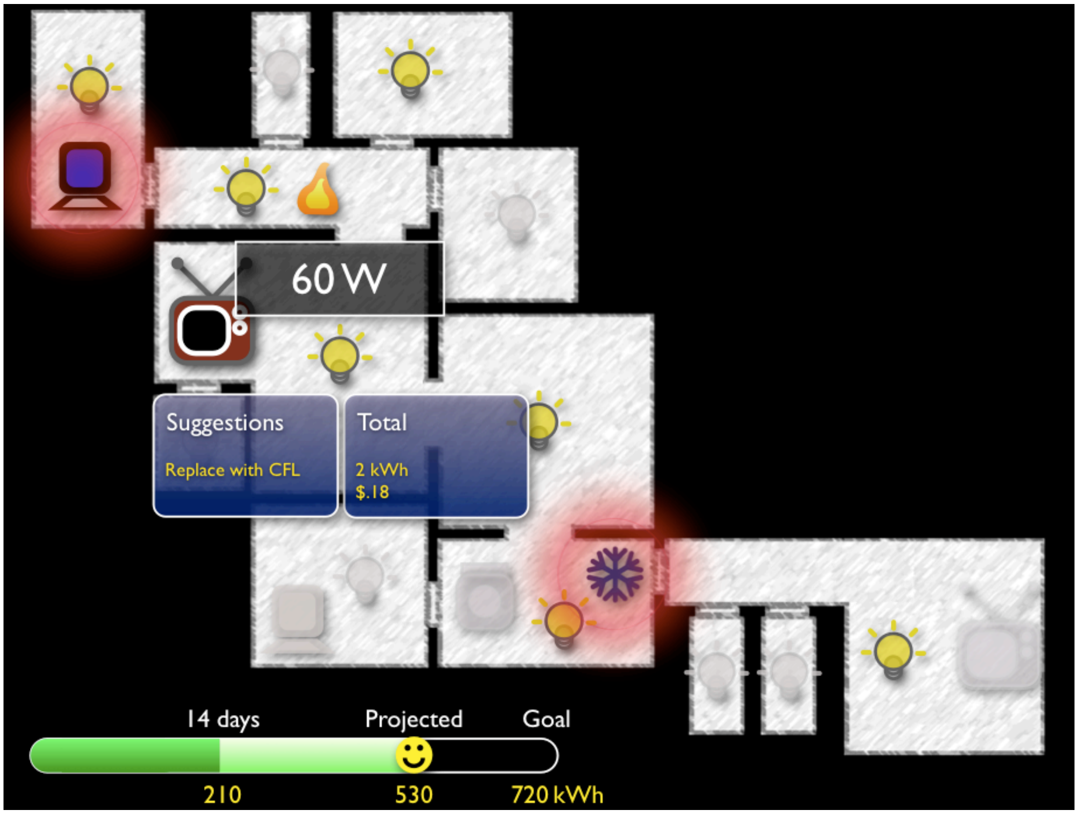


Figure 4. Detailed information and energy saving tips about each appliance can be brought up with a single tap.

lights and appliances. The interface can potentially become cluttered very quickly, making it hard to immediately understand at a glance. Second, there is no way to see how much of each type of appliance was contributing towards the total amount. For instance, if a resident wants to see how much energy all of their lighting was using, they are forced to tediously add up the watt-hour values of each of the lights and compare that to the cumulative amount. This is clearly not a practical solution. Lastly, while there is a monthly goal represented, there is no obvious indication in the interface of how to obtain this goal. That is, there is no real-time goal indicator. It is unclear how turning off a light or a computer effects how much energy is currently being used and how that relates to the monthly goal.

3.3.2 Prototype 2

The second prototype was designed to remedy the drawbacks of the first, while still satisfying the design heuristics.

First, in an effort to reduce clutter and complexity, the main display is designed to be as simple as possible while retaining the use of appealing visuals (H1). There are two main elements to the UI: the left side shows a meter with the cumulative monthly usage, while the right side shows a meter with the real-time usage (H6). Units can be shown or hidden as desired. This minimalist display not only scales well and is easy to understand at a glance, but it has the added benefit of allowing this interface to be used in as many places as possible without taking up a lot of room (e.g., as background wallpaper on a computer, or on a mobile device like the iPhone).

Goal setting is again incorporated into the cumulative meter (H2, H5). Similar to the first prototype, the top of the meter represents the monthly goal, and the dotted box shows an end-of-the-month projection. The smiley face again acts as commendation that says the resident is doing well (H7).

Unlike the first prototype, however, the goal is also utilized in the real-time display on the right. The horizontal bar acts as a "suggested maximum usage," which means that if a resident stays underneath this mark most of the time, he or she will be guaranteed to meet the goal. This makes it clear what residents need to do to meet their monthly goals. It also makes it clear what effect turning on and off appliances does to the real-time total. If a resident turns on a TV for instance, the real-time bar will immediately increase to reflect that; if the bar goes past the

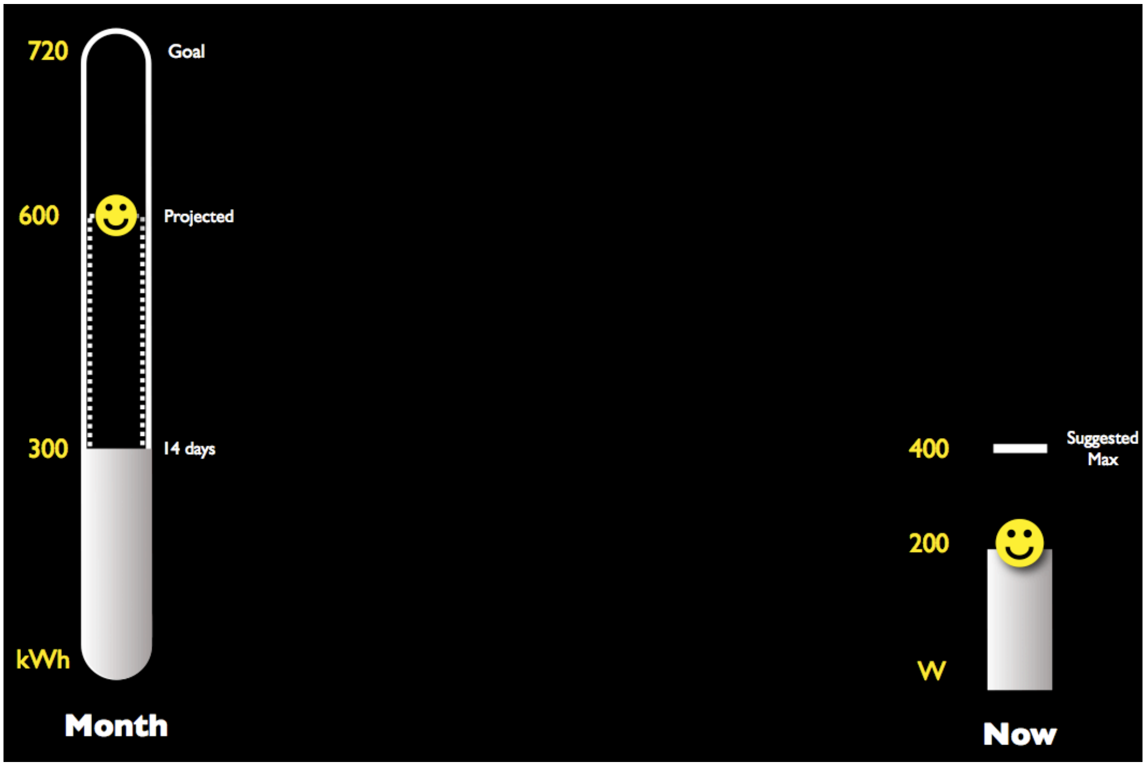


Figure 5. Main screen of the second prototype. Units are currently shown but can be hidden to further reduce clutter.

suggested max, the resident knows that that other appliances or lights should be turned off to counter the increase.

