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Ronald A. Metoyer

As non-renewable resources dwindle and costs increase, it becomes ever more important for people to understand and control their electricity usage. Eco-feedback devices are being developed to increase user awareness and reduce consumption. In order for feedback devices to be successfully adopted into the home, however, they must be appealing and show the desired information. The best way to accomplish this is to involve users in the design process. In this work, we discuss results from two studies on awareness feedback devices as viewed from three demographic groups. In the first, we interviewed potential end-users to gain insights into their current level of understanding about their own electricity use, motivations to conserve, and to learn about user preferences for a feedback device. We present our findings regarding current understanding, motivations, preferences for location, and views on ambient devices, among others. The second study consisted of three workshops in which we asked potential end users to design electricity feedback devices that they would want to use in their own homes. We present the resulting designs and discuss implications for designing feedback devices for the home.

Studying Electricity Feedback for the Home with an Emphasis on the User

by

Josie Elizabeth Hunter

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

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Josie Elizabeth Hunter, Author

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CONTRIBUTION OF AUTHORS

For the study performed in Chapter Two, Dr. Ronald Metoyer and Karl Smeltzer participated in study design. Karl Smeltzer, Andrew Atkinson, and Catharina Vijay were involved in conducting the in-home interviews, including data collection. The entire research team (Dr. Ronald Metoyer, Karl Smeltzer, Andrew Atkinson, and Catharina Vijay) analyzed data. Dr. Ronald Metoyer and Karl Smeltzer made significant contributions to the writing of Chapter Two.

The design of the workshops conducted in Chapter Three was assisted by Dr. Ronald Metoyer and Karl Smeltzer. The workshops were conducted by the entire research team. Dr. Ronald Metoyer, Karl Smeltzer, and Andrew Atkinson were involved in data analysis. Dr. Ronald Metoyer and Karl Smeltzer provided recommendations and edits to the text of Chapter Three.

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1 General Introduction

As environmental concerns grow, consumption of limited resources, especially fossil fuels, must be controlled. More than a third of the electricity used in the United States, which is generated primarily by coal, is a result of residential use [47, 48]. As such, electricity use in the home is an excellent target for which to encourage reduction.

Unfortunately, electricity can be difficult to monitor and control. Unlike water, electricity is not visible to consumers. Rather, its use is a byproduct of using electrical appliances. This can make it hard to understand exactly how much electricity one is using at any given time, and which appliances are using the most. Without this information, it is difficult for users to effectively limit their usage and reduce costs. This problem of cost is only compounded by the introduction of dynamic pricing, where the cost of electricity can fluctuate throughout the day.

Both environmental psychologists and members of the HCI community have studied electricity feedback for the home. Psychologists have focused more on the user, studying the effects of feedback, and how to create behavior change. The HCI literature focuses on the feedback device itself, but usually not on its effectiveness [16]. In our work, we begin to bridge the gap between these two fields by applying concepts from Prochaska's Transtheoretical Model for behavior change [36], and by more closely involving potential end-users in the design process, in order to ultimately create an effective feedback device.

This thesis discusses the work and findings from two separate studies. The first study, presented in Chapter Two, consisted of interviews with participants in their homes. These were done in order to gauge the level of current knowledge and to understand user motivations and preferences with regard to electricity and feedback devices. Chapter Three presents results from participatory design workshops that we held on Oregon State University's campus. We discuss some of the feedback designs created by our participants, as well as interesting themes and ideas that emerged. Both studies focused on participants from three demographic groups: older adults, families, and students in shared housing, and attempted to discern the differences between them.

2 Designing Visual Feedback for the Home: A Field Study

Ronald A. Metoyer, Karl Smeltzer, Josie Hunter,
Andrew Atkinson, and Catharina Vijay

2.1 ABSTRACT

The home provides a unique opportunity when considering the use of visual feedback in support of awareness. It is a hierarchical structure, divided into floors and then rooms, with potentially many users who move throughout the structure in their daily routines. In this paper, we discuss our field study examining electricity consumption awareness in the context of the home with an eye towards design issues for visualization in the home. We focus on three demographic groups: older adults, families with children, and college students. We present themes that evolved from the field study analysis and present avenues of exploration in the design space for visual feedback systems in support of energy consumption awareness in the home. We conclude with speculation regarding the evolution of awareness devices and how we may be able to borrow from another domain in which feedback is essential–time management.

2.2 INTRODUCTION

In the United States, the domestic sector accounts for more electricity use than either the commercial or industrial sectors [48]. This makes it a good candidate for work examining consumer behaviors, knowledge, and decision making processes in an effort to reduce overall electricity consumption. Pierce and Paulos reviewed the spectrum of sustainable HCI literature [33], which pointed to an opportunity to engage with other communities to inform emerging technologies and systems. We make a similar observation about under-explored opportunities in working directly with consumers to better understand their knowledge, desires, motivations, and habits with respect to their electricity consumption.

Electricity is a particularly intangible resource. Unlike water, its use is not directly visible to the consumer. Instead, electricity is consumed merely as a consequence of using electrical appliances. In order to make informed decisions about electricity consumption then, consumers must be well informed about the requirements of their appliances and their patterns of usage. While such technical specifications are sometimes available from manufacturers, they presume some technical understanding on the part of the consumer. Even armed with such knowledge, the consumer would still need to closely track the amount of time spent operating each appliance and perform a calculation to determine their own usage.

Establishing or improving general awareness is generally considered the first stage of behavior change. Without being aware of the need for change, or how such a change could be made, behavior change cannot take place. Prochaska developed one of the most widely known models of behavior change, termed the Transtheoretical Model [36], which maps behavior change processes to the appropriate stages of change. The transtheoretical model begins with the *Precontemplation* stage, in which the first process is *Raising Consciousness*. This closely aligns with our understanding of increasing awareness [38].

While Prochaska's model applies to individual behavior change, the home presents a much more complex environment in which the goal is to promote improved consumption behaviors among the entire household where each member may potentially be in drastically different stages of behavior change and motivated in drastically different ways. To complicate things more, the home is a complex structure, hierarchical in that it is divided into floors and then rooms, and customized by the routines of the inhabitants. In short, moving an entire household is understandably much more complex than eliciting change from an individual. Nonetheless, Prochaska gives us an excellent base upon which to begin to understand how to affect behavior change. Riche et al. drew upon Prochaska's model in 2010 and suggest that energy consumption behavior changes can be generalized into three main steps of 1) Raising Awareness, 2) Informing complex change, and 3) Enabling maintenance of that change [38].

In this work, we set out to explore requirements for designing always-on visual feedback devices to support these three phases in the home context. Each phase depends necessarily on the consumer being able to interact with and understand his or her relevant consumption data. We report on a field study in which we interviewed participants, in their homes, to understand various aspects of the design space with a focus on where their knowledge gaps lie, how to support change through awareness and goal setting, and how to support maintenance of changes with feedback devices. These design issues are structured loosely by investigating each in terms of what to show, when to show it, and where to show it in the home context.

After presenting related work, we will discuss our field study methodology and the qualitative results. We will cast our findings in the context of the change model presented in [38]. We will discuss particular questions and activities from our field study and how those questions shed light on the design space. We will conclude with the description of a theoretical framework for the design of energy awareness visualization systems informed by the field study and by the historical evolution of another important awareness device – the clock.

2.3 RELATED WORK

Figure 1: Traditionally, feedback has been provided by paper bills, devices on the outside of the home (left) and more recently, devices placed on each appliance, such as the Kill-A-Watt monitor and feedback device (right).

A number of tools have been designed and implemented for energy consumption feedback (see Figures 1 and 4) and a number of papers on the challenges and design concerns of feedback devices in the context of utility usage have been published in recent years [13, 16, 45]. While these begin to give direction to future research on eco-feedback, a number of unanswered questions still remain. In particular, existing work has focused primarily on the question of what to show consumers to maximize awareness. While this is a key component, little research has tried to unite this with the questions of where and when to provide feedback.

A substantial body of work exists showing the general effectiveness of feedback technology in reducing domestic electricity consumption [9, 12, 44]. With that justification, newer work has evaluated existing designs and attempted to identify the relevant concerns and design criteria [13, 15, 27, 32, 34, 45] to be considered when designing such feedback devices. All of this work, however, focuses on single devices located at specific appliances or in a centralized location. Domestic settings are complex, and providing timely feedback that leverages household routines and takes a form that addresses consumer needs remains a difficult problem. The home context provides a rich set of opportunities, which will motivate and frame our discussion.

Because homes are both highly personal and symbolic in nature [19], designing effective, interactive technologies specifically for the home must account for a set of criteria distinctly different from commercial settings [1]. Many household members are willing to make modifications in pursuit of more sustainable behavior, under the condition that such additions allow for the expression of identity [54] and are both meaningful and fun [6]. The accepted methods for studying these home-specific requirements include both cooperative design of low-tech prototypes and cultural probes [51], which have directly informed this work.

The conveying of information in homes is also understood to take advantage of additional contextual meta-information [8]. Across multiple cultures, particular locations in the home are used to house information, display information, and to create and consume information, thereby enriching the data with additional context and meaning [8, 11]. Leveraging this context when designing domestic feedback devices might increase their effectiveness by increasing the likelihood of garnering attention.

The importance of this context has also been acknowledged specifically for electricity consumption feedback, suggesting a number of dimensions worth examining: whether such a feedback device should be centralized in a single position or distributed around the home, whether it should be fixed or movable, how quickly the display should update, and what time range should be shown [52, 53]. By examining these aspects directly, we hope to extend the understanding of these design concerns and their relative importance.

Ueno et al. [49] studied the effect of installing energy monitors and single-point feedback terminals in family homes in Japan. In addition to finding a general reduction in energy consumption after installation of the devices compared to before, they were able to extract information about how the devices were used. Tracking which feedback data were viewed most frequently determined that participants preferred detailed feedback such as daily load curves of their consumption to more aggregated data such as a 10-day overview. Our findings are not in conflict with this, but indicate that consumers prefer to have access to a number of options rather than a single view.

