PowerSocket: Towards On-Outlet Power Consumption Visualization

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Abstract
Power consumption is measured in *W* and *Wh*, but what do these units mean? Water consumption can easily be understood, as we all know what a liter of water looks like. Common power meters rely on the physical units or their translation to costs as display. We classified existing displays and ambient visualizations in a taxonomy that focuses on the characteristics of power consumption displays. We adapted representatives of the different categories of displays to an on-outlet display and compared these using a combination of soft- and hardware prototyping.

Keywords
Energy consumption, feedback, visualization, ambient displays, sustainability

ACM Classification Keywords
H.5.m Information Interfaces and Presentation (e.g., HCI)

General Terms
Design, Experimentation, Human Factors

Introduction
Power consumption and its impact on sustainability in HCI have been a topic of increasing interest during the

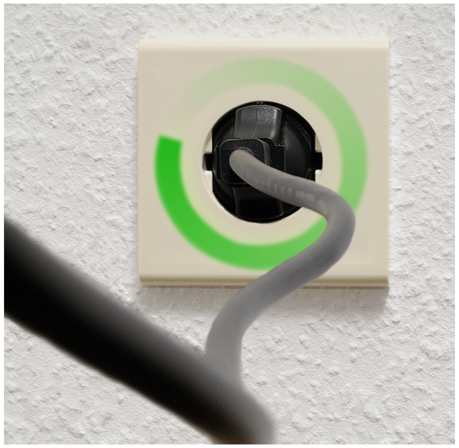

Figure 1. The PowerSocket visualizes the power consumption directly on the outlet. This figure demonstrates the rotation visualization, similar to a clock, that spins faster if more power is drained at that outlet. Additionally, the color of the rotating light fades from green to red.

last decade. Overall, studies show that increasing the awareness through more appropriate feedback results in decreased energy consumption in the order of 10-15% [7][4]

With the broader dissemination of smart meters, getting real-time energy consumption data becomes easy. This is an important step as it allows the user to monitor her power consumption more frequently than with the monthly bill, which has been shown to be insufficient [1]. However, most of these measurement systems display the current consumption in *W*, *Wh* and sometimes mapped to actual and/or predicted costs. Displaying the physical units is certainly the most precise way, but unlike with water consumption, the physical units are perceived as meaningless [3]. Power consumption is neither tangible nor visible. Probably, most persons would turn their computer to standby mode if they had to generate the power consumed by the PC while not used on a cycloergometer. Devices that measure only the consumption of directly connected devices have the advantage that identifying hidden energy consumers is much easier. Nevertheless, popular personal energy meters (PEM) like the Kill-A-Watt encounter the same problem when it comes to visualization. Additionally, the small LCDs need specific attention to communicate the information. Recently, a number of devices were developed that introduce alternate visualizations. Wattson[1], in addition to an LCD, fades through colors from blue to red, thereby creating an ambient artifact that let's you quickly observe the current overall power consumption in the home.

[1] http://www.diykyoto.com/uk

In this paper, we present a taxonomy for power consumption visualization and compare the different types of displays, based on a combination of a physical and software prototype.

Related Work

Power consumption feedback and its impact on environmentally sustainable behavior has been studied for more than 30 years. However, the work done in the field of environmental psychology does not directly focus on the feedback display itself [5]. In the area of HCI, alternative displays for energy consumption feedback are currently of great interest. 7000 Oaks and Counting [8] visualizes the power consumption of a whole building, by consecutively replacing healthy green oaks by appliances on a public display as the consumption increases over the day. On a much smaller scale, the Coralog [10] measures the idle time of a computer and communicates the energy consumption behavior by showing the impact on a coral reef. The ténéré [9] uses such a metaphorical display for on-outlet visualization, showing a tree that looses its leaves as consumption increases up to the point where only the trunk is left. Commercially available is the Wattson, a device that visualizes the overall power consumption of a home by fading through colors. This kind of consumption display can also be seen in modern cars like the Honda CR-Z Hybrid. It offers three different driving modes, *ECON*, *Normal*, and Sport with a dashboard illumination in green, blue, and red respectively. The Energy AWARE Clock [2] is an artifact that, when placed in a central room of the home, allows all inhabitants to easily monitor the overall consumption in real-time and its progress over time.

