

Energy Cube and Energy Magnets

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Combining the easy to use characteristics of tangible interfaces with the peripheral representation of ambient displays, two prototype energy displays - Energy Cube and Energy Magnets - were designed to help people become aware of their home energy consumption patterns. This paper reports on the design and evaluation of those two displays.

I. INTRODUCTION

We are interested in innovative ways to help people conserve energy usage at home. Several studies show that the key to energy conservation lies in education and behavior modification [1, 2]. The first step toward this goal is to make people aware of their energy use. Discussions with homeowners show that very few know what consumes the most electricity in their home and even fewer look at the electricity meters attached to their house. The typical US household electricity meter consists of an odometer style numeric display and a rotating wheel that provides a real time indicator of electricity consumption. Although regular readings from the meter offer a general understanding of consumption, homeowners often describe the task as tedious. The utility bill reflects data collected from the meter. However, it only shows a sum of all energy use. It does not inform homeowners where in the house energy use is high, or where people could consider changing energy use behavior. In short, the cognitive overhead involved in keeping track of energy consumption far outweighs the level of information and understanding that it provides. Several factors are to blame: the means of representation, the granularity of information, and the location of the meter. If a system or device were created to make energy use data accessible in the right way, it could have made a difference in the way people use energy in their households, particularly in this era of rising energy prices. As an initial investigation into displaying energy consumption, two prototype displays were designed to bring the information indoors, break the information into understandable parts, and to make the information easy to read.

This paper begins with an overview of our work including a scenario and information from key discussions during the early stages of development for devices to display energy consumption. We next review related work in ambient displays and energy consumption awareness in order to frame our research. Two prototype displays are then introduced and described in technical detail. Finally, the paper presents a heuristic evaluation of one of the prototypes and discusses directions for future work.

2. PROJECT OVERVIEW

The goal of the energy displays is to bring energy consumption information to the attention of homeowners. As an initial study, we focused on the consumption of electricity. Future work will take the consumption of other resources such as water and natural gas into consideration.

In the future, household devices could include embedded displays that provide information about the energy consumption of each device. Current household devices only provide a basic peripheral understanding. If we know the device is on, then we know it is consuming electricity. However, this device-by-device understanding is too fragmented. Therefore, homeowners often lack the big picture of their patterns of electricity consumption. The

whole house view of the typical electrical meter is too broad, and the binary on/off state of individual devices is too fragmented. We argue for a simplified energy display system with an intermediate level of information. Two components are needed to make this energy display system work: an easily deployable sensor network, and usable, visible information displays. While researchers at Intel Research Seattle began work on the sensor network, our research focused on the design and construction of information displays.

2.1. Scenario

The underlying assumption throughout this work has been that the typical energy meter works well for the utility company, but it doesn't provide the homeowner with adequate information. However, utility companies have a strong interest in energy conservation and often offer incentives for adopting energy efficient technologies. It is easy to imagine that these companies could offer a temporarily deployable kit to homeowners to help increase awareness and encourage conservation.

Suppose that a homeowner borrows such a kit from the utility company. The homeowner then deploys and configures a non-invasive sensor network. The sensor network collects energy usage information and then displays it on the included information display(s). Over the next month, the occupants slowly become aware of their energy use and gain an understanding of the effect their habits have on consumption. At the end of the month, now with a new level of awareness, the homeowner boxes up the kit and returns it to the utility company.

2.2. Designing Information Displays

The displays presented in this paper were designed by students in an edition of a physical computing studio, the goals, methods, and pedagogy of which are described in [3]. They followed an iterative process to explore a wide range of ideas and then constructed, presented, and documented two prototype displays. During the early stages of design two important conversations occurred, summarized in the two following subsections.

2.2.1 Information

Among the early brainstorming sessions was a discussion of the type of information that could be displayed. The conversation began with the expected comparisons of current use with historical use as well as current use to national averages; it also explored other possibilities. Perhaps the most interesting is the social aspect of comparing energy use with neighbors or households with similar occupancy profiles. Although this didn't make it into the prototypes, it is worth noting for future development.