The interface also enables residents to see more specific details via zooming. A single tap on either meter will zoom that meter to show how the usage is broken down by category (Lighting, Appliances, Heating/Cooling, and Water Heat). The size of each category box is proportional to how much energy was used from that category. This makes it much easier than the first prototype to see at a glance how much each category contributes to the total.

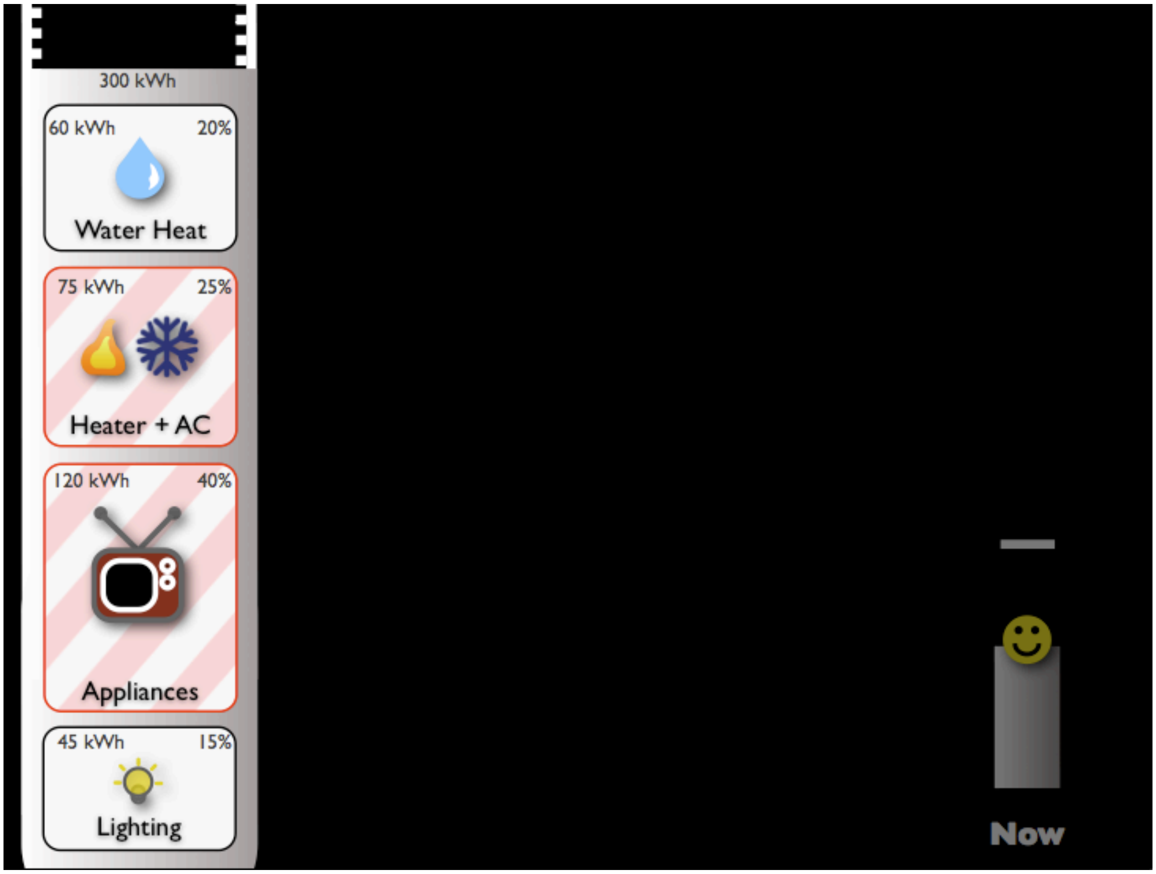


Figure 6. The zoomed in view of the cumulative meter.

Efficiency behavior is encouraged through the red highlighted categories (H3). These are categories in which there are inefficient appliances being used.

Users can drill down into categories for even more detail. Selecting a category brings up a pop up menu of all the individual items within that category. The size of each item box again corresponds to how much energy that item used within the category. The red highlighted items are items that are inefficient (e.g., an incandescent bulb would be highlighted red, since more efficient compact fluorescent bulbs exist). Users can tap each item, which flips it over to reveal personalized tips (H4). Efficiency tips are highlighted in red, while curtailment tips are black.