The Commonwealth Edison electric utility company performed a field trial with 8,500 of its customers to examine the effects of dynamic pricing models, feedback technology (including an advanced in-home display created by OpenPeak), and education on electricity usage rates [20, 21]. In contrast with other work [12, 17], analysis showed no statistically significant change in electricity consumption was associated with the feedback devices, but only a small population was selected to receive the devices and less than 10% of those customers selected actually installed the device. We conjecture that the lack of significant results and low enthusiasm shown by participants might result from using feedback devices without first consulting consumers directly about their wants and needs.

2.4 METHOD AND PARTICIPANTS

We conducted a qualitative study of 14 households consisting of a total of 37 participants. In an attempt to gather information for a diverse range of living arrangements, we recruited households of families, students, and older adults (defined as 55 or older). We interviewed 6 family households consisting of 15 family members, 3 of which were children under 16, 12 students distributed between 3 households, and 10 older adults from 5 households. Fifteen participants were female.

Households were recruited through email. Families were targeted through lists associated with local schools and students were targeted through lists associated with Oregon State University. Our older adult population was recruited from the Center for Healthy Aging Research Life Registry. All participants were compensated with $20 in cash. All sessions were conducted in the households of the participants in order to contextualize the process.

Our study sought to discover the current awareness level of our participants and gain insights into their motivations, preferences, habits, and ideas in an effort to understand how to leverage these aspects in supporting energy consumption. We determined that a semi-structured interview would provide us with the best method for gathering this information, allowing us to clarify ambiguities and allow for brainstorming, while still keeping the desired level of organization. Such approaches have been used successfully in previous work [6]. The interview consisted of activities meant to gauge current knowledge and awareness, understand the household dynamics with respect to energy consumption, and to explore the design space.

We asked participants to supply photos to provide additional information after the completion of the survey. All sessions were audio-taped.

2.4.1 Appliance Awareness

In the first activity, each household was asked to create a list of all of the electrical appliances within their home, and then rank them from appliances that use the most electricity to the least. Our goal was to understand their general awareness of the consumption levels of appliances and to determine if there are any common misperceptions.

2.4.2 Routines and Traffic

Next, we asked them to draw a floor plan of the residence, label large appliances in the home, and then talk us through their morning and evening routines. We also discussed non-daily routines such as seasonal work and laundry schedules. This allowed us to identify high traffic areas in the home, and electricity usage with respect to routines. Finally, we asked participants to mark areas where they do activities like paying the bills or using a computer as information centers. This activity was videotaped for later analysis.

2.4.3 Interview Questions

We then moved into the semi-structured question segment of the interview focused on understanding the design space for energy consumption awareness in the home. We asked several design questions regarding topics including motivation to reduce consumption, the preferred feedback format and units (e.g. cost, kilowatt hours, etc.), motivating children, ambient feedback, and feedback device location. We gauged intra-household communication by asking how household members delegate control and discuss concerns about costs and electricity with each other so that we might better facilitate this process. The final questions were in regards to competition and whether it might be a motivating factor.

2.4.4 Supplemental Photos

At the end of the interview we asked participants to take pictures of objects around their homes that reminded them of electricity and their usage for the following two weeks. This was intended to provide us additional information about what sparks thought about electricity.

2.4.5 Analysis

All of the interviews were transcribed and broken into "statements" where a statements was defined as a set of sentences from the participants that addressed a single question or idea. We then used content analysis to develop a coding scheme for each interview question as well as a general set of codes. We categorized each "statement" using an ad-hoc coding process. We held group coding sessions, for each of which at least two of three primary research members were present to ensure consistency. The "statements" were then counted and related for overarching themes that we will present in the following section.

2.5 STUDY FINDINGS

In the following sections, we present our findings from the study and organize them by focusing on the most interesting themes identified during analysis. We pay particular attention to the home context as a 'display' of information and in Section 2.5.3, we discuss how to apply principles from the information visualization domain to this complex display environment.

2.5.1 Raising Awareness of Appliance Consumption

To gain a coarse understanding of the level of awareness across study participants, we asked them to generate a list of the electrical appliances in their home and to sort them from highest consumer to lowest consumer. Because some appliances are used more frequently than others, participants factored their own usage habits into this comparison.

We extracted the ten most commonly named appliances among all households from these lists in order to reduce the variation between items in the lists. This final list included the following appliances: hot water heater, furnace/heat, refrigerator, lighting, clothes dryer, oven/range, computer, dishwasher, television, washing machine. Even with this truncated list, not all households contained every appliance. In particular, some household hot water heaters and furnaces were gas-powered rather than electric. Additionally, some households considered the washing machine and clothes dryer together as a single unit rather than separate appliances. We accounted for these variations in the evaluation of the results.

Next, we generated a list of rankings to serve as a standard of expected rankings (Table 1). We created this list by merging average consumption estimates from both the U.S. Energy Information Administration [47] and from utility companies [43, 37].

Table 1: The baseline expected ranking of appliances

Ranking	**Appliance**
1	Water heater
2	Furnace
3	Refrigerator
4	Lighting
5	Clothes dryer
6	Oven and range
7	Computer
8	Dishwasher
9	Television
10	Clothes washer

We used the Kendall Tau Distance [23] from this expected ranking as a measure to determine the relative accuracy of each household. This gave us a rough but simple metric by which to determine the degree of correctness that each household ranking exhibited.

As discussed in the literature [6, 24, 38], households are generally not aware of the consumption amounts of appliances in the home. The mean and median error rates in our ranking measure were both approximately 17%, which is equivalent to each appliance being ranked out of place by a 17% distance. Families were the most accurate, followed by student households and older adults.

We also examined error rates for each individual appliance (averages shown in Table 2). To calculate this we averaged the number of positions a ranking was removed from its correct position. For instance, if a household had ranked the refrigerator as the highest consuming appliance when it should have been ranked as the third highest, then that would give an error of two positions.

The least accurately ranked appliance, with an average error of 30.0%, was the household lighting. Most households ranked lighting as a lower consumer than our estimates indicate to be accurate, although there were exceptions. The next most inaccurate rankings were for washing machines and dishwashers, with average errors of 29.8% and 21.7% respectively. Both of these were consistently ranked too high in consumption by participants. We speculate that this could be caused by consumers forgetting that, while these appliances often use a great deal of hot water they do not heat that water themselves.

The most consistently correct appliance was the electric hot water heater. Every household which contained an electric hot water heater ranked it as the highest consumer, which is in agreement with our estimate, leading to a zero average error rate. However, since fewer than half of our participant households contained electric hot water heaters it is difficult to reason about whether this is a trend or a coincidence.

Following the hot water heater, the most accurate rankings were for refrigerators and computers, with average errors of 9.0% and 10.6% respectively.

Table 2: The average error in participant rankings

Average Error (%)	Appliance
30	Lighting
29.8	Clothes washer
21.7	Dishwasher
21.4	Furnace
19.9	Oven and range
19.8	Clothes dryer
10.9	Television
10.6	Computer
9	Refrigerator
0	Water heater

2.5.2 Feedback Dimensions

The ranking task was in agreement with previous work and reinforced the understanding that home inhabitants lack awareness of their appliance consumption levels and/or their own habits. In this section we examine ways in which we can utilize visual feedback in the home to improve awareness.

The home is a complex environment. It is hierarchical in nature, typically described as a collection of floors, rooms, furniture and appliances. In addition, the home is dynamic. It is inhabited by individuals, with varying motivations and responsibilities, who move throughout it during the course of daily routines. Such a complex environment raises interesting questions regarding *when* to show information, *where* to show it, and *what* to show. While there are many other dimensions in which to study feedback in the home [15], we will focus on these three.

It is important to note that *when* information is presented (e.g. push vs. pull) should not necessarily be considered separately from *where* (e.g. localized vs. centralized) or even *what* is shown. These concerns are tightly inter-related, especially when considered in the context of the home which provides many small contexts specialized by the inhabitants and their location in the home. Certain data is only relevant in certain places and potentially only at certain times of the day, and possibly only to certain people. We will therefore discuss elements of *when*, *where*, and *what* concurrently.

2.5.2.1 *Framing the Feedback*

The *what* dimension of visual feedback is concerned with properly framing the feedback in units that make sense to the viewers. Concretely, consumption data can be presented in many forms (cost, pounds of carbon, kilowatt hours, trees consumed, etc.). Our participants professed a wide variety of motivations for wanting to reduce total electricity consumption. Environmental and financial concerns proved to be the leading *motivators* by a large margin, each occurring in 51% and 40% of the motivation-related statements respectively. This would indicate that data should be framed in terms of direct financial cost, possibly combined with either pollution or some more abstract representation of the environmental impact of electricity consumption.

However, when *explicitly* asked which types of feedback data they would most prefer, participants strongly favored representing everything in terms of cost (54% of statements for this question). Only 3 households felt that a representation based on pollution and other environmental information would be a good choice, two of which also mentioned cost (only 21% of statements for this question). In total, 9 of 14 households favored a view based directly on cost. Even participants whose motivations were strictly environmental tended to prefer framing feedback in terms of cost. Some participants felt that displaying feedback in terms of pollution would be overcritical, saying, “leave the judgment up to me”. Others felt that something like a measure of carbon dioxide output might be “a little abstract”, and therefore difficult to understand.

Presenting consumption data in concrete form is useful when attention is focused on the feedback device. Raising awareness, however, often requires that the feedback system gain the attention of the user who is otherwise not actively engaged in gathering consumption data. We now focus on two aspects of framing consumption data that is abstract: **pre-attentive processing** and **push feedback**.

2.5.2.2 *What sparks thoughtful consideration of consumption?*

During this first stage of change, the goal of a feedback device is to increase the awareness on the part of the electricity consumer.

A consumer at this stage of behavior change is, by the definition of the model, not actively engaged in making informed decisions about their usage. Because we cannot rely on the consumer to actively consider the ramifications of a decision, feedback must be designed such that it sparks their thought process and provides visual insight in a pre-attentive manner (without focused attention) [50]. A reasonable goal is to make important features of consumption, such as amount or rate, “pop out” of the surrounding environment without requiring focused attention.