2.2.2 Central and Distributed displays

Two display models were defined from in-class discussions: central and distributed. A central display is a single display that would be located in a prominent place in the home. In contrast, distributed displays are a set of displays that would be scattered throughout the home. Each has its merits. A central display offers opportunities for greater depth of information. It represents a whole house view that allows internal comparisons as well whole house comparison to outside sources. In contrast, distributed displays offer opportunities to map energy use information to the areas using it. This natural mapping reinforces the relationship between the displays and the physical zones in the home.

3. RELATED WORK

This section describes examples from three key categories of related work: energy displays, peripheral awareness, and tangible interfaces. These examples strongly influenced the design of the two energy display projects we describe in this paper.

3.1. Energy Displays

A number of energy display projects have been designed. Here we would like to mention two examples: Strata/ICC [6] and the Watt Bug [7]. Strata/ICC was designed by Brygg Ulmer at the MIT Media Lab and the Watt Bug was designed by Turkish design team Mutlu Inc. for the Viridian competition [8].

The Strata/ICC project was an interactive installation for a Tokyo museum. Strata/ICC is a computationally enhanced physical model of a skyscraper that serves as an information display. The two-meter tall model is built of etched acrylic and contains embedded LEDs and microcontrollers. It uses shifting light patterns to represent changes in information. Near the base of the model sits a physical icon (phicon) based interface that allows the user to select between electricity consumption, water consumption or network utilization. Placing the phicon into a 24-hour time wheel allows the user to request the display of resource consumption for a particular time frame. The scale and visual representation of this project are well designed for a museum installation. However, it wasn't designed for and doesn't fit the needs of homeowners. Our work focuses on residential energy consumption and takes the form of much smaller artifacts that are easy to move around and interact with.

The first (2000) Viridian design competition (inspired by science fiction writer Bruce Sterling and sponsored by the Sustainability Institute, in cooperation with the International Network of Resource Information Centers) challenged participants to "devise a meter that looks good, is commercially feasible and helps users change wasteful habits". The competition only called for conceptual designs; it did not require designers

to build working prototypes. The winning design, the Watt Bug [7] is an anthropomorphic energy display with animal-like characteristics. Purring when energy consumption is low and flashing a red light on its tail when consumption is high, the display takes on a playful personality. Like a pet, the sound and visual feedback of the display asks the user to pay attention to it. Rather than simply informing the occupants, it becomes an occupant. In contrast, our goal is to integrate the display such that it would support peripheral awareness instead of demanding to be the focus of attention.

3.2. Peripheral Awareness

The notions of ambient displays and 'calm technology' was introduced by Mark Weiser and John Seely Brown in a widely cited article [9]. Providing users with a peripheral awareness eases the burden created by information rich environments. Believing that a home should be a place for relaxation, one ought to be cautious in how one uses the home to provide information to people. Below we briefly discuss two projects that focus on peripheral awareness: Sideshow [10] and the Ambient Orb produced by Ambient Devices, Inc.

Certainly sophisticated Web based information displays can be developed. Microsoft's Sideshow is a screen based awareness application that displays important web-based information. The application places a sidebar on the desktop that users can be customized with information, which is displayed as tabs called "tickets." The user can retrieve more information by clicking on the appropriate ticket. Through its simple sidebar interface Sideshow provides peripheral awareness of layers of information that are accessible on demand.

Although this interface works well for office scenarios, people at home typically don't spend their entire time sitting in front of their desktop computer. For this reason, information about home energy consumption should leave the desktop and be displayed in the physical environment. We have taken the approach to develop stand-alone tangible interfaces instead of employing a Web-based display of this information because the area of information appliances is relatively unexplored territory.

The commercially available Ambient Orb is an information artifact designed to display a user chosen channel of information. The translucent glowing globe uses shifts in color to indicate shifts in information such as the rise and fall of the stock market. Although an elegant display, the Ambient Orb's lack of an interface eliminates the ability to provide layers of information or to break the information into understandable categories. To provide users with a means of interacting with the information, our projects employ the use of tangible media and physical interaction.

3.3. Tangible Interfaces

The ability to manipulate physical objects to specify the type or layer of

desired information resonates with a wide audience. This section focuses on two tangible media projects: Toolstone [11] and mediaBlocks [12].