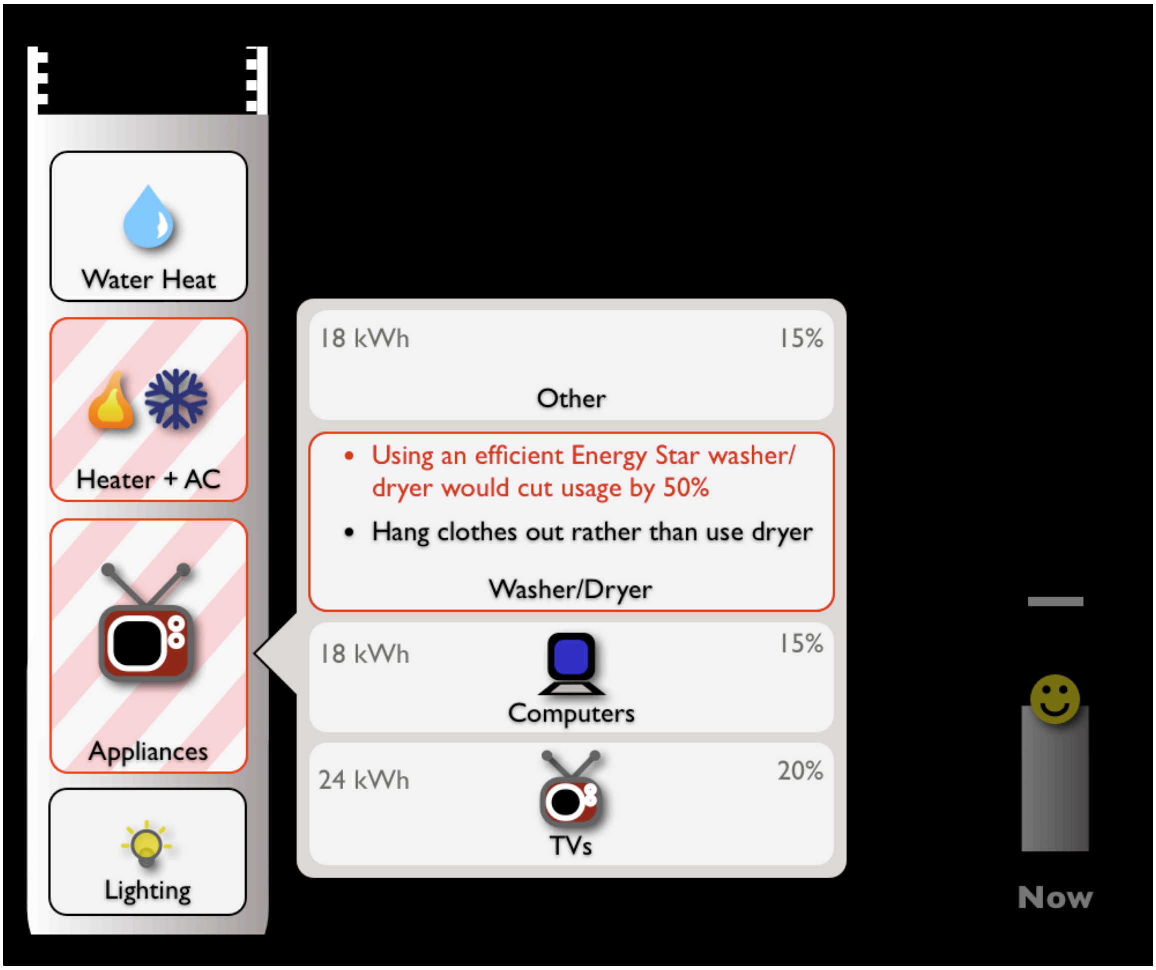


Figure 7. Washer/dryer has been flipped over to reveal targeted tips.

This prototype solved the significant drawbacks of the first iteration. However, there were still some minor problems. First, the fact that the cumulative meter was closed off gave it the appearance of a thermometer; while this wasn't necessarily bad, some people remarked that it made it appear like a fund-raising meter. This goes contrary to our desires as people typically try to fill fund-raising meters as much as possible, whereas our meter was designed to be filled up as little as possible. Hence, we did not want to encourage people to attempt to fill their meters and surpass the goal; rather, we wanted to encourage people to use less than their goal. A second problem was the similar appearance of the meters. While we wanted to maintain consistency, the fact that the meters looked the same implied that they should somehow be related, when in fact they represent two completely different sets of units (kWh vs. watts). It was unclear that these meters should be thought of as completely distinct and representing separate, independent measurements. Finally, there was also a large amount of negative space present in the default view, which may have led users to believe that something was missing.

3.4 Final Prototype

For our final prototype, we kept the basic design of the second prototype while tweaking the visuals to fix some of its drawbacks.

First, we enlarged the cumulative meter in order to differentiate it from the real-time meter and to better indicate that it represents a larger amount of energy

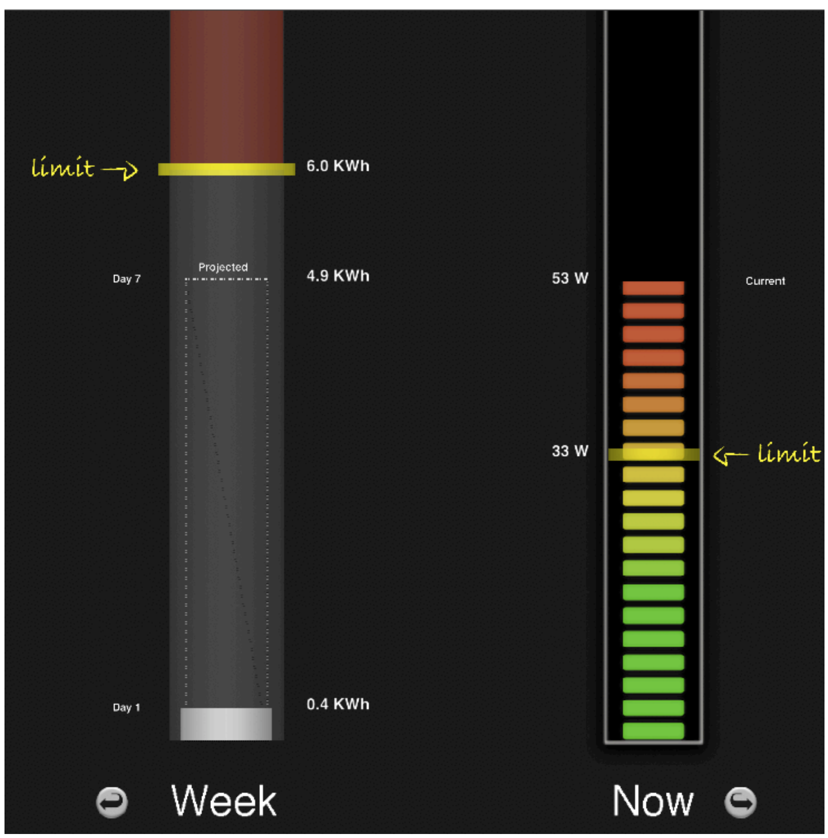


Figure 8. The cumulative and real-time meters for the final prototype. Unit labels can be toggled from KWh to dollars or can be hidden completely.

usage. We also removed the rounded portions at the top and bottom to reduce the "fund raiser thermometer" appearance. To indicate the goal, we put a prominent yellow line with the word "limit" next to it. Above the line is a red area that indicates a danger zone that should not be entered. This design better reflects the fact that the goal is not a minimum amount that needs to be achieved; rather, it is a ceiling that should not be surpassed. The cumulative meter was further modified to show either monthly or weekly accumulation, depending on the user's preference.

We also drastically altered the appearance of the real-time meter. While the cumulative meter always accumulates as the month goes on, the real-time meter