To understand what kinds of events spark this thought process in consumers, we asked our participants directly (See Figure 2). Three major themes emerged. Participants most commonly considered their electricity usage when: (1) noticing wasteful usage such as a television left on but unattended, (2) being reminded of standby power usage, frequently via small LED lights on appliances which were thought to be powered off, and (3) using appliances believed to be relatively high consumption devices such as clothes dryers. Of all statements made, approximately 67% fell into one of these three categories. From these themes, we can explore some design avenues for feedback targeting consumers in the raising awareness stage.

Figure 2: Two photos submitted by study participants for cultural probe portion of the study showing events and objects that sparked thought about electricity consumption. They depict a number of LED appliance lights shining in the dark despite the appliances being turned off (left) and unused lighting fixtures in a neighboring room during mid-day (right).

First, both the waste and standby power themes indicate that consumers are likely to give thought to their power consumption when it is manifested through some tangible or visible channel. This indicates that the use of attention-getting visual feedback, particularly lighting, is likely to be an effective tool in raising awareness. Such designs are used in many of today's appliances for communicating awareness of on/off states, however, these visualizations can be modified to provide additional information. For example, LEDs with color encoding (i.e. green to red hues) or motion (i.e. flashing) can be used to not only indicate on/off states, but the current cost or even rate at which the appliance is consuming electricity, much like the flow rate of a water faucet provides awareness of usage (and waste).

Second, perceived high-usage appliances cause consumers to consider their usage habits. This indicates that feedback might be best presented *immediately and at the point* *of use*. For instance, feedback presented immediately, upon starting a clothes dryer, is likely to be engaging. This is in accordance with Fischer's findings, which indicate that immediate feedback may help users link actions and their effects [12].

2.5.2.3 *Push via Ambient Display Devices*

A distinction exists in data feedback between "push" and "pull" technologies. "Push" feedback is that which is somehow thrust upon the recipient, such as through a text message or sound alert. "Pull" feedback is that which requires the recipient to actively request the information before it is presented. The act of querying for a weather forecast via the web is an example of "pull" feedback.

Summarizing existing work on feedback in the context of sustainability, Froehlich noted that feedback is likely most effective when offering some combination of push and pull feedback techniques [15].

In the context of raising awareness, push feedback may be best-suited for initially engaging the consumer and causing a spark of thought about usage habits. Pull feedback, on the other hand, can be used to supplement push feedback by offering more granular detail upon request.

The apparent effectiveness of lighting as a feedback mechanism indicates that ambient feedback [35] may be more effective than traditional feedback (e.g. actual data values on display devices) specifically for consumers in the raising awareness stage via a "push" mechanism.

In our study, 6 of 14 households mentioned that LEDS and discovering unused appliances sparked thought about electricity (making up 36.5% of statements regarding this question). "Leaving an outdoor light on or a garage light on when it doesn't need to be on [reminds me of electricity]. I think about in our room because you have a lot of those energy vampires in our room that have built-in LED lights."

This suggests that ambient feedback that makes use of lighting may be an ideal candidate for engaging these consumers. This is in agreement with Rodgers et al. who explored the space of designs for ambient feedback in the home [40]. In addition, Kim et al. examined the use of ambient feedback in the context of persuasive technology and found that it could be used to improve awareness around specific, problematic activities or individual appliances [25].

We also asked participants specifically about the acceptance of ambient devices in the home and we discussed the option of audio-based feedback. Members of all but one participant household found the idea of ambient feedback appealing. The most popular suggested usage for ambient feedback was to encode the current cost of electricity, accounting for 8/11 responses (73% of statements). All of the participants paid a flat-rate for their electricity, but were explicitly asked to consider emerging technologies such as dynamic pricing throughout the interview. We also hypothesized that ambient feedback would be preferred for goal feedback, however, no participant mentioned using ambient feedback to encode consumption goals or goal progress.

Surprisingly, a majority of households were also willing to consider ambient audio notifications, outweighing those against 9 to 4 (12/16 or 75% positive statements), however, they also often stated that the alerts could not be 'obnoxious' and wanted control over toggling alerts on/off.

2.5.2.4 *Distributed versus Centralized Feedback for Awareness*

The preference for ambient feedback also suggests another distinction, namely that between centralized and distributed feedback. Froehlich defines location in terms of localized (at the appliance) or independent (e.g. paper bill or portal) [15]. We define similar but slightly generalized terms. Distributed feedback corresponds to feedback displays distributed at multiple locations throughout the home, not necessarily at the appliances. Centralized feedback, on the other hand, corresponds to data, possibly collected from multiple locations/appliances, but displayed on a single device in the home. In both cases, the data presented may fall upon a continuum of raw single appliance data to aggregated data (room, floor, home, appliance type, etc.).

Since we are most focused on establishing an awareness, it might intuitively seem that centralized tools would provide this most effectively. Unfortunately, this is complicated by the fact that we need to reach consumers who are not actively focused on consumption and thus would suggest offering feedback in multiple locations via a push mechanism rather than expecting them to seek it out (pull).

In practice, feedback can and should be designed to take advantage of both types. In fact, our participants discussed a wide range of preferences for location ranging from centralized to distributed at appliances and/or high traffic areas and even on mobile devices. When asked explicitly whether devices should be centralized or distributed, they were fairly evenly distributed with 50% of statements indicating centralized and 41% indicating distributed. This indicates that a mixture of devices may be most appropriate to accommodate the many preferences in homes as well as the many motivations and phases of behavior change. A single device or mechanism can be used, for example, to provide a “pull” mechanism for actively accessing the data while feedback devices can also be distributed to provide per-floor, per-room, or per-appliance “push” information for consumers to consider at the points of use or thought.

2.5.2.5 *Leveraging Routines*

Utilizing both centralized and distributed feedback maximizes the opportunities for households to gather information and raise and answer questions.

As discussed in the previous section, consideration should be paid to the location at which feedback is provided. Because consumers at this stage do not reliably “pull” information, it must be located such that it integrates with their routines in such a way that grabs attention and preferably engages exploration of the data.

We asked participants where they would place a hypothetical, centralized feedback device in their home. Some participants suggested specific locations: 6/14 households suggested the kitchen as a good candidate (in 10/28 or 36% of statements), and 5/14 households (in 6/28 for 21% of statements) suggested their information centers (where they pay bills, go online, etc.). Other participants spoke more generally with 7 households (in 8/28 or 29% of statements) suggesting high-traffic areas in which visibility would be high.

We also conducted an exercise to uncover household routines. Similar to the approach by Crabtree and Rodden [8], our goal was to analyze household routines to identify high traffic areas and areas used as information centers . Both of these serve as potentially ideal locations for display technology because of the increased likelihood of users seeing or actively engaging with it.

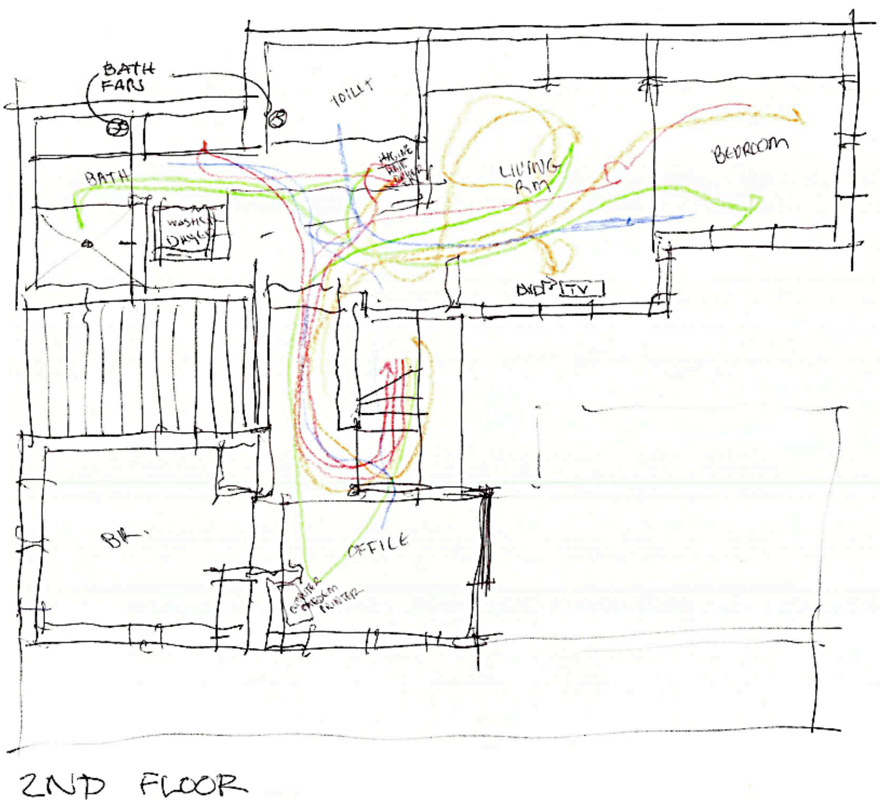

Figure 3: Example map from the routine task. Note the high traffic in the stairwell/ hallway as well as in the kitchen. Each color represents a different house inhabitant.

We identified several high traffic areas as those in which most/all household members travelled during their routines and which could be used as opportunities to push information to the user (See Figure 3). As expected, these areas generally correspond to stairways, hallways and communal rooms such as the kitchen and family/TV room. Stairways and hallways are particularly interesting because they are the hubs of the house hierarchy. Stairways connect (and provide access to) floors while hallways connect (and provide access to) rooms. Individual rooms are generally trafficked by only one inhabitant. Information centers, on the other hand, typically correspond to very low traffic areas like an office which is visited seldom and only by a single or select few people. While activities such as bill payment may happen at these locations, they are not necessarily useful for exposing the entire household or pushing information frequently.

One design option to explore is the placement of multiple feedback devices in high traffic hallways, but associated, for example, with individual rooms. These displays would push information to those inhabitants of each room, while also allowing all who travel the halls to gather and assimilate feedback from multiple sources to build a larger picture of consumption.