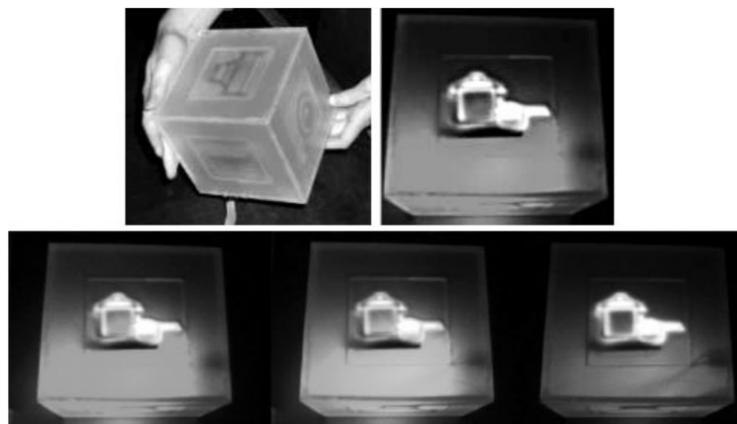
Jun Rekimoto's Toolstone project, designed at the Sony Interaction Lab, is a six degrees of freedom input device. The orientation of the wireless object is mapped to commands in an application. Designed for use in the non-dominant hand, users are able to quickly execute commands by simply rotating it. This frees a user's dominant hand for precise actions such as using the mouse in a drawing program. Although one of our projects - energy cube - uses orientation as a means of input, our project is a stand-alone artifact that isn't mapped to another application.

Ullmer et. al.'s mediaBlocks project uses a set of physical objects as containers for information. Files are represented by a set of simple wooden blocks. The user is then able to transfer files between networked devices by simply taking the block to the reader on the other device. Similarly, our Energy Magnet project maps information to a set of physical objects. While the mediaBlocks become generic icons for the mapped files, our magnets are predefined icons that use a visual representation that is easy for users to recognize and use.

4. ENERGY CUBE

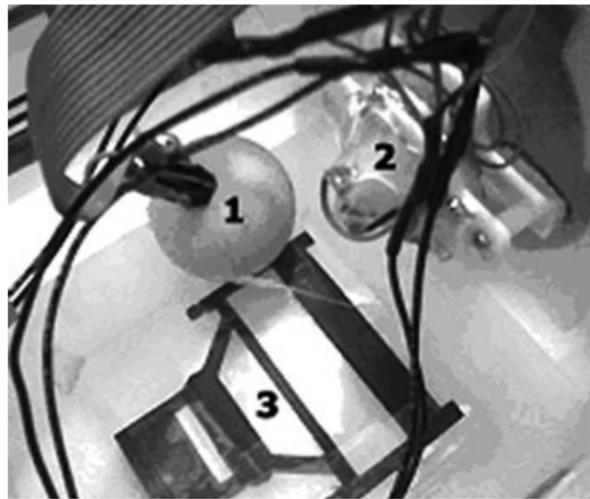
The first prototype, Energy Cube (Fig 1), borrows a tangible interaction paradigm from our earlier Navigational Blocks [4] project. It maps household zones to the faces of a cube. Rotating the cube so that the zone of interest represented on the top face sets the cube to display energy use for that zone. Made of translucent acrylic plastic, the color of the glowing cube indicates present use compared to the average use in other zones. A homeowner who is curious to know how much energy their kitchen habits consume rotates the block so that the kitchen icon is face up. As the color of the cube shifts from blue (low consumption) to red (high consumption) the homeowner becomes aware of energy use in the currently selected zone.

► Figure 1 - Left: Users rotate the Energy Cube to see the icons on each face. Right: A glowing 'pots and pans' icon represents the kitchen and dining spaces. Bottom: It glows in red for high usage, purple for medium usage and blue for low usage.



4.1. System Overview

The energy cube consists of four main parts: an orientation sensor, electroluminescent icons, a set of high intensity LEDs, and a microcontroller (Fig 2). For the prototype, the microcontroller and circuitry were tethered to the cube rather than embedded. This allowed easy debugging and refining. However, in future versions the components will be embedded.



◀ Figure 2 - Inside the Energy Cube.
1: Ping Pong Ball Diffuser for the LEDs.
2: Orientation Sensor. 3:
Electroluminescent Icon.