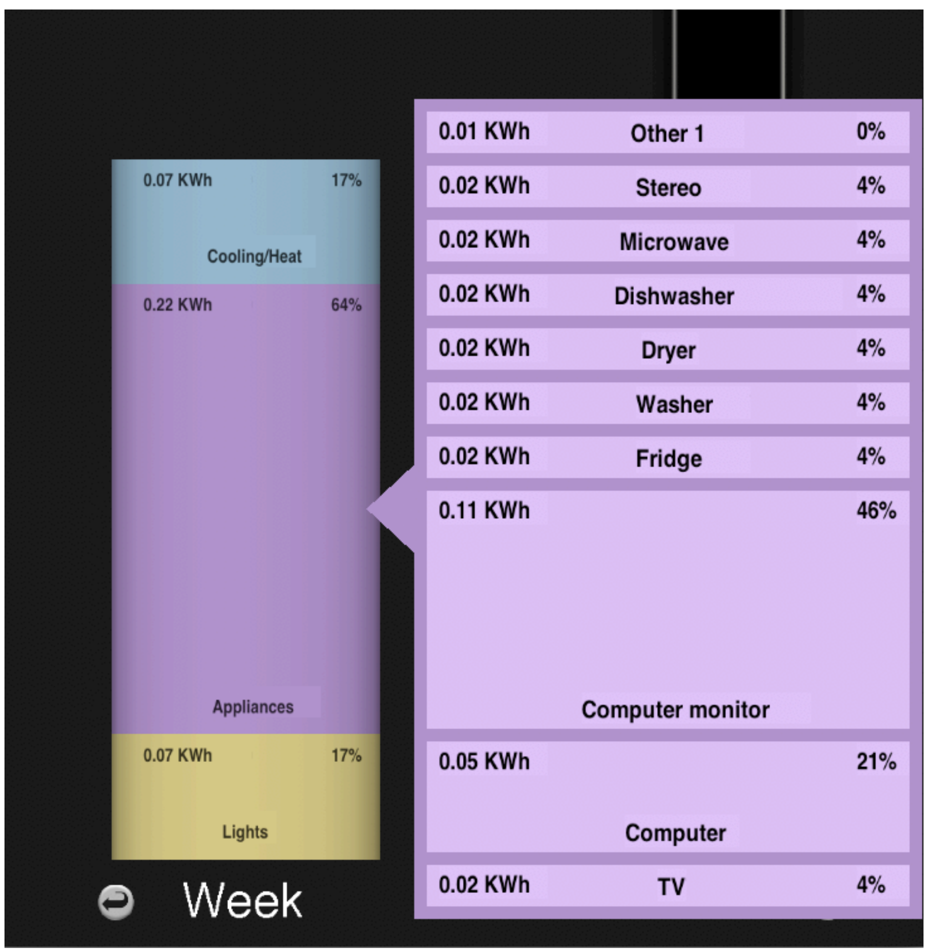


Figure 9. The zoomed in view of the cumulative meter. The appliance category has been selected for a more detailed view.

Figure 10. The zoomed in view of the real-time meter. Devices that are detected to be inefficient are highlighted in red. Efficiency tips are presented as well.

can move up and down depending on the resident's current usage. To better illustrate this, we gave it a design more similar to a volume meter. When energy consumption is low, the meter is green; as usage increases, it turns to yellow and finally red. To maintain as much consistency as possible, we used the same yellow "limit" bar as the cumulative meter. Both meters are still zoomable as before.

In addition to changing the visual appearance of the cumulative and real-time meters in this prototype, we also added two significant features: a history view and a community view.

3.4.1 History View

The history view provides further historical feedback beyond the cumulative view. By clicking the gray arrow next to the cumulative meter, the display flips over to reveal a chart of the last sixth months' (or weeks') cumulative usage. This allows residents to track their progress from month to month, as the bars are presented within the context of the cumulative goal. The colors of the bars correspond exactly to the categories represented in the zoomed in view (e.g., blue for cooling, purple for appliances, yellow for lighting).

The real-time meter can be flipped as well to reveal a graph of the last hour of usage. Each bar in the graph represents the average usage over five minutes. The

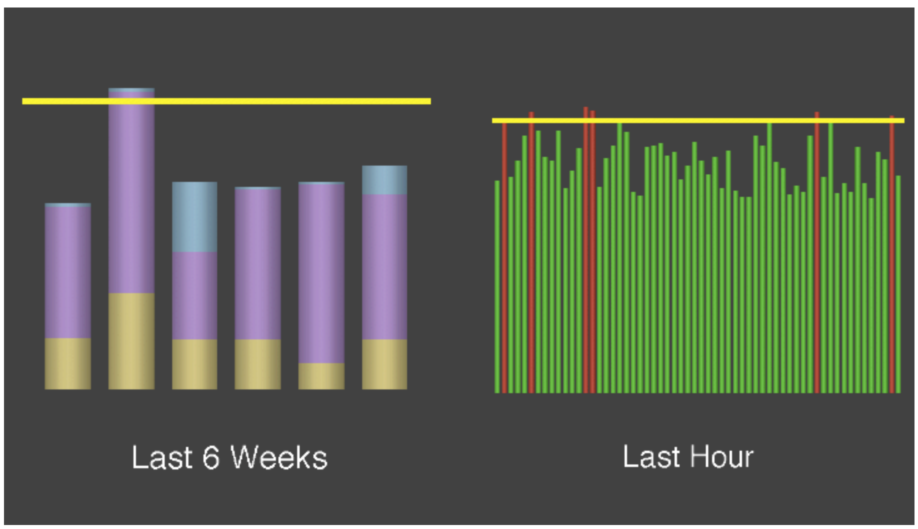


Figure 11. The history view. The left side shows cumulative usage over the last 6 weeks or months. In this example, each bar represents a single week. The right side shows usage over the last hour, with each bar representing an average over five minutes. Green bars mean the goal was met.

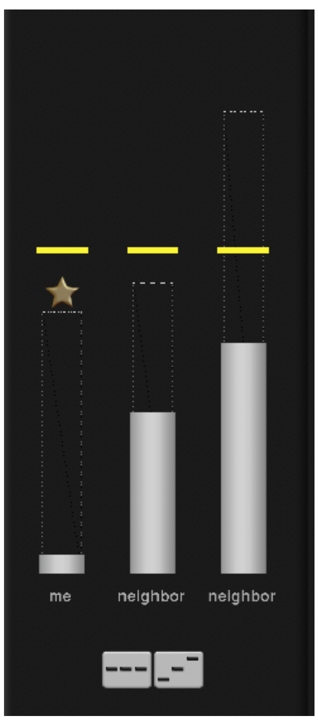
bars are red if the average usage was above the real-time goal and green if below. These colors are consistent with the colors used in the real-time meter.

3.4.2 Community View

The community view is an additional segment separate from the cumulative and real-time meters. This view is designed to provide a comparison of a resident's progress with his or her neighbors using the concept of small multiples [56].

Neighbors are represented as miniature meters labeled “neighbor” that show their current cumulative usage, their projected usage, and their goal. The current resident is shown as a miniature bar with the label “me”.

In our second prototype, commendation was presented in the form of a smiley face on the cumulative and real-time meters. In this final prototype, we moved the commendation to the community view in the form of a gold star for the resident who is demonstrating the best conservation behavior. This form of commendation is more similar to that demonstrated to be effective by Schultz et al., as it is a social comparison.



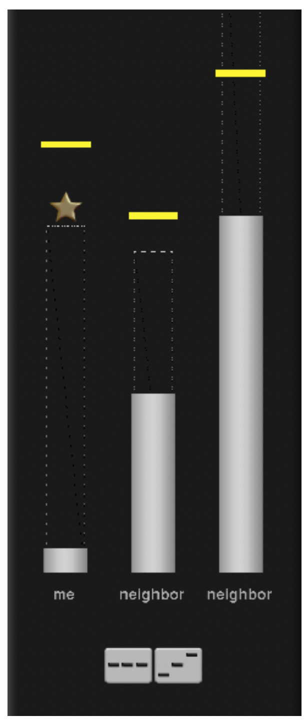


Figure 12. Two different presentations of the community view. The left side is the default normalized view. The goals are presented equally and bar heights adjusted according to the goals. The right side is the literal view, showing the goals as they are according to their true amounts. As this example shows, the resident with the gold star actually has a higher projected value than the middle neighbor; however, this resident is projected to use a smaller percentage of his or her goal and hence receives the gold star.