2.5.3 Visualization Design Applied to the Home

Our primary goal in studying real households was to explore the home as the design space for visual feedback. Traditional information visualization systems often aim to provide several levels of insight ranging from overview awareness to specific data details. One approach to designing such systems is articulated in Shneiderman's well known information visualization mantra: "overview first, zoom and filter, then details-on-demand" [41]. The mantra is generally considered in the context of a single visualization system. For example, we can consider an energy consumption display device that provides an overview of the entire home (e.g. floor plan view) along with the ability to zoom in on specific appliances or rooms and to get additional detailed information such as a time series consumption usage for a particular device (Figure 4). Many such interfaces have been proposed for centralized consumption display devices, however, little research has considered the mantra as applied to a system of devices distributed throughout the home, potentially at multiple levels (appliance, room, floor, etc.). We will examine the mantra in terms of its application to the entire home as a display. The findings presented in Section 2.5.2 indicate that the home is an ideal canvas in which to provide information. Consider, for example, a home fitted with multiple displays based on design ideas presented earlier. Awareness of consumption patterns may be provided by push notifications at the proper locations (appliances, rooms, etc.) and possibly with ambient display mechanisms. These notifications help the home inhabitants build an *overview* of their consumption patterns and potentially do so by utilizing another information visualization tool, pre-attentive processing.

Figure 4: A prototype design of Intel's home energy management device, released in 2010.

Filtering, then, is an artifact of a person's motion throughout the home. As a person follows his/her regular routine, he/she will be exposed to only that data that corresponds to their routines and usage.

Zooming, in this context, corresponds to a user moving deeper into the hierarchy of the home. Notice, that this is not a geometric zoom in which elements appear in finer detail because one is physically closer to the element, but rather, a semantic zoom in which the format of the information changes as the user moves deeper in the hierarchy and closer to the appliances. For example, a person may, upon entering a room, observe a display device near the door showing the room-level consumption and be exposed to multiple displays (possibly simple LEDs) on individual appliances, providing a finer level of detail (e.g. actual cost, or rate of consumption).

Finally, details on demand require focused engagement through interaction with a device. A person, for example, examining a particular device with a local outlet monitor, for example, could actively inquire to gain further details about that appliance.

The home context provides natural mechanisms to support the mantra, and visualizations designed for the home should take advantage of these natural affordances.

2.6 DISCUSSION

We have presented the results of a field study of 14 households designed to explore the design dimensions of feedback devices for energy consumption awareness with an emphasis on the home as a visual display environment. We now discuss two tangentially related topics: demographic differences and the home's natural communication channels, as well as a general outlook on how consumption feedback devices may evolve over time.

2.6.1 Demographic Differences

One of our goals was to explore demographic differences in this design space. In general, we observed very similar responses from our three demographic groups, however, there were several notable differences both expected and unexpected. Recall that we break our transcripts into 'statements' and code those statements with themes.

We report differences here in terms of the percentage of statements regarding a particular theme under consideration and speculate potential reasons for these differences.

In terms of motivation, while all three groups articulated financial motivations, older adults and students did so less often than households with families with 55% of the financial statements being made by families compared to 24% and 21% for students and older adults. Families also made more statements regarding pollution (54% as compared to 33% and 13% respectively for students and elderly households).

In discussing energy consumption habits, we were interested in understanding the decision making processes in our households. It was not surprising that a *communal* decision making theme was stated more often by student households (48%) than in older adult and family households (25% each). This is expected considering that student households are often shared by many students, each with equal financial responsibility in the home and thus equal interest in making decisions.

In general, older adult households were more likely to be interested in comparing individual appliances. Out of the statements on appliance comparison, 73% of them were made by older adults compared to 27% for families and students combined.

Finally, as discussed above, we were interested in understanding the role of ambient feedback in the home. Out of all the statements regarding ambient devices, 45% of them were articulated by families, 35% by students, and 20% by older adults. One could argue that ambient feedback is a relatively “new” approach to feedback and it is quite possible that it is simply something that the younger generations (students, children in families, etc.) are more familiar and comfortable with.

2.6.2 Natural Home Communication Channels

Finally, participants were also asked to discuss ways in which their homes already communicate with them. Our goal was to understand if ambient cues already exist in the home and whether they provide awareness levels of home functions. Surprisingly, participants were able to articulate many ways in which their homes provide ambient cues. For example, a large percentage of households discussed natural operating sounds (creaking, blowing, etc.) as being useful in their awareness of certain devices in operation (air conditioner, furnace, etc.). Others stated that moisture on windows helps one to understand the difference between indoor and outdoor temperatures. This suggests that one design opportunity worth exploring is the use of ambient mechanisms that may be designed to fit naturally within the sights and sounds of the home.

2.6.3 Maintaining Consumption Habits

The discussion to this point has focused on awareness of energy consumption behaviors. Ultimately, households must progress through the stages of change to inform complex change through goal setting and to maintain those changes in the long term. These are difficult problems that must be explored beyond simple awareness, and we do not attempt to address them in this work. However, we have historical examples to draw upon in order to gain insight as to how to support such complex change and maintenance.

We argue that as conservation and sustainability become more important to more of the population, energy consumption awareness devices will evolve to support various levels of awareness and behavior change. In many ways, this evolution may prove to be similar to that for *time managemen*t devices.

Consider, for example, that agriculture-dominated society used ambient feedback, in the form of the sun, to manage their workdays. However, as we moved to an industrial-driven society, more fine-grained awareness of time became necessary in the form of indoor clocks and push notifications (alarms, bells). Likewise, while energy consumption awareness may possibly be supported with low-bandwidth push notifications via ambient devices, more detailed information will be necessary to inform goal setting and more complex change. Ultimately, society may be willing to physically carry consumption devices (or apps) with them just as we wear watches to help manage our timeliness. As time pieces moved into homes, aesthetics became more important and such concerns must be considered for consumption awareness devices as well. More recently, we have become a 24/7 society where many people are "always working" and thus need more aggressive management strategies. The digital calendar allows us to schedule our days out for as far into the future as we desire and to manage our time to meet obligations to work, family and play! Again, as consumption management becomes more important, similar tools may be necessary to allow for intricate planning, goal setting, and consumption scheduling as part of a long term maintenance strategy.

2.6.4 Threats to Validity

In this work, the most significant threat to external validity stems from the participant population. While care was used to ensure that our three demographic groups were equally represented, all participants were self-selected and all lived in the same geographic region. This necessarily prevents us from drawing statistical inference to a more general population.

There were also natural limitations in the way we evaluated the correctness of our participants' appliance rankings, as discussed in Section 2.5.1. Because we wanted the participants to demonstrate their level of practical understanding, we asked them to account for their personal usage habits while ranking their appliance consumption. Because we did not have access to their actual consumption data, we were forced to estimate error based on typical consumption.

2.7 FUTURE WORK AND ACKNOWLEDGEMENTS

In future work, we plan to use the findings from this study to design and implement a participatory design workshop with the three demographic populations in an effort to further explore some of the design ideas identified in this work.

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3 Exploring Electricity Feedback for the Home through Participatory Design

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3.1 ABSTRACT

Eco-feedback is a growing field in the HCI community, and there have been numerous recent research projects focused on providing users with information about consumption of resources in their home. Very few research groups have utilized participatory design, however, which is a useful tool for gathering user preferences and ideas. In this work, we present designs created by potential users and explore common or interesting themes among these designs. We also discuss differences and similarities we noticed between the three demographic groups in our study: older adults, families with children, and students in shared housing.

3.2 INTRODUCTION

Research into electricity feedback began around the 1970s, and was primarily done in the field of environmental psychology [16]. Since then, resource management has grown into a highly researched area with a particular emphasis on electricity in the last decade. Unlike water consumption, electricity usage is intangible. This prevents consumers from physically perceiving their own usage, making it difficult to reason about and deserving of supportive feedback devices.

Much of the work in this area, particularly in designing eco-feedback feedback devices, is missing user input or clear reasons for design decisions [12, 13]. The field could greatly benefit from participatory design, which involves potential users in the design process at its inception rather than purely as an evaluation strategy. Another missing component of eco-feedback research is that of evaluating differences between demographic groups [5].

The work presented in this paper represents a phase in a long-term project. Our previous work involved interviews with participants from populations of older adults, families, and students to learn about the current level of understanding regarding their electricity use, their motivations to conserve, and design preferences for a feedback device (R. Metoyer et al., “Designing Visual Feedback for the Home: A Field Study,” unpublished). The second phase, presented here, builds off of findings from phase one, and explores some of the concepts we found most interesting (e.g. abstract or ambient designs, distributed or centralized systems). We held participatory design workshops with the same three demographic groups, with the goal of gaining user-created designs for eco-feedback.

After presenting some background on participatory design and the motivation for our work, we will provide the methodology used for our study and design dimensions to create context. Our findings present some of the more interesting designs produced by our participants, along with discussion about some of the themes that emerged.

In this work, we aim to provide new perspectives and potential design ideas for household electricity monitoring through participatory design techniques in order to create designs. We will also explore potential differences between certain populations, particularly families with children, students in shared housing, and older adults.

3.3 PARTICIPATORY DESIGN

The growing interest in sustainability and eco-feedback technology in the HCI community has produced a substantial amount of recent research. In 2010, Froehlich et al. surveyed the corpus of eco-feedback research from the fields of environmental psychology (89 papers) and HCI (44 papers) [16]. The former of these two fields primarily studies the effects of feedback on behavior, while the latter has focused on the specific design of devices, often gathering user responses regarding understandability, functionality and aesthetics. Two years later, Brynjarsdóttir et al. reviewed 36 papers related to sustainability between 2009 and July 2011 [5]. The authors take a critical look at recent literature. They argue, among other things, for more user inclusion in the design process, having found only 3 papers (from 2 research groups) that made use of participatory design. Despite the mass of work in this area, there is an overall lack of justification for design decisions [12, 13], and little of it has utilized participatory design to gain user input early in the design process [5, 14, 28, 42]. The input of non-experts is crucial if they are the intended users of the new technology.