4.1.1 Orientation Sensor

The orientation sensor is constructed of a six-sided gravity-fed ball bearing switch. The switch was harvested from a “Cube it Up” toy that is manufactured by ToyBiz™. After re-wiring the switch to fit the project, each position of the switch was mapped to a digital input on the microcontroller. As the cube is rotated, the orientation of the cube can be identified.

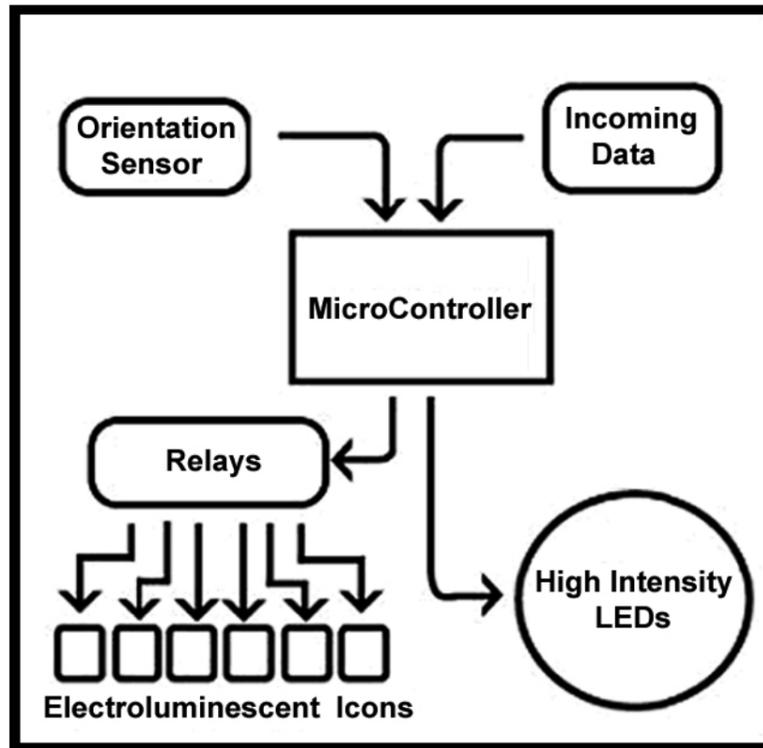
4.1.2 Electroluminescent Icons

Each face of the cube has icons that represent the associated household zone. The icon on the top face glows to aid recognition and visibility. The glowing icons are constructed of electroluminescent (EL) strips. Power for the icons is supplied through a 9-volt battery, a power inverter, and a set of relays that the microcontroller switches to illuminate one of the six icons as the cube is rotated.

4.1.3 High Intensity LEDs

Floating in the center of the cube is a set of high intensity red and blue LEDs. Embedded in a ping-pong ball that is used as a diffuser, the resulting color gradient shifts from a deep blue to purple and finally to an intense red as electricity consumption increases.

► Figure 3 - System diagram for the Energy Cube



4.1.4 Microcontroller

Fred Martin's Handyboard microcontroller [5] is used in this prototype. Designed as a stand-alone robotics controller, the Handyboard is programmed using an easy-to-learn subset of the C programming language. Its wide range of inputs and outputs make it ideal for prototyping.

A set of digital inputs on the Handyboard reads the orientation sensor described above. This information determines which power port to turn on and which analog sensor port to use for data collection. A set of relays attached to the power ports light the electroluminescent icon on the top face of the cube. The analog sensor data is used to determine the appropriate color to set the LEDs that make the cube glow overall.

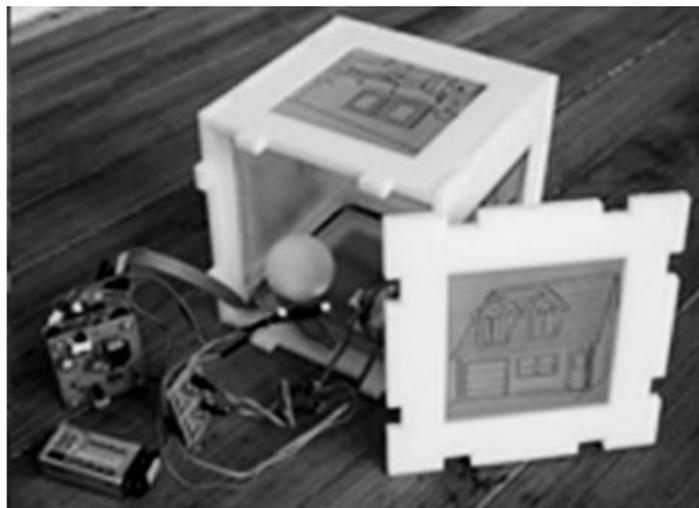
In the future, when a sensor network has been completed, the analog sensor ports that are used for data collection will be replaced with RF communication. Without the sensor network to feed data to the display, the students had to mock-up the data to generate a proof of concept. Embedding CdS photocells into rooms in a generic floor plan, the display used the shift of light on the photocells to represent the quantity of energy being consumed. This allowed reviewers to easily manipulate the data being displayed by placing their hands over, or shine light onto, the embedded photocells.