In order to encourage fairness and decrease the mistrust associated with community comparisons, all comparisons are done within the context of each resident's cumulative goal. This means that residents are judged only by how well they are meeting their goals and not by total usage. This allows for comparisons between greatly diverse sets of residences; e.g., a family of five living in a six bedroom home could be compared with a single college student living in a one-room apartment, despite the fact that the family could be using three to four times the amount of energy. If the family is projected to be 20% under their goal, and the student is projected to be 10% over his/her goal, then the family will receive the goal star.

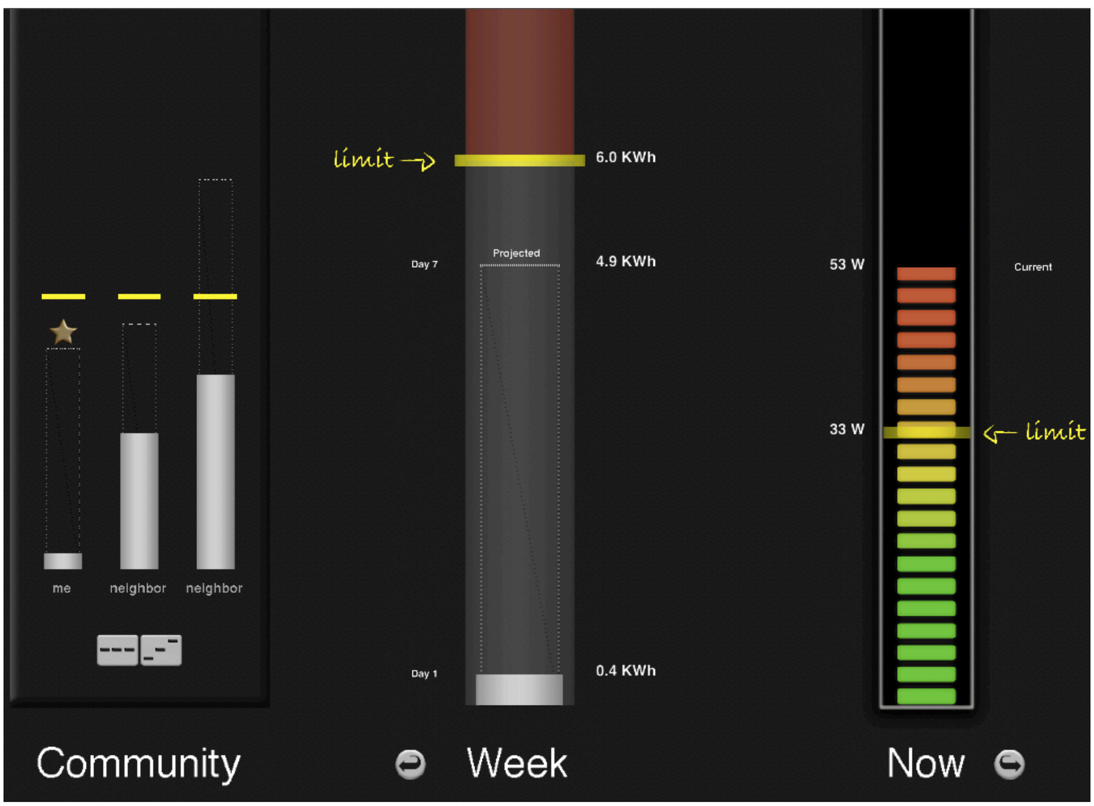


Figure 13. The full interface, with community view. The cumulative and real-time meters can be flipped over to reveal their corresponding historical views. Units can be shown in watts, dollars, or hidden completely.

The community view can be displayed in either normalized or literal representation. The normalized view shows all the goals as equal and adjusts the height of the bars based on the goals. The literal view shows the bars in terms of how much actual energy the represent. The default view is normalized in order to present a more trusted initial comparative view.

The community view implemented in our prototype required only three comparisons, as that was the number of users in our pilot study (described in Chapter 4). However, the view could easily be scaled to accommodate more by simply reducing the size and position of the bars as necessary.

3.5 Implementation

The final prototype was implemented in Java 1.5 using the Java3D framework. In order to collect data on electricity usage, multiple Watts Up? [60] devices were plugged into separate appliances and then connected to the prototype machine via

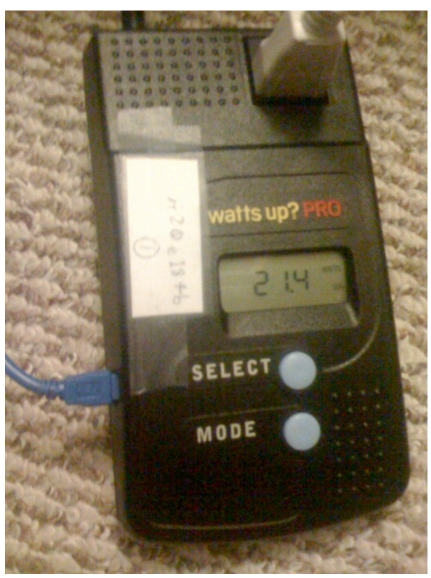


Figure 14. A Watts Up? energy meter. Appliances are plugged into these meters, and consumption data is sent via USB to the computer every second.

USB. The prototype is multi-threaded, enabling it to poll each device continuously while still allowing for interaction with the UI. Both the real-time and cumulative meters are updated every second.

The real-time goal is dynamically adjusted according to how well the resident is meeting their cumulative goal. If the user is projected to go above their weekly or monthly limit, the real-time goal will adjust downward in order to compensate. This effectively allows residents to "catch up" even if they use a lot of energy early in the month. The real-time goal will adjust upwards as well; however, it will never go higher than its initial starting point. This ensures that users who are practicing good consumption behavior are not tempted to use more energy than necessary.

In the initial implementation, the real-time goal is calculated naïvely based on a flat 24-hour usage pattern. More sophisticated methods could be implemented to take into account reduced night time or work-day usage.

The projection is also a simple linear calculation based on how many minutes the meter has been in use for the month, how much energy has been used that month, and how many minutes are remaining in the month. Better projections could be made according to time of month or seasonality.

The community view is implemented with a client-server model. Each client registers with a server upon initial startup. The server keeps track of updated cumulative usage for each client. Every five seconds, each client send its updated cumulative data and requests the latest values from the server.

Chapter 4: User Study

We performed an initial pilot study in order to begin evaluating the effectiveness of our design heuristics and interface prototype.