Participatory design (PD) is a method of including potential users in the early stages of design. This method views users as collaborators who bring their experiences and expertise to the design process, and are given the ability to make design decisions from the beginning of the project. The process of including PD in the development of technology began in Scandinavian workplaces in the 1970s and 80s, primarily via labor unions intent on ensuring that workers had the ability to give input on tools that they were supposed to adopt [3, 30, 14]. The emphasis of this movement was on creating a more democratic workplace through "direct and effective worker participation (not mere 'involvement') in design activities and decisions" [30]. This distinction is important. Gaining user feedback on a prototype, after all initial design decisions are made, will restrict ideas to the current design. Asking users to take part in the creation of designs allows for a wider range of possible ideas that may better suit their needs. Not only does this create more mutual understanding between users and designers, but designs have the potential to be more effective for the user when drawn from multiple perspectives and knowledge bases. Those users directly involved in PD may also benefit by becoming more engaged and developing a sense of ownership for the project [10].

The previous papers that included participatory design each addressed a distinct setting for resource reduction. All three projects therefore held workshops with a particular set of participants appropriate for their focus. Miller et al. worked with students to design ways to encourage waste reduction on the Grinnell College campus [28]. To reduce energy consumption in the workplace, Foster et al. met with business professionals to brainstorm ideas and discuss potential problems and implications [14]. Shrubsole et al. focused on designing home electricity monitoring with families and their children [42].

All three of these works show great promise for participatory design and its uses in designing technology aimed at sustainability. Each project emphasized a single location or type of user. Acknowledgement of this restricted context is critical, as it can cause significant changes in perspective. Brynjarsdóttir et al. also suggested the sustainability research should be driven by more than one type of user [5]. For some projects, such as the aforementioned, such restrictions might be appropriate. For example, Foster et al. [14] were focused exclusively on the workplace, and deemed aesthetics unimportant. In this case, paying consideration to the particular demands of a domestic setting would have been fruitless.

This work contextually limits itself to a domestic setting, but not to any particular population. We are interested in a more universally applicable home monitoring device and we hope to begin alleviating the thus far too-narrow focus by including different populations in our study. We hope to provide fresh insight into the field of electricity feedback devices through the analysis of preferences and design ideas coming directly from a sample of potential users.

3.4 METHOD AND PARTICIPANTS

We held a series of three participatory design workshops at Oregon State University's Student Sustainability Center to gather user input and ideas about potential designs for an electricity feedback system. The Sustainability Center is located in a converted house, complete with kitchen, living room, office, and yard. This setting provided participants with a home-like atmosphere that was intended to help contextualize the task of designing a device for their home [29, 2].

A total of 24 participants each attended one workshop. We strove to recruit people from varying living situations, focusing primarily on those that fit into at least one of three categories: students in shared housing (but not those with University paid utilities), families with children, or older adults (defined as 55 or older). We worked with nine students from three separate houses, in the age range 18 to 25, six family members from two distinct families, each with one participating parent (age range 39 to 55) and two children (age range 9 to 19), and nine older adults from six different homes, all age

55 or above. Our participants were evenly split according to gender: 12 male and 12 female.

We recruited these individuals by first contacting the participants from a previous field study and then by using snowball sampling (asking participants to recruit their acquaintances). This sampling included Oregon State University's Center for Healthy Aging database, called the Life Registry, which consists of older adults who have expressed interest in participating in aging related research. We also contacted people from a university course on energy supplies, usage, policies, and new technologies in an effort to recruit people who would be interested in energy conservation.

The workshops lasted approximately five hours including breaks, and each participant was compensated at $80 per person. Each workshop was structured as follows. After a brief introduction, we broke up into small groups for a practice activity. Each small group consisted of two or three participants and one researcher. We asked participants to design a device that would help them monitor their sleep patterns. After a few minutes, we re-convened to let the participants present their designs to the group at large, and to encourage discussion. The goal of this practice activity was to get the study participants accustomed to their group-mates, the design process, and the structure of our activities. After the practice activity, we went through three design activities, each following a similar structure: brainstorm and come up with designs in small groups, present to the larger group, and discuss the ideas' strengths and weaknesses. Each design activity lasted thirty minutes and was broken into two distinct tasks.

3.4.1 Activity One: Representation

For the first activity, we were interested in seeing how users might want their electricity data presented. We were particularly interested in looking at centralized systems versus distributed systems. Centralized systems, ideally, are located in a central area of the home, and inform the user about electricity data for the entire household, whereas distributed systems consist of many devices, placed throughout the home, that might display information for that part of the house only, or even for a particular device. Participants were asked to design a distributed system for Task 1, and a centralized system for Task 2. For each task, users were given a set of questions to prompt them to consider design problems or new possibilities. For this activity these included:

- In the distributed system, is each device the same or can they be different?
- Would you want other people to see them (household members, friends, visitors)?
- Are the devices intrusive or annoying? Are they too easily forgotten?

3.4.2 Activity Two: Goal Setting

The second activity focused on setting and attaining goals related to electricity conservation. For Task 1, participants were asked to extend their designs to allow for goal setting. We wanted to see how users might input goals into the system, and we wanted to ensure that varying levels of goals were supported. This includes long term goals that stretch over several months or years versus short term goals that only encompass a few days or hours. We assumed that electricity usage goals can be accomplished through targeting a reduction in various resources (e.g. money, kilowatt hours, or carbon). We also wanted participants to consider goals that target specific appliances, parts of the home, or users, as well as more general goals for the entire house.

In Task 2, participants added communication of goal progress to their designs. We were looking to see how, when, and where participants wanted to see feedback regarding goals. Some of the questions provided to participants included:

- What kind of goals will you be setting? Financial, appliance specific, room specific, etc.?
- Who sets goals?
- How do you know if it is a reasonable goal? Not too easy or too hard?
- How would you change a goal after it has been set?

3.4.3 Activity Three: Alternative Uses

We are also interested in ways that electricity information might be used for purposes other than informing users about their electricity usage. To explore this, we asked participants to consider specific scenarios that we created, and to design a device to convey the required information. The two areas we wanted to focus on were health monitoring and screen time monitoring.

In Task 1, we asked participants to assume they had a loved one they might want to monitor, perhaps for health purposes. Using electricity information from the loved one's kitchen, participants were asked to design a device that would help create shared awareness of the loved one's activities.

Task 2 involved participants designing a device that could help them monitor their household's screen time, which we define as time devoted to using electronic devices like televisions, computers, smart phones, etc., by using electricity usage data. As electronic devices continue to develop, people are spending more time staring at some kind of screen, be it a phone, music player, television, gaming system, tablet, or computer. Oftentimes parents try to enforce rules limiting screen time for their children, and we thought it might be useful to see screen time data for everyone in the home. Again, we provided questions to consider:

- Are you using visual or audio devices or both? Something else?
- Are they embedded into everyday objects or are they new things you're designing?
- Would it bother you if your family member had this information about you?

3.4.4 Analysis

Following the study, we took photos of all the designs and identified general themes using affinity diagramming. We then assigned codes to those themes, and two researchers coded 20% of the designs with an agreement rate of 94.74%. A single coder then coded all of the designs.

3.5 DESIGN DIMENSIONS

Here we briefly describe design dimensions and themes commonly associated with eco-feedback technology, in order to provide context for our findings.

3.5.1 Frequency

Researchers in eco-feedback have come to agree that frequent feedback (daily or more) is the most desirable, suggesting that immediate feedback is the best way to help users connect actions with their usage [12, 13, 16].

3.5.2 Data Granularity

Home electricity data can be organized in a variety of ways. It can be divided by rooms, floors, appliances, indoor usage versus outdoor, activities, or by users. Users have expressed a desire for individual appliance information, and have attempted to deduce this information if it is not directly available [13, 45]. Froehlich et al. suggest that activities should supplement individual appliance data in order to recommend actions for reducing consumption [17].

3.5.3 Time Granularity

The data granularity must be shown with respect to some time granularity. This can be anything from per year to per minute or second (Froehlich et al. explored month, week, and day). Users have shown a preference for the ability to switch between various levels [17].

3.5.4 Comparison & Competition

It has been established that self-comparison is the most effective and desired method of analyzing and evaluating one's electricity usage [13, 16, 45, 17]. Often this data is given in comparison to the past year's usage to account for seasonal effects, though [45] suggests looking at other factors as well, such as weather, temperature and weekends.

People are often intrigued by what are called normative or social comparisons (comparisons with other households), but are often skeptical of whether these comparisons are fair [13, 17]. There is also the risk of causing some users to increase their usage if they are below the average [12]. Competition, which is a type of normative comparison, is a polarizing subject. In addition to the issue of fairness, some people have expressed reservations about making resource consumption a contest rather than a cooperative effort [17, 14].

3.5.5 Goals

Often discussed as another type of comparison, goal-setting has been found to be an effective tool in reducing consumption, and important in helping to bring about behavior change [38, 16]. We asked participants to think specifically about designing goal-setting capabilities for this reason.

3.5.6 Measurement Units

Electricity data can be measured in many different ways, though the most common choices are in terms of wattage, cost in currency, or carbon emissions. All three of these options can be measured in terms of volume or as a flow rate (e.g. total dollars vs. dollars per hour). Some users prefer cost because it is the most motivating or relatable. Others found cost meaningless because of fluctuating electricity prices, or because the cost of individual consumption actions was deemed effectively insignificant (for water usage) [45, 17].

3.5.7 Responsibility & Blame

The option of distinguishing who is using resources and how much is another polarizing issue. Some users seem to like the idea of accountability, and suggest dividing the bill accordingly. Others see it as blame-inducing, and a potential cause for argument [17].

3.5.8 Placement & Attention

Areas like the kitchen, living room, entryway and other high traffic areas of the home are suggested as ideal locations for a feedback device as they are more likely to regularly grab attention, rather than distributed systems located at power outlets, for example, which may be out of sight [13, 38]. We argue that distributed systems will be located closer to where the actions take place, and help support users in understanding the effects of those actions, as recommended by Fischer [12]. Of course, out-of-sight systems will not be as effective, but distributed systems need not necessarily be restricted to outlets. In Activity 1, Task 1 we wanted our participants to explore ideas for how distributed systems might work.