4.2. User Feedback

Reviewers (faculty and graduate students from the University of Washington, Seattle as well as human-computer interaction researchers from Intel Research Seattle) found the Energy Cube engaging. The potential of having several of these displays distributed throughout the house sparked conversation and helped identify an issue that was reinforced in the heuristic evaluation described later in this paper. The current version of the cube cannot make people aware of unusual conditions in unselected zones of the house. For example, if the cube is oriented such that it is displaying energy use in the living room zone, then it can't tell you that there has been a sudden spike in the energy use in the kitchen.

4.3. Second Generation Energy Cube

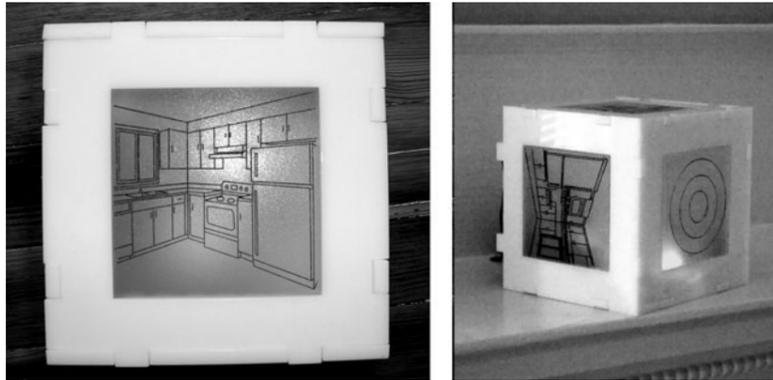
We have not repeated the energy displays project in a subsequent physical computing studio, which focuses more generally on embedding computation into the built environment. However, we have redesigned, rebuilt, and reengineered a second-generation energy cube to connect to real sensor data collected from the Intelligent Workplace at Carnegie Mellon University. Figure 4 shows the new Energy Cube constructed with a simple short hop "SureLink" radio frequency communication module from Needham Electronics. The cube's housing is manufactured with digital fabrication using a laser cutter for tight-fit robust construction and etching the icon pictures on each face.



◀ Figure 4 - Second Generation Energy Cube

Even though the sensor data did not provide enough detailed information for our scenario (i.e., different data from different rooms), the data server provides real time sensor data. Figure 5 shows one face glowing blue to indicate low energy consumption for the kitchen.

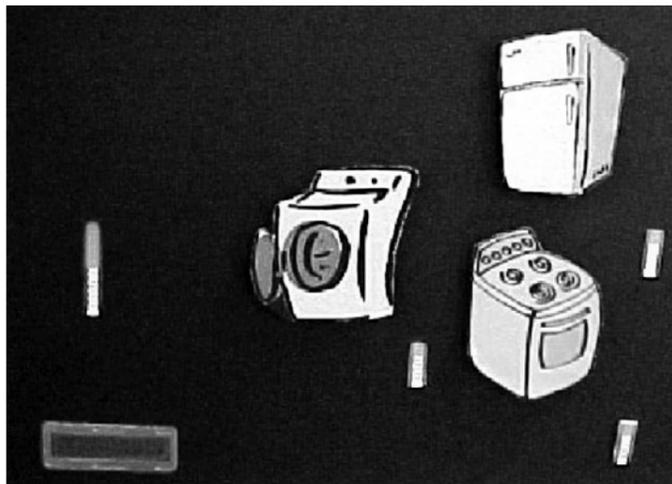
► Figure 5 - Energy Cube with face showing icon for kitchen (Left)