4.1 Methodology

Since our interface was designed to be used in real world residences, we felt that performing a lab study would be insufficient to properly evaluate it. Therefore we decided to perform a three week field study in which we installed our interface in the residences of three volunteer subjects. This study used a within-subjects design comparing our interface to an interface that was representative of standard existing text-only solutions. The first 10 days of the study was run using the standard text interface, and the second 10 days was run using our new interface. This study was conducted in accordance with IRB #08453.

4.1.1 Subjects

Subjects were recruited via email to UIUC campus mailing lists. Of those who responded, subjects were selected in such a way as to get a range of different types of residences and living partners. The three subjects selected were as follows:

- *Subject A*. Male graduate student. Lived in a house off campus with his spouse.
- *Subject B.* Male undergraduate student. Lived in a dorm-like room in a fraternity with two roommates.
- *Subject C.* Male undergraduate student. Lived alone in a one bedroom apartment.

No monetary reimbursement was provided to the subjects.

4.1.2 Equipment

Equipment consisted of four to five Watts Up? energy meters per residence. Each meter was hooked up to a single appliance. Additionally, a single Mac laptop computer was placed in each residence. The Watts Up? meters were connected to this laptop via USB cables and a USB hub.

The Mac laptop was used to display the simple text interface for the first 10 days and our graphical interface for the second 10 days. The text interface was based on "The Energy Detective" interface [55], as seen in Figure 15. It shows a simple readout of current energy usage at the top, with cumulative month-to-date (MTD) and projected (PROJ) usage below.

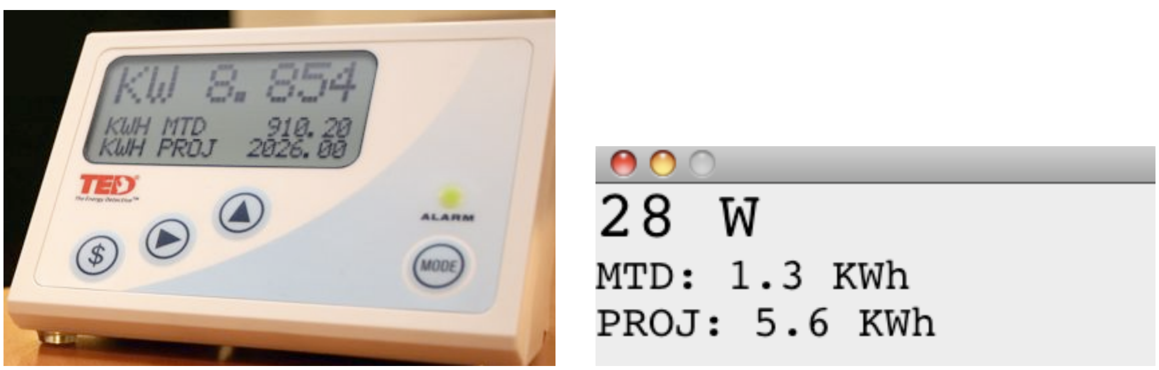


Figure 15. Left: The Energy Detective (TED). Right: Simple text-based interface based on TED. The interface on the right was used as a point of comparison for our interface and was displayed for the first 10 days of the study.

4.2 Procedure

Our procedure for each subject consisted of an initial interview, a three week field study, and a concluding exit interview. We describe the initial interview and study procedure here; results from the exit interview are presented in section 4.3.

4.2.1 Initial Interviews

Subjects were interviewed about their knowledge and attitudes towards energy consumption. Two of the subjects (A and C) were aware of approximately how much they spent on energy per month ($150 and $70 respectively), while subject B was completely unaware, as he never saw a monthly bill (his fraternity covered the cost for his room). Neither subject A nor C was aware of the amount of energy used in terms of KWh; they only knew about their consumption in terms of dollars.

Subject A felt somewhat aware of the amount of energy taken up by individual appliances; he believed that his air conditioner and water heat took up the most. He based this on the fact that one month when he didn't use his air conditioner his bill dropped to $40. Subjects B and C said they had no idea of the amount of energy their individual appliances used.

Subjects A and C both attempted to conserve energy in some way. Subject A tried to keep appliances off when possible, keep his heat down, and keep the water heat off. He had also replaced all of his lights with compact fluorescent bulbs (CFLs), and all new appliances he bought were Energy Star compliant. Subject C tried to turn lights off when possible, and had replaced some of his bulbs with CFLs. Subject B did not practice any energy saving behavior.

When asked if they would attempt to reduce their consumption if they could see how much energy they were using, subjects B and C said they would. Subject A said he didn't know, but that he would be interested to know which appliances were using the most energy.

4.2.2 Installation and Field Study

The Watts Up? meters were installed in a single room in each residence due to the need to hook each device up to the Mac laptop with physical cables. Location was chosen based on the amount of appliances present and availability of an easily visible location in which to place the laptop.

Subject A's meters were installed in his home office room. Subject A had four appliances monitored: two laptop computers, a monitor, and a lamp. Both he and his wife worked in this office.

Subject B only had a single room, so meters were installed there. Subject B also had four appliances monitored: a TV, a laptop computer, a lamp, and a monitor.

Subject C had his meters installed in his living room. Subject C had five appliances monitored: a TV, a laptop computer, a lamp, a monitor, and a Roomba robot vacuum charger.

Figure 16. Left: Subject A's setup. The laptop on the left desk was used to show the visualization. The Watts Up? meters were placed below the right desk. Right: Subject C's setup. The laptop on the TV shelf showed the visualization. The Watts Up? meters were kept tucked away out of sight underneath the shelf.

We chose devices to be monitored based on availability and amount of use. All the devices monitored were located together and had heavy daily use. Furthermore, they were devices which provided ample opportunity for curtailment; for instance, lamps, monitors, TVs and computers can all be turned off when not in use.

The field study was run concurrently with all three subjects. The first 10 days consisted of the simple text based interface. Subjects were given a brief explanation of the interface and told what each of the three text fields meant. Subjects were also given the ability to turn off the laptop screen any time they did not want to see the monitor, though data was still being logged continuously.

For the last 10 days, subjects were given our graphical interface. Again they were given a brief explanation of the UI and how to use it. The goal of each resident was set at 15% savings and was based on the usage of the first 10 days. So if a resident consumed 10 KWh the first 10 days, his goal for the next 10 days would be 8.5 KWh.

Total consumption data was saved to the hard drives of each subject's laptop. In addition, interaction data for our graphical interface was saved so we could get an understanding of which parts of our interface were being used by the subjects and how often.

4.3 Results

4.3.1 Quantitative

Cumulative results are shown in Figure 17 below. Subject B and Subject C both used less energy the second 10 days, while Subject A used more. However, Subject A still consumed much less energy overall than both Subject B and C.