3.5.9 Privacy & Aesthetics

Some users have stated a desire for location of the device to be hidden, but this usually seems to be out of a desire to keep their data private from visitors, or for aesthetic reasons. Users seem to either be very concerned with privacy, or not at all. Aesthetics are an important aspect of designing for the home, as many people do not want unsightly devices visible. Riche et al. note that this preference may be stronger in women. Both issues of privacy and aesthetics might be solved with abstract representations. [38, 17].

3.5.10 Play vs. Functionality

Studies have found that users, adults and children alike, often find playful, emotionally engaging designs, and even simple ambient designs, to be more engaging than standard graphs or numbers [13, 45, 17]. Froehlich et al. caution against making designs more interesting as consumption increases, however, so users will not be tempted to try to intentionally increase usage to view it [17].

3.6 FINDINGS

In the following sections, we present designs created by our participants, organized by themes we identified during analysis, as well as possible motivations and implications.

3.6.1 Abstract Designs

Many of our participants were very interested in abstract designs, i.e. those that convey information without the use of charts, graphs, or numbers. Several of the electricity feedback designs included elements of abstraction.

The family with younger children (ages 9 & 11) used abstract designs for nearly all of the activities. For the centralized device design, they created a rug for the living room, the pattern on which alternates depending on whether or not they use too much electricity. Another idea for the same task was a scented candle that smells like roses when they are doing well, or cinnamon when they are doing poorly. For goal setting, they had digital flowers whose petals fill with color to represent the goal versus their past and present usage (Figure 5).

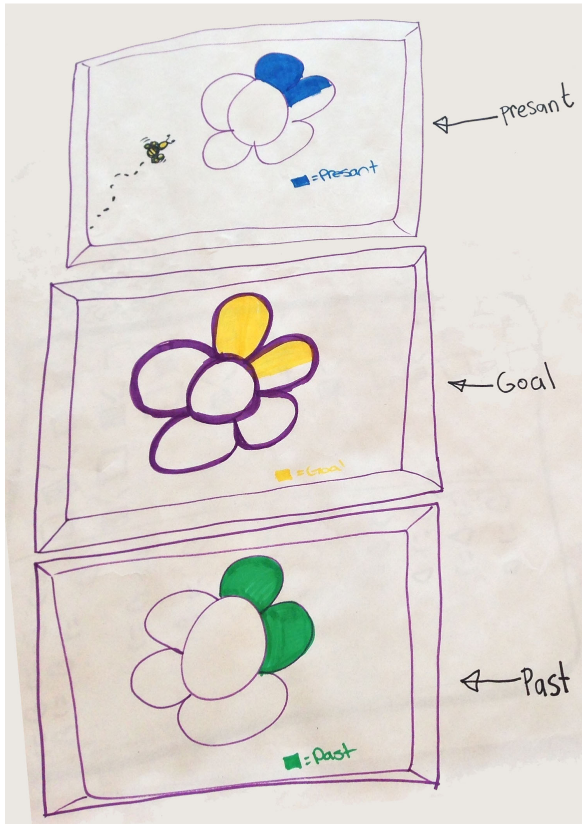

Figure 5: Three virtual flowers show present household usage, the goal amount, and past usage.

A group of students came up with an abstract design for the distributed task, stating that “if this is going to be in every room, I’m not going to want some boxy mechanical-looking thing. I’m going to want something that goes with [the room], that is kind of decorative”. Their design resembles a digital picture frame (Figure 6) that displays a blue-dominant image if they use less than normal, a green-dominant image for average usage, and a red- or orange-dominant image for high usage. This design places one of the picture frames in each room, complete with customizable photos. They also included a button on the bottom right corner that, when pressed, switches the photo to a detailed information display. This more detailed screen includes charts that show usage over time, or displays a floor plan indicating which outlet is using the most energy. These participants were primarily concerned with the aesthetics of the device and how it would fit into their home, but also wanted to be able to access the non-abstract information depending on the circumstances.

Figure 6: A framed picture shows a digital, customizable image. The dominant color signifies low (blue), average (green), or high (red) electricity usage.

Another group's design includes an indoor plant that moves up and down on the wall corresponding to high or low usage, one member stating that she wanted to avoid more screens in their home (Figure 7).

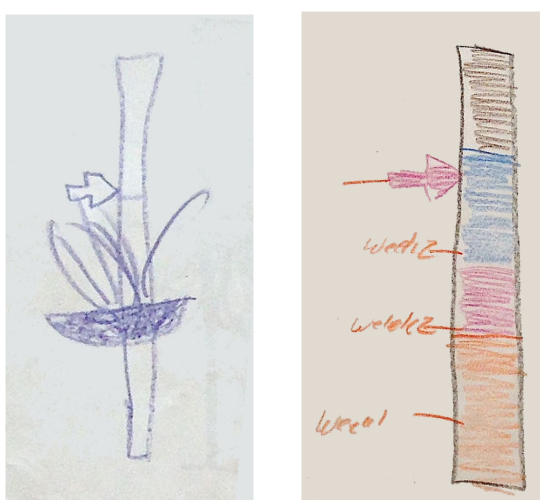

Figure 7: This design involves an indoor plant that moves up and down to indicate high usage or low usage. The usage goal is represented by the arrow. The bar behind the plant (right) shows the breakdown of which appliances are currently in use.

Four groups out of nine explored using abstractions as the display medium, indicating a high level of interest in these designs. This may be due to a variety of reasons. In line with findings regarding ambient displays–which we include in our definition of abstract designs–some participants, especially the children, may have found them to be more engaging than traditional charts and graphs [13, 45, 17. Others were concerned with aesthetics in their homes, and preferred more artful representations be visible, or wanted to avoid adding more screens. This would be more visually pleasing as well as create privacy from visitors. Another possibility is that abstract designs may be more attention grabbing. A new photo on the wall, or a new smell might direct attention more successfully than a spike on a graph.

The wide range of possible motivations for using abstract designs suggests that they could appeal to several different populations. The effectiveness of ambient designs has not yet been well tested in this context [16], but previous studies suggest that ambient-only displays do not provide users with enough information [13]. As done in the digital picture frame design, we suggest supplementing abstract designs with more detailed information available on demand.

Many of the designs for the kitchen monitoring task are also abstract. Most participants felt that monitoring a loved one's kitchen activities seemed invasive, and so instead of designing a device which showed all of the available data, many restricted their view to a small piece of information that would simply let them know that the other party was alright. Seven of the nine groups did this through abstraction. For instance, a group of students designed a fruit bowl (Figure 8) that sits in the kitchen, where each fruit is associated with some appliance in their loved one's kitchen. If an appliance is not used for a long time, the corresponding fruit will start to ripen or turn brown. Noticing that the banana is green would let the viewer know that the appliance associated with the banana has recently been used, and that their loved one is behaving normally. Not only does this protect the privacy of the loved one, but it also allows for at-a-glance information conveyance.

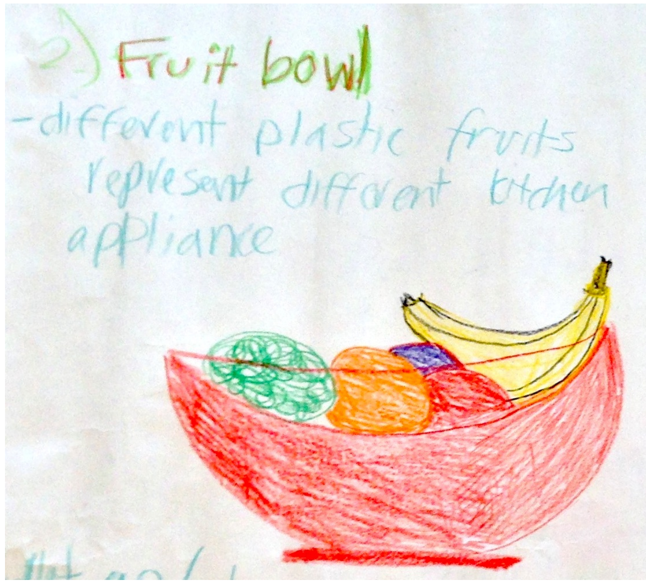

Figure 8: Plastic fruit are each tied to a particular appliance's electricity use. The color of the fruit gets darker (or brown) if the appliance has not been used for several hours.

The group with younger children also used an abstract design for this task with tangible media such as lights and scents. They knew that their grandparents always drink coffee in the morning, so when the coffee brews, the kitchen in the kids' house will smell like coffee. At night, their grandmother always reads a book before bed, so when her reading light is on, a corresponding light turns on in the kids' home. Since abstract designs were the frequent choice of this group, it is difficult to say whether there were other motivations for using an abstract design in this case. However, their design is one of the few that identifies particular activities being performed by their loved ones. This would not only let them know their grandparents are alright, but it might also create a connection between them, much like how Lottridge et al. created connections and feelings of "closeness" between couples in long distance relationships [26].

When using electricity feedback to monitor others, our participants tended to use abstraction. They were not interested in seeing usage. They simply wanted to be aware of the presence and well-being of their loved ones, and this can be easily and aesthetically done with abstract designs.

3.6.2 Semantic Zoom

When representing data, it is often important to be able to zoom in to or zoom out of the data: to get closer and see more detail or back out and see more of the overall picture. Oftentimes when the term 'zoom' is used, it is in reference to geometric zoom, which essentially makes objects larger or smaller. Some common examples of geometric zoom are zooming in or out on a map or a photograph. There is another type of zoom, which in the field of information visualization is called semantic zoom, that changes the presentation of the data in a more complex way. Semantic zoom often involves structural changes to the representation itself, which may help give context to the data [4]. For instance, imagine a virtual calendar. A calendar can be viewed at many different levels of detail: yearly, monthly, weekly, or daily. Switching to a new view is an example of semantic zoom. Instead of appearing to get closer or farther away from the calendar, the structure changes to accommodate the selected granularity. This also allows for different subsets of data to be displayed. Information about small daily tasks, like a meeting time or location, for example, would appear in the daily view, and possibly the weekly view, but are unlikely to be shown in monthly or yearly views.