5. ENERGY MAGNETS

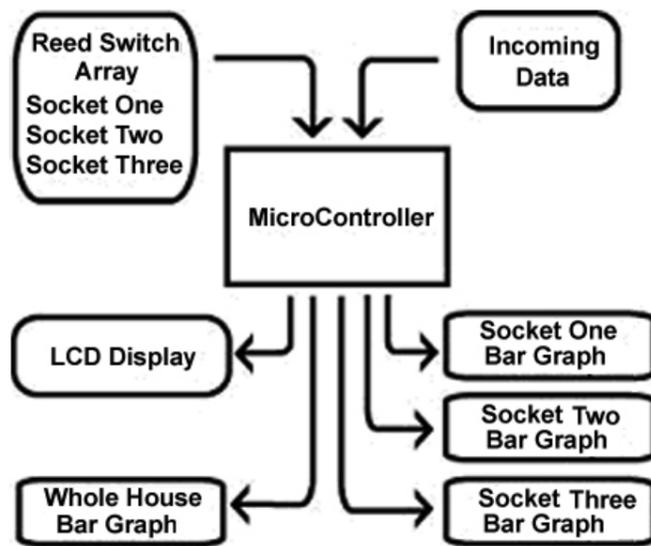
The second prototype, Energy Magnets (Fig 6), allows the homeowner to easily configure the information being displayed using a tangible interface of physical icons in the form of refrigerator magnets. The Energy Magnets are composed of a display board and a set of magnetic icons that represent household appliances. Placing a magnetic icon onto the board triggers a nearby bar graph to display the related appliance's energy consumption. If the homeowner wants to know more about the consumption of their dishwasher in comparison to their clothes dryer they choose the appropriate magnets and place them on the board. Audio echoing indicates recognition of the magnets, the LED bar graphs come alive, and a small LCD screen on the board provides more detailed information in text. To see the consumption for the whole house, one places a large bar graph on the board. Now, as the day progresses, a simple glance at the display provides a quick understanding of consumption and reading the LCD text display provides detail information on current and cumulative use.

► Figure 6 -Three Energy Magnets each with an associated bar graph, and a whole house bar graph attached to the display board. The LCD screen at bottom left displays rolling text of energy consumption.



5.1. System Overview

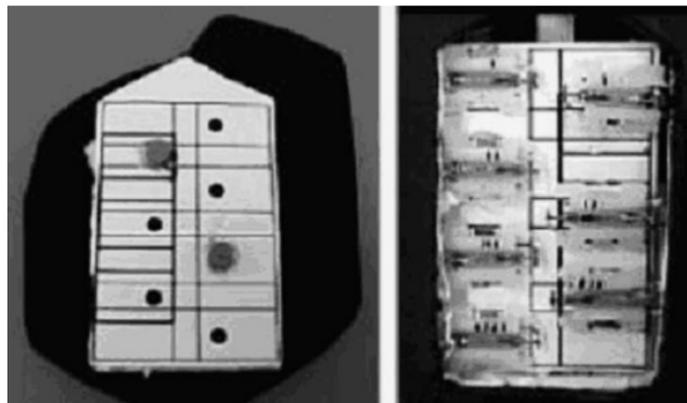
The Energy Magnets are composed of four parts: a set of magnetic physical icons in the form of magnets, a set of LED bar graphs that indicate current use, an LCD display for detail information and a microcontroller to process and display the appropriate information (Fig 7).



◀ Figure 7 - System Diagram for Energy Magnets

5.1.1 Magnetic Physical Icons

The back of each physical icon is divided into two columns (Fig 8 Left). The first column identifies the icon and the second column identifies the type of information to be displayed. Carefully placed magnets on the back of each icon allow an array of reed switches on the display board (Fig 8 Right) to identify the selected icon and the type of information that is associated with it.



◀ Figure 8 - Left: The back of an energy magnet showing the placement of two magnets that identify it. The left column identifies the type of information, and the right column identifies the appliance. Right: The reed switch configuration used to read the magnets.

5.1.2 LED Bar Graphs

Next to each socket on the display board is an associated LED bar graph. After the physical icon is placed on the board and identified, the bar graph begins to display the associated energy use for that icon. Meanwhile, a larger bar graph at the side of the display board provides a quick understanding of the energy use for the whole house.