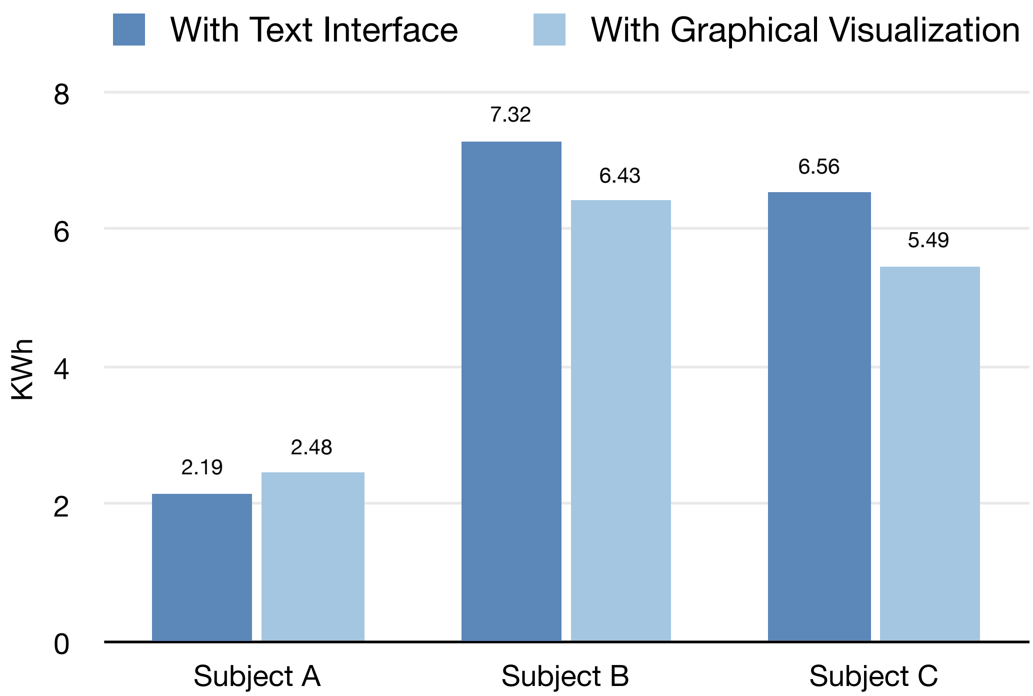


Figure 17. Cumulative energy usage for each subject with both the text interface and the graphical visualization.

Figure 18 shows results broken down by appliance for each subject. Subject A's increased usage can be attributed to the second computer, which he had to use more during the second 10 day period. However, monitor usage was reduced, as he began manually turning it off when not in use during the day, rather than waiting for it to sleep on its own.

Subject B's TV usage reduced drastically during the second period. Subject B made a note of this during his exit interview, mentioning that he began to turn off the TV whenever it was left on by his roommates, since the real-time meter showed a large amount of usage. For him, the visualization "served as a constant reminder that I should be saving power."

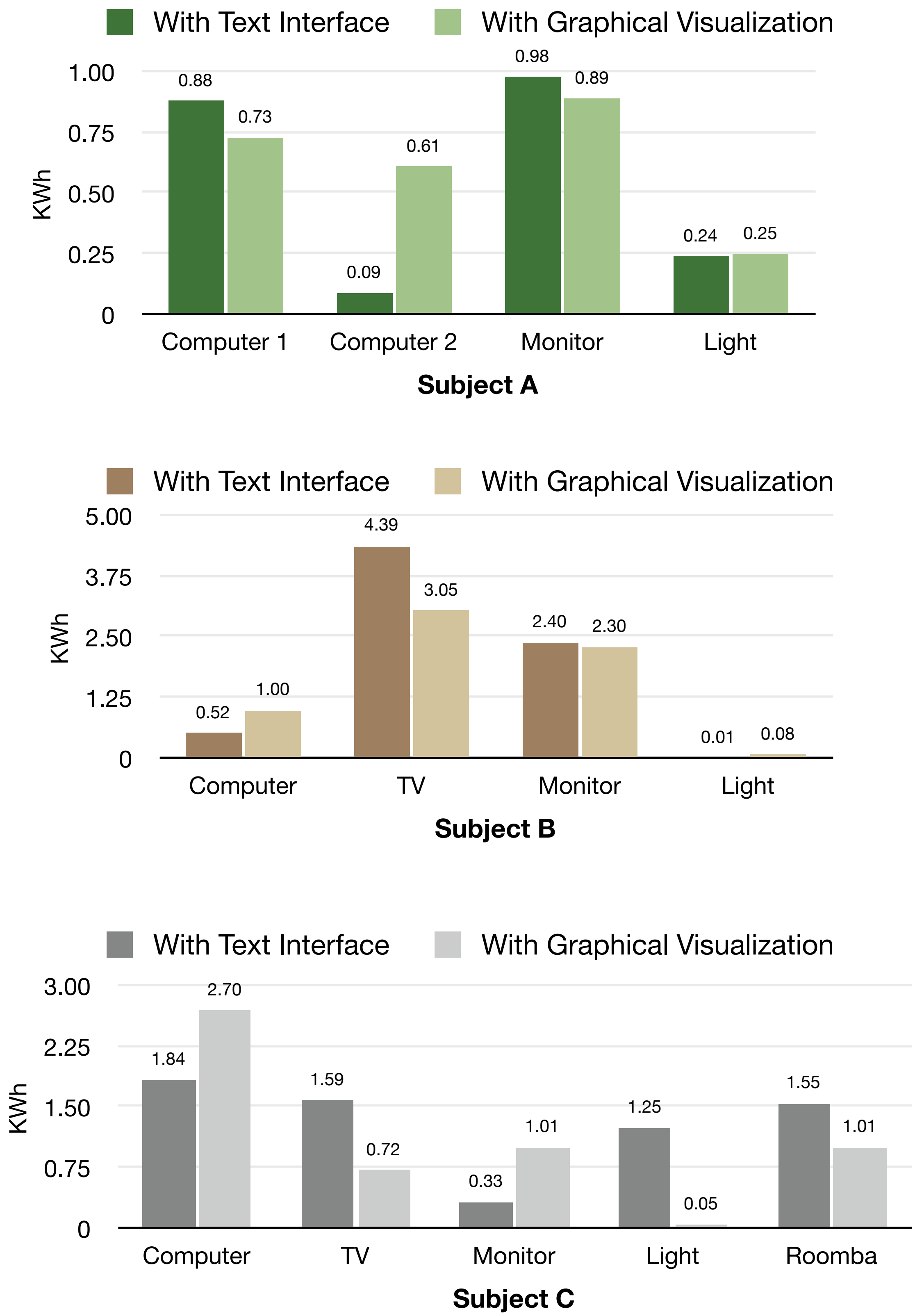


Figure 18. Cumulative energy usage for each subject broken down by appliance.

Subject C also reduced his TV usage, as he saw that by unplugging it when it was not in use he could save a large amount over the 10 day period. However, he reduced his light usage even more, as he saw that when it was on, it was contributing over 50W, more than any other appliance except the TV. He realized he didn't need that particular lamp to be on very often, and by turning it off he saved over 1 KWh on his cumulative usage.