In analyzing the designs, we found that eight out of our nine groups created systems that allow for semantic zoom. In most cases, these designs involve showing some subset of zoom levels including overall home, home regions or floors, individual rooms, individual light switches or outlets, and individual appliances. Many of these designs involve a simplified floor plan showing the rooms in the house, followed by a more detailed floor plan of each room. Often each appliance can be selected to show a bar or line chart showing usage over time (Figures 9, 10). Several of the abstract designs mentioned previously present a simple view of overall household usage, with more details available as desired. This type of design is also considered semantic zoom, with the abstract representation at the highest level of granularity.

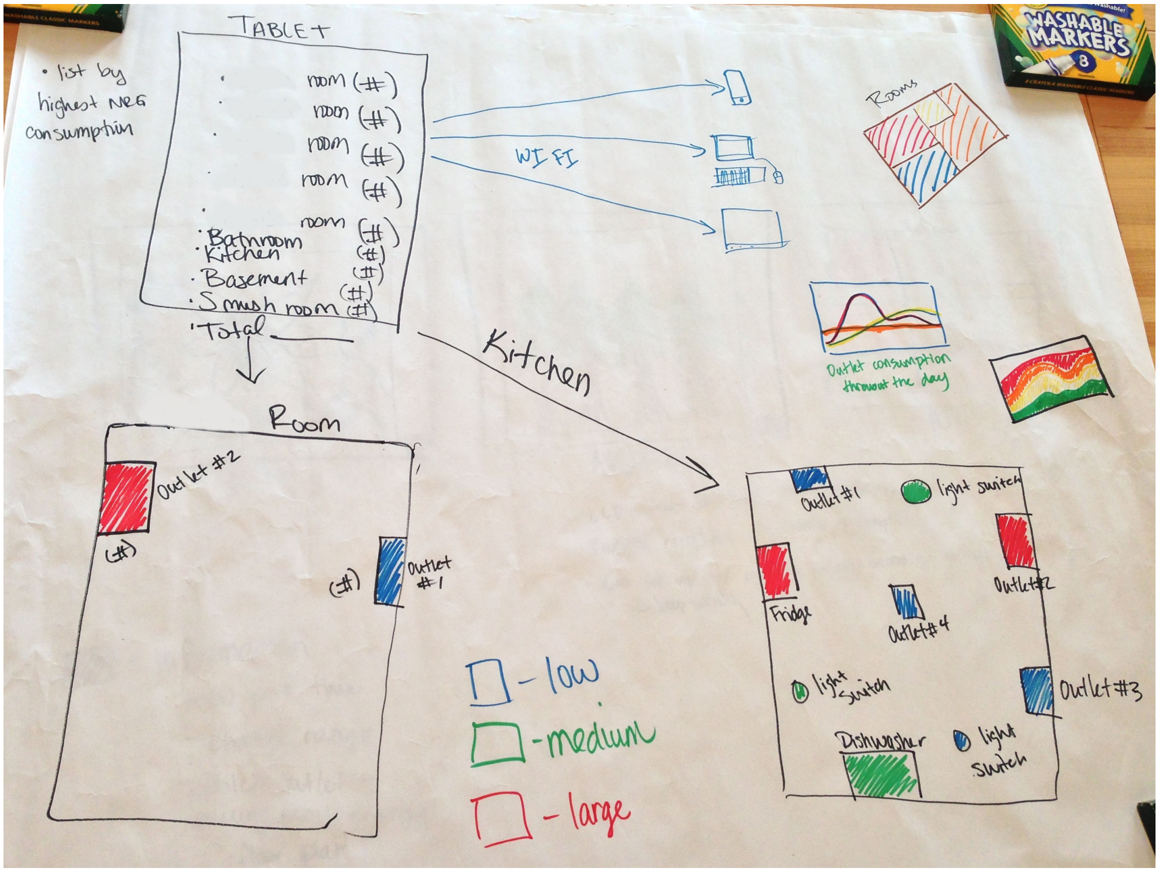

Figure 9: The overall house image (upper right) shows each room, colored according to the amount of electricity used. Another view shows a list of rooms in order from most electricity used to least (upper left), with specific numbers to provide context. Each room in the list will pull up a floor plan view when clicked (bottom images), showing each outlet in the room with a color corresponding to low, average, or high usage. Each outlet can be selected, which will pull up a line chart of the day's usage (center right).

We found that designs involving semantic zoom were prevalent across all populations. This indicates that the use of semantic zoom with this type of data is intuitive, and that there is no single representation that gives people all the information they want to know. The similarities in the levels of detail and designs chosen by participants suggest that there are fairly natural ways to break up this data, and that people like interactive devices that default to more coarse data without sacrificing the ability to depict more detailed data on demand. These findings are in line with Shneiderman's mantra [41] on effective visualization interface design, which suggests that successful designs should not put undue pressure on user short-term memory. Allowing users to view only the subset of data they desire helps to limit this.

Figure 10: Another design involving semantic zoom. Again, the overall house image (upper right) shows each room, colored according to the amount of electricity used. Participants wanted to see a bar chart of their usage compared to their goal for the overall house, the lights, outlets, or heat sources (bottom right). For a more detailed view, each room can be selected and will show a floor plan with all outlets, lights, and heat sources in the room, with a simple bar chart showing room-use compared to the goal (bottom left).

3.6.3 Projection

Ideal measurement units have yet to be established. Showing a flow rate (e.g. dollars per minute, gallons per minute for water usage as in [17]) has the benefit of showing exactly how much electricity is being used at any given time, which puts an emphasis on immediate feedback. Turning a device off or on will have an instant effect on usage, and can help users to see what actions make the largest difference. However, one drawback of this is that the usage numbers will often appear to be very low. This has potential to be meaningless to some people, or worse, may cause apathy if the cost is considered insignificant [17].

Showing the aggregate usage, or volumetric data (e.g. total dollars, gallons for water usage [17]), over a time period (often the pay period), does not show immediate usage, so turning appliances on or off will not have an immediate effect. Leaving an appliance off for a few days would be reflected, but may not be obvious if users are not familiar with how much electricity is used when the appliance is on. This is not ideal, as it has been shown that the best way to impact behavior change is to give users feedback immediately, so they connect their decisions to the effects [12]. The benefit of this option is that it shows cost in more meaningful amounts, with the amount at the end of the month matching the monthly bill. For the first day or two, though, the cost would still likely be very low, which may cause users to be more attentive to their usage only toward the end of the time period.

Two of our groups were interested in seeing their data *projected* through the end of the month or year. That is, participants wanted to see an estimate of how much electricity they would consume by the end of the time frame if they continued with their current usage patterns. This could help mitigate the issue of flow rate costs seeming insignificant, because it would give an overall figure for the time period and it should help to ensure that users are paying as much attention to their consumption at the beginning of the month as at the end.

Projection in conjunction with immediate feedback (flow rate) might be a good compromise. Projection will provide users with meaningful numbers regarding their usage, while immediate feedback will help users to understand how their decisions to unplug an appliance or to use an appliance affect their overall electricity usage.

3.6.4 Responsibility

One of the primary differences between our three chosen populations is in how financial matters are handled. Families and married couples often combine their income, especially for shared expenses like the electric bill. Some families might ask children–especially older children–to help pay the bill, or at least to make wise decisions regarding usage. We note that seven of our older adult participants are married and the other two live alone. Students, however, are in a unique position in that they are all financially independent from their cohabitants. In most cases this results in the electric bill being divided evenly between residents, which can be an area of stress since some students are more frugal with their energy consumption than others.

In our design session, three of our four student groups created systems that monitor how much electricity each housemate uses. With this information, they could potentially divide the bill proportionally, or at least identify which housemate to talk to about using less. Two of our four student groups designed systems that can directly compare each person's usage. A third student group designed a system that has a password protected account for each housemate. Their design also allows remote access for the control of outlets, and so each person has a separate account to prevent a housemate from turning off something in another student's room. Through this system, it would also be easy to see how much electricity each housemate's room used. It can be argued that students in shared housing, or potentially others who identify themselves as independent (especially financially) from their roommates, are more likely to be interested in devices that allow them to hold their housemates accountable.

One of the older adult groups designed a similar method of password protected accounts so that each person could set their own goals. The family with young children, however, specifically mentioned that they would set goals together. This could suggest that families with children, who might see themselves as more of a cooperative unit, are more interested in providing learning opportunities and discussion about better strategies to conserve as a group rather than individually.

3.6.5 Self-Comparison & Time Selection

In line with previous findings [13, 16, 45, 17], each group of participants created designs that allow them to compare current usage to past usage. A common way to do this is to compare the current date to the same date the previous year. This helps to ensure that the outside temperatures, and therefore the level of heat or air conditioning, are similar, and provides a base line for a more 'fair' comparison. Some groups took it a step further, and wanted a virtual calendar included from which they can select a specific time frame to view, choosing both the start and end dates themselves. This can be used to select a customizable amount of time, such as the length of a vacation, to see how much electricity is used when no one is home, or to compare usage between the summer months and a heat wave in the spring. If, for instance, somebody has a job in which they work from home certain days of the week but not others, then they may just want to compare particular weekdays. One group even included a thermometer (Figure 11) that allows them to view the recorded temperature on any given day, to more precisely compare usage.

The interest in highly customizable time granularity indicates that some people are interested in having the ability to analyze their data very precisely, and would like an electricity monitoring system that provides tools to help them do that. It also speaks to concerns about fairness in terms of usage comparison. Often a concern in nominal comparisons, people are generally hesitant because they want to be sure they are being compared with similar sized houses and families [17]. Likewise, people want to ensure that the historical comparisons are fair in terms of starting with the same environmental conditions.

Figure 11: Usage is shown in terms of cost, kilowatt hours and carbon. Goals are set on the right, as a percentage of past usage. These will be reflected to show the goal in all three metrics. A calendar and thermometer are available for analysis of past usage to help determine the new goal.