5.1.3 LCD Display

In the lower left corner of the display board is an LCD display that provides more specific information associated with the selected icons. As an icon is placed on the board the identification of the icon and its energy use in kilowatts per hour is displayed in text on the LCD screen.

5.1.4 Microcontroller

Like the Energy Cube, the Energy Magnets use a Handyboard microcontroller. Reading a set of analog inputs on the Handyboard, the program determines which icons are on the display board. After identifying the icons, the Handyboard beeps and displays the appropriate information on the attached LCD screen. Using sensor input as a form of data collection, the Handyboard maps the appropriate data to the LED bar graph next to the icon by using its motor ports and some external circuitry.

5.2. Summary

Reviewers liked the layers of information this project provided. The color and height of the bar graphs provided general information and the LCD screen displayed more explicit detail using text. Providing a mechanism that allowed people to get more specific information was seen as an attractive feature that would support the curiosity of the homeowner as they became more aware of their energy use. The ability to configure the display of information through physical icons was also praised by the reviewers. With the icon not only representing a specific appliance but a type of information-current use, last 24 hours, last seven days-the physical icons made configuration easy to understand.

The reviewers pointed out that the relationship between the bar graphs and the user placed physical icons needed improvement. They suggested that the relationship would be strengthened if the icons could become self-contained displays with a constantly updated display of energy consumption. Then, by placing the icon onto the display board the user could query the system for more specific information.

6. EVALUATION

We conducted a more thorough heuristic evaluation of the Energy Cube project to explore possible further development using Mankoff and Dey's

heuristics for evaluating ambient displays [13]. Although the Energy Cube is not a traditional ambient display, its tangible interaction and means of output make their heuristics appropriate to evaluate the display. In this section we describe the methodology of the evaluation, the problems identified, and discuss future work.

6.1. Methodology

The heuristic evaluation includes two parts: problem identification and severity testing. The problem identification section was conducted as a group to allow a more thorough process of discovery. Afterward, the severity testing was conducted at an individual level to eliminate the influence of strong personalities.

6.1.1 Problem Identification

Seven people with a background in human-computer interaction were gathered to evaluate the Energy Cube. The session began with a set of rules for this stage of the evaluation. The rules prohibited discussion and evaluation of the identified problems, tips for re-designing, and defensive responses. All problems were to be treated equally and everyone was encouraged to voice their concerns. The people involved in the heuristic evaluation of the Energy Cube responded positively to the display. They also identified a set of issues to be addressed in future development. The result of this problem identification session was a twenty-one-point list. Although many of the issues were overlapping or variations of each other, all were included on the list for severity testing.

6.1.2 Severity Testing

Severity testing was conducted on an individual basis. Each participant was provided a list of the problems identified in the previous section and a five point Likert scale to address the severity of each issue. A rating of four indicated a major usability flaw and a rating of zero indicated that it wasn't a problem. The responses to the severity test were then averaged to identify key issues for future work.

6.2. Results

Of the twenty-one issues identified in the first stage of the evaluation seven were given a high severity rating (Table 1). The most pressing issue is the same one identified during the initial evaluation: "There is no way to display information about other zones without the user physically interacting with the cube."

► **Table I - The top seven issues identified by the evaluation and their severity rating.**

Severity Rating	Problem
4	There is no way to display information about other zones without the user physically interacting with the cube.
3	The icon that represents the zone you are currently monitoring is not visible from more than five feet away and is only on the top face of the cube.
3	The energy cube does not allow you to compare current usage to past usage. This includes not being able to compare current usage to energy usage at this same time yesterday or compare current usage to average usage.
3	The granularity of the zones is too broad. This includes not being able to indicate which specific room or appliance within a zone is causing the heavy usage.
3	The energy cube faces provide no extra information other than lighting up if they are the top face.
3	It is easy to forget which side is up and being monitored. This requires the user to approach the cube rather than keep it in their periphery.
3	There is no depth of information. I cannot get any more information from the cube other than the currently monitored zone's color.