More closely related to our project is the power-aware cord [6] that visualizes the power consumption of devices attached to a power strip through different glowing patterns, produced by electroluminescent wires molded into the transparent electrical cord of the strip.

Classification of existing visualizations

To get an overview over existing visualizations, we adapted the taxonomies for ambient information systems proposed in [13] to more accurately represent the characteristics of power consumption displays (cf. Table 1). We left out the dimensions of *notification level* (make aware), *source* (local), and *dynamic of input* (medium) since they are all equal for the systems we classified. We replaced the dimension of *abstraction level* by the characteristic *representational fidelity* as defined in [12]. This dimension describes the relation between the measured value and its representation. Displays categorized as indexical have a direct connection to the value, e.g., the reading of a measuring instrument. Iconic displays represent the measured value through a metaphor for example and thus have an intermediate level of connection. Symbolic signs, finally, need a code or convention to be understood and are thus the highest level of abstraction.

The PowerSocket

To get an overview on how people understand power consumption we did a survey with 252 participants. We asked people to estimate the average power of common home appliances. Results show that this is quite complicated for devices where the power consumption per run or per year is more important than the specified peak power, e.g., washing machines or refrigerators. However, for appliances like hair dryers, televisions, or vacuum cleaners, a minimum of 70% of the participants were able to classify the power of these devices accurately. A second observation is that most of the participants (83%) know PEMs, but only few (37%) have ever used one and only 11% use it regularly.

To reduce the effort of consumption measurement, we integrate a power consumption measurement circuit in every socket. To make consumption visible, the PowerSocket is an ambient display fully integrated in the power outlet, showing the local information of currently utilized power at that socket. Once installed, the precise and fast measurements allow direct power consumption feedback without any additional hardware. To visualize power consumption we adapted five representatives of the different categories from our taxonomy to our socket.

		Electricity Meter	Kill-a-Watt	Ténéré	700 Oaks and Counting	Wattson	Energy Aware Clock	Power Aware Cord
Transition	Slow				■			
	Medium			■			■	
	Fast	■	■			■		■
Representational Fidelity	Indexical		■					
	Iconic	■		■	■		■	
	Symbolic					■		■
Temporal Gradient	History			■	■		■	
	Current	■	■			■		■
Modality	Visual		■	■	■	■	■	
	Movement	■						■
Representation	Physical	■				■	■	
	Integrated		■	■				■
	2D				■			

Table 1. Classification of existing power consumption displays along the different dimensions of our taxonomy.

Design

To get a meaningful mapping between power consumption and visualization, one first has to think about the range of the data that has to be displayed. For our case, we assume that a single outlet is connected to a circuit that is secured with a 16*A* fuse. With the 16*A* fuse and a voltage of 230*V*, a maximum power of 3680*W* can be consumed at this outlet. This is a theoretical value as in most installations several outlets are connected within the same circuit.

To keep the abstraction level low, we used well known visualizations (cf. Figure 2).

- *a) Rotation* consists of a colored streak that rotates around the plug. When low power is consumed, the rotation speed is very slow; under high load, the rotation is very fast. Additionally, the color fades from green under low load to red under high load circumstances. This display maps consumption to movement.
- *b) Pulse* consists of a lit ring around the plug that continuously fades from no to full brightness. The color is mapped to the power consumption but the pulse-length is constant. The animation only plays a minor role since it does not carry any information, we thus classify this visualization as abstract.
- *c) Spin* The spin-animation is an abstraction of the horizontally spinning wheel in a classic electricity meter. Physically, this is a rotating disk with a colored mark. The number of revolutions of this wheel is proportional to the consumed power. Our adaption consists of a slightly illuminated green horizontal bar above the plug and a white point that simulates the colored mark of the wheel. This point moves from left to right, and once disappeared at the right end of the bar, reappears on the left end.
- *d) Bar graph* shows an LED bar graph on the left side of the outlet. This visualization is often used as a volume display in the context of audio. The vertical bar is divided in three parts. The lower part is of green color and represents the values below 250*W*. Values up to 1000*W* continue filling up the bar in orange color and finally, values up to the theoretical maximum of 3680*W* add a red part on top.
- *e) LCD* shows the currently consumed power in *W* above the plug. This is very close to the common devices like the Kill-a-Watt and maps power to its symbolic representation in *W*.