3.6.6 Tradeoffs

For the goal setting activity, two groups talked about ways to stay at or under the goal level by looking at tradeoffs among their appliances. One group's design takes in the user's preferences for which appliances they are most willing to give up or use less often. One participant said he wanted the system to "tell [him] how things have to change so that [he] can make that goal, based on the history of usage." Their device gives suggestions like "unplugging the radio would reduce consumption by 5%". Several different options will be presented, and the user can choose the one that is most agreeable. Usage for certain appliances, such as the refrigerator, is difficult to alter. The refrigerator cannot be unplugged, and ways to change its consumption are limited. On the other hand, taking shorter showers to reduce hot water heater use or air drying clothes may have a substantial effect and are more easily attainable. Tradeoffs allow users to easily identify feasible actions they can take to reduce consumption. It also allows users to choose which actions they are not willing to take, and find alternatives.

The second group did not have suggestions that were quite so specific, but wanted to see a breakdown of usage by appliance category, so users can quickly glance and see (1) whether they are within the limits of the goal and (2) which appliances are currently using electricity and how much. If too much electricity is being used, they easily see which appliances to unplug in order to remain on track (Figure 7). Both of these strategies give users quick information about which appliances are consuming the most and which appliances are unnecessarily using electricity, allowing them to make the most effective changes possible.

3.6.7 Dynamic Feed Icons

For the third activity, designing for alternative uses, we saw two designs that incorporated aspects of social media. Participants said that for the screen time monitor they wanted to see a live feed of their usage similar to a twitter feed or the text message history on a phone (Figure 12). This suggests that these types of designs are intuitive or may provide some level of familiarity. At least some of the justification for these dynamic feed designs is to help parents make more informed decisions. Nearly every group acknowledged the issue of distinguishing "good" and "bad" screen time (e.g. using a computer to do homework as opposed to casually watching television) and the feed can help them distinguish these to determine if any changes need to be made.

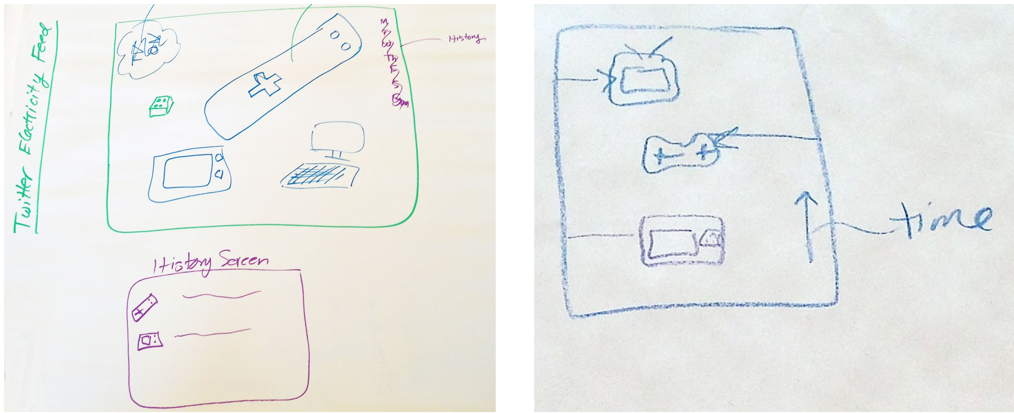

Figure 12: As devices are used, their icons grow larger (left). Use over time is shown on a live "twitter-like" feed (left purple screen and right). The vertical axis represents time.

3.6.8 Social

For the kitchen monitoring task, some participants talked about the social aspects of being connected to a loved one. Aside from being able to see whether the person monitored is sticking to normal activity patterns, some people liked the idea of using the system to also stay connected. One participant mentioned that if she noticed that she was in the kitchen at the same time as her grandmother, she might call to talk about the food they were preparing. Another group designed the kitchen monitoring system to be nearly identical to their home electricity monitoring system. In this way, they could view their data side-by-side with their loved one's data. This could easily create friendly competition between households in addition to awareness of activity. They also suggested that for like-minded people who want to save electricity together, social media could be used to connect them, their data, and help them encourage each other to stay on track.

Some groups' designs simply sought to create a presence, as previously described with the coffee smell design. Other designs with similar effects include another picture frame design that adds color to a black and white image as the loved one uses appliances, and a floor plan design that illuminates tiles on the floor in front of appliances the loved one uses, giving an indication of where they might be walking in the kitchen (Figure 13). These designs do not connect users as concretely as something like social media would, but give ambient awareness that might provide a level of comfort to the user knowing their loved one is cooking in the kitchen. This idea of presence and ambient remote monitoring is explored in more depth in [31, 26, 39]. Seven groups incorporated some social elements in their designs, indicating a high level of interest.

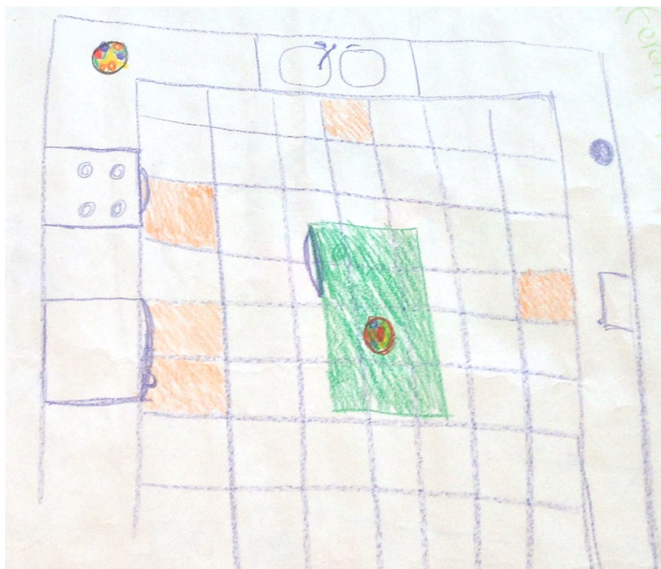

Figure 13: The floor illuminates (shown in orange) below appliances in use.

3.7 DISCUSSION

3.7.1 Distributed versus Centralized

We noticed during the workshops that nearly all of the groups used distributed systems to display fairly basic information. In discussion, participants said that since distributed systems could be located throughout the house instead of in only one location, they would be "pesky" in a positive way, reminding users of their rate of consumption. Participants agreed that distributed systems have the advantage of providing immediate feedback closer to the time and place of action, whereas centralized systems might not be in sight for many of the actions that affect electricity usage. Only one of the groups used semantic zoom in their distributed system, compared to eight of nine groups using semantic zoom for the centralized system. The centralized system, then, has the advantage of allowing users to do in-depth analysis of their usage data. It was also easier for participants to design the centralized system to accommodate goal setting activities. Users generally agreed that both systems were useful in their own right and that a combination might be ideal.

3.7.2 Cost

In this work we do not discuss the potential costs associated with building an electricity monitoring system, though some participants attempted to keep this concern in mind. In line with participatory design methods of designing for the future [30], we encouraged them to disregard aspects like cost and how to collect data in favor of focusing on ideal methods of feedback. Cost is certainly an important concern, as we would not want the expense of the system to be prohibitive for anyone interested in reducing energy consumption (especially as low-income families may be among those who benefit the most from a system such as this). However, while still in the design phase of our research, we did not want to begin making sacrifices for cost.

3.7.3 Participants

In our study, we attempted to diversify our participants by recruiting from three different populations, hoping that different perspectives and experiences would lead to more diversely applicable designs. We acknowledge, however, that our participants were recruited in Corvallis, Oregon, which is a highly educated and fairly environmentally conscious community, and should not be considered representative [7]. Since we only had 24 participants, none of our findings are statistically significant. Our chosen demographic factors, plus factors such as income, race, level of education, and additional types of living environments should be explored in more detail.

3.7.4 Designs

To help our participants understand the scope of the design space, we showed them some eco-feedback designs from past studies and futuristic mock up designs ranging from ambient devices to more standard devices with line graphs. We grant that in doing so we may have influenced the designs our participants created. None of these examples were described in detail, however, so participants were forced to expand on any borrowed elements.

3.8 FUTURE WORK AND ACKNOWLEDGEMENTS

The next step in our project is to select one of our participants' designs, or a synthesis of multiple of these designs, implement it, and deploy it into homes for an extended study of the effects on behavior.

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4 General Conclusion

Our work has sought to more closely involve users in the design process to learn about how to create an effective home monitoring system. Not only do users have to understand the data, but they have to accept the system into their home and be prompted to view the data at the proper time and place.

In our first study, participants were often concerned with both the financial and environmental impacts of their electricity usage, but generally preferred to receive feedback in terms of cost. We explored events that capture users' attention, and found that ambient feedback, especially in the form of lights, may be a good mechanism for grabbing attention and providing push feedback in order to help raise awareness. We also learned that our participants were equally interested in distributed and centralized systems, indicating that a combination of the two may be ideal. Based on these findings, we suggest a home monitoring system that leverages a person's routines and paths through the home to provide awareness of electricity usage relevant to their actions.

The findings from the second study provide interesting design ideas created by potential users. Some of the most prevalent elements included in these designs were those of abstraction and semantic zoom. Abstract designs can be used to grab attention, create engagement and privacy, and increase aesthetics. They can also be used in conjunction with semantic zoom, serving as the highest level of zoom. This allows for users to view more detailed information on demand, limiting cognitive load and allowing for more in-depth analysis. Other interesting design ideas included projection of usage, highly customizable time frame selection, tradeoffs, and responsibility and how different types of users may prefer more individualized data than others. We also found that participants liked the idea of using distributed devices for immediate push feedback, and centralized devices for more complex analysis (pull) and goal setting. Dynamic feed icons provide interesting ways to view screen use over time, and many designs for monitoring a loved one's kitchen use involved social aspects or 'presence' to help provide connections.

We hope these insights into user preferences and design ideas prove useful for future research into eco-feedback and will encourage more researchers to involve users more directly in the design process. The designs created have the potential to provide users with the information needed to make important decisions regarding conservation.

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