4.3.2 Qualitative

Reactions to the visualization were unanimously positive. All three subjects felt it was easy to understand and learning it took only a matter of minutes. Subjects were asked whether or not the visualization increased their awareness of energy use and whether or not it impacted their attempts to conserve energy. All three agreed that it did increase their awareness and their attempts to save. Subjects A and C mentioned that it was especially helpful for pointing out devices that "leeched" energy a little bit at a time even when they were off. Subject A began turning off his monitor when away from the computer, and Subject C started unplugging his TV when not in use. Subject B liked that the visualization served as a persistent reminder to save energy. He highlighted the projection, last hour history, and appliance-level breakdown as useful features.

Subjects also appreciated seeing the cumulative view with the integrated goal and projection. Subject B said the goal was "definitely useful... it makes you not want to go over and encourages you to save as you get closer to it." Subject C said the cumulative view was "critical to me", because "it's shown me that even though my TV only uses 6W [when it's off], because it uses it all the time, it uses a lot of energy over the course of the day."

Subjects had differing attitudes about the community display. Subjects B and C enjoyed seeing the consumption of their neighbors. Subject B said the view of his neighbors was by far "the coolest feature." He said that he "didn't want to be the hog in the neighborhood" so he made sure to turn his monitor and TV off when it wasn't in use. Subject C took pleasure in competing with the others, going so far as to unplug various devices in order to ensure his victory. He said he need to "beat that sucker on the right, so I've unplugged my television, as it had been consuming 17% of total energy so far, without me watching it." He also started putting his laptop into sleep mode overnight, when he normally would have simply left it on.

Subject A, however, did not care for the community display. He said it was "not useful," as he was only concerned with how much he personally was using. He also didn't feel the comparison was valid, as the neighbors were using different devices. Subject C also had concerns that the community view was unfair:

> "I certainly do want to better than my neighbors, but I still am unsure if I'm being compared on an appropriate scale. Like, who are these people? These anonymous people might have big houses, or small rooms; how am I to know?"

It seems, then, that we did not entirely succeed with our attempts to alleviate trust issues through a normalized goal-based comparison.

All three subjects said that they would want a display like this one as a permanent part of their home. Subject A said it "definitely helps a lot", but he would want to be assured that the display itself was energy efficient. Subject B said it was "definitely something worthwhile to use" and wished he could hook up all of his appliances to it.

Each subject also had different feature requests. Subject A wanted cumulative usage on a daily resolution instead of weekly. Subject B liked the rotating display and felt that even more detail could be displayed on the back side besides just the hourly history. Subject C wanted wanted a smaller form factor with a less intrusive display. Subject C also wanted graphs of each individual appliance over time. This points to the need to allow user customization of form factor and visualization content.

4.4 Discussion

Though it is difficult to formulate any generalizable conclusions from such a small pilot study, results were nevertheless encouraging. Two of the three participants saved over 12% on their energy consumption when using the visualization compared with the simple text-based interface. From the exit interviews, it seems several different features of the visualization may have accounted for this reduction in consumption.

First was the ability to see a detailed look at how much each individual appliance was contributing to the total. This allowed subjects to discover some surprising facts; e.g., in Subject C's case, he saw that his TV used 6 W even when it was off, leading him to unplug it when not in use. He also was able to see that his small lamp was actually a large contributor to his total.

The cumulative view along with the goal and projection placed energy usage in a context the subjects could easily understand. Subjects B and C took special effort to try to meet their goals, with Subject C succeeding in saving over 16%. Even though Subject B did not meet the 15% goal, by making the effort he still succeeded in saving over 12%.

The community element was perhaps the most successful component of the visualization. Subjects B and C were especially excited by it and actively competed to beat their neighbors. Subject B seemed to be most affected by social guilt, as he mentioned how he did not want to use the most energy and look bad.

Of course, there were also elements of the visualization that were not as successful. The built in tips were not mentioned by any of the subjects as being helpful. This may in part due to the fact that they were somewhat generic (e.g., “Turn off your monitor when not in use”) and not as insightful as they could be. More research will be needed in order to determine the best tips to display.

The community display also had some problems. Subjects A and C both mistrusted the display and did not feel the comparison was fair. Subject C felt that not enough information was given in order to make a judgment about whether or not the comparison was valid. Also, the community comparison may encourage residents to use more energy if they are already using much less than their neighbors. It may be necessary to hide those neighbors who use significantly more energy and show only those who use a similar amount or less.

Finally, all the subjects felt that more information could be shown on the display. Subjects A and C wanted graphs of individual appliances over time, and Subject B wanted more detail in the hourly history. While the goal was to keep the display simple and minimalist to facilitate ease of learning, it seems that once subjects become familiar with the current features they desire even more. It may be helpful then to provide some mechanism to reveal features slowly to users who request them.

Chapter 5: Conclusion

5.1 Future Work

There are several areas in which the interface can be improved. Graphs of individual appliances over time will need to be added in a way that scales gracefully to dozens of appliances. Better tips are needed so that residents will find them helpful; new tips could be updated periodically from the Internet so that residents don't simply check them once and then forget about them. And the community display will need to be altered so that residents are more trusting of the comparisons being made, perhaps by providing more detailed comparisons on an appliance level.

There are also many new directions in which the community aspect of the meter can be taken. For instance, integrating it with social networks like Facebook would greatly increase the number of people who could see the comparison and thereby increase the amount of social pressure to conserve. Other possibilities include displaying the meter in a public place (e.g., outside your house or car) to allow others around you to see how well you are doing.

While our pilot study provided a good first step for understanding what was useful about the interface and what needed improving, larger long-term studies will also need to be conducted in order to gather generalizable results about the interface and the heuristics it is based on.

5.2 Summary

We have presented a new visual interface for a residential energy consumption indicator. We first performed a comprehensive literature survey of strategies for encouraging energy consumption. We synthesized these strategies into a set of design heuristics that are applicable to any ECI interface attempting to bring about change in consumption behavior. We then built a fully functioning example interface that satisfies all of our design heuristics and performed a pilot study to help gauge its effectiveness. The interface received a unanimously positive reception from the study subjects, and two of the three saved over 12% on energy consumption when using the interface compared to a standard text-based interface. Further work can be done in improving the amount of information the interface displays and also expanding its community-based feedback.

Appendix A: Interview Questions

Initial Interview Questions

1. Are you aware of how much total energy you typically use in a month?

2. Are you aware of how much energy your individual appliances use?

3. Are you aware of how much you spend on energy?

4. Are you aware of where your energy comes from, and its environmental impact?

5. Do you attempt to consciously save energy in any way?

6. If you could see how much energy you were consuming, do you think you would attempt to reduce your consumption? Why or why not?

7. Other comments:

Exit Interview Questions

1. Was the visualization easy to understand? How long did it take you to learn?

2. Did the visualization increase your awareness of your energy use?

3. Did the visualization have an impact on your attempt to conserve energy?

4. About how often did you glance at the visualization?

5. About how often did you interact with the visualization?

6. How did you feel about the community aspect?

7. Would you want a visualization like this to be a permanent part of your home?

8. Would you prefer a permanent visualization to show less, more, or about the same amount of information?

9. Other comments:

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