6.3. Discussion and Future Work

The heuristic evaluation revealed a set of useful information and issues to resolve. It is interesting to note though that the other project, Energy Magnets, addressed some of the problems identified with Energy Cube. Specially, the breadth and layers of information may be hard to address in the 3D Energy Cube, but can easily be supported in the 2D Energy Magnets. Different physical and geometric attributes are appropriate for different types of information display. For example, people may find 2D web information maps with fisheye distortion more interesting and easier to read than cryptic (but visually appealing) 3D information landscapes. Energy Cube and Energy Magnets are different in nature and have its merits. It would be interesting to integrate the components of these two distinct but related systems in a toolkit.

The heuristic evaluation of Energy Cube provided a set of issues to resolve in future work. We are currently focusing on two areas of future work: dynamic mapping of faces, and adding layers of information.

6.3.1 Dynamic Mapping

One solution to providing information about other zones could have the cube dynamically re-map the zones to its faces. Then, when the cube is left alone, it could display the zone with the highest use. If the homeowner picks up and rotates the cube, then it could display the selected zone for a specified period of time before returning to the high use zone. Another important piece of this problem is being able to clearly indicate the zone being displayed so that it can be understood from a distance. This issue was highlighted in the heuristic evaluation and becomes even more pressing as the faces are remapped. The ability of the Energy Cube to monitor and

display important changes or spikes in energy use will strengthen the users understanding of energy consumption in their home.

6.3.2 Layers of Information

The current version of the Energy Cube only provides a simple zone based understanding of energy consumption. There is no current mechanism for getting more specific information. Although more alternatives need to be explored, one potential solution is to have small LCD screens on each face of the cube. The screens could support both the dynamic re-mapping of zones as well as offer a means of burrowing into the related information. Whatever form the added information comes in, it is important that adding the ability to get more specific information doesn't destroy the simplicity of the current interaction.

7. DISCUSSION

Research and production efforts for energy efficient solutions for new and existing buildings are abundant (e.g., [14]). The story of Oberlin College's Adam Joseph Lewis Center (AJLC) for Environmental Studies as a Zero-Energy building [15] is particularly encouraging. The AJLC project employed over 150 environmental sensors installed throughout the building and landscape to make interactions between the built and natural environments visible and easy to interpret. A major part of the project is a data monitoring system for real-time energy flows. The premise of the project is that "real-time feedback on building and ecological performance increases awareness, connectedness to place, and motivation to act" [16]. We have taken a similar position in our work.

We presented prototypes of two ambient information display devices to help visualize the energy consumption information in a house. Unlike the typical energy meter attached to the outside of the home, the Energy Cube and Energy Magnets projects offer a quick peripheral awareness of energy consumption. Through simple interaction, the displays also provide a granularity of information that is not available in typical meters. We anticipate these displays would help homeowners become aware of their energy consumption. It remains a challenge for information to reach people's awareness. There are many opportunities for future development. For example, one reviewer suggested formatting information as in terms of cost (e.g., 0.02/min or \$1.20/hour). As we further develop the projects, we may consider using the cube to send signals to control the different usages, zones, and intensity levels of household appliances. Although these devices could be used for decision-making we see them more as an educational tool. We have also not attempted a full-scale user study of these prototypes in a residential setting. For this sort of future work, we would like to pursue funding and partners for research to explore the opportunities to connect our devices with real time monitoring system such as the AJLC project

mentioned above. We are currently investigating opportunities to put the Energy Cube in a building that has a sensor network already deployed.

Combining tangible interfaces with the qualities of an ambient display creates information artifacts that not only provide peripheral awareness but also offer opportunities for the user to become engaged with the information being displayed. Although these projects are in their early prototype phase, they each represent an interesting and engaging first step. The underlying ideas that they express and the positive response from outside reviewers give us confidence in the future development and real-life user testing of these energy displays.

Acknowledgements

Drew Bregel and Michelle Goodstein designed the initial Energy Cube. A later version was redesigned, reengineered and rebuilt by Ken Camarata. Alex Tomita, and Sairam Rajagopal designed the Energy Magnets. Intel Seattle researchers Sunny Consolvo, Anthony LaMarca, and Chris Beckman provided frequent critiques and acted as sounding boards for these displays. We thank the reviewers for thoughtful comments and suggestions for this paper. Portions of this paper were presented in the G-CAD Symposium at Carnegie Mellon University in July 2004.

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