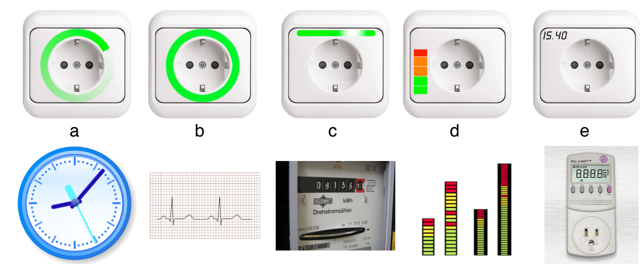

Figure 2. The different visualizations and their real-world counterparts.

Study

To guide our comparative study, we made use of the advantages of software prototyping, i.e., low cost, easy implementation, easy adaptation, etc. to evaluate a hardware idea. We implemented a software on the Apple iPad that simply shows a power outlet on a wall (cf. Figure 3). We can control the type and parameters of the visualization that overlays the virtual outlet. This

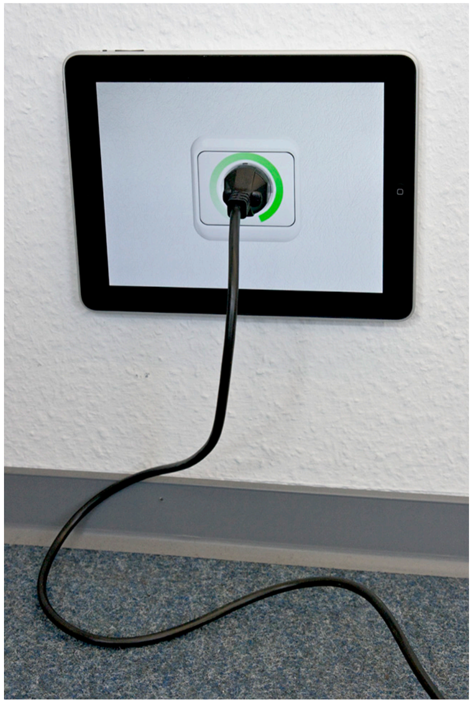

Figure 3. The software prototype running the rotation visualization for low consumption.

allows us to rapidly switch the visualizations and simulate different power consumption settings over WiFi. We installed the iPad on the wall such that the virtual power outlet is at a usual height. We removed the pins from a power plug and fixed it on the virtual outlet to increase realism. We "attached" different home appliances to the power socket to make the participants familiar with the different visualizations. We related the visualizations behavior to known home appliances that we know are good to estimate (vacuum cleaner, charging cellphone, LCD-TV, light bulb, energy-saving lamp).

We asked the 14 participants (12 male, average age 29) to rate the visualizations on a scale from one to five regarding the following characteristics [11]:

- **Consistent and intuitive mapping** How difficult is it to understand the visualization?
- **Visibility of state** How difficult is it for you to read the consumed power with this visualization?
- **Aesthetic and pleasing design** How pleasing do you find the design of the visualization?
- **Peripherality of the display** How obtrusive do you find the visualization?

Results

Expectedly, the LCD visualization was rated significantly easier to read and less obtrusive than the other visualizations. Although the differences in the ratings of the ambient displays were not significant, there was a tendency towards better ratings concerning pleasing design. Generally, we received interesting feedback on the different visualizations as the following quotes illustrate. One characteristic of an ambient display is to visualize data in the users periphery without requiring specific attention. This is not the case for the LCD: "I wouldn't notice it when passing by". With the LCD, the original problem of displaying abstract physical units still persists. Although participants with strong technical background qualified it as to be specific and accurate, other participants had problems to relate the value to the specific consumption: "I don't see any relation to the attached appliance. It is just a number". On the other hand, the benefits of the ambient visualizations are that they, as expected, allow quick estimation of the consumed power. Even though precise readings are difficult, categorization is feasible. "It [pulse] is very simple and clear if I have to differentiate only three categories" or "[...] I can divide that [rotation] into four to five categories like standby, below 20W, normal consumption and electricity hogs. [...]". The mapping to colors makes this classification easier than the precise numbers: "With the LCD, I have to decide if 100W are good or bad [...] With the colors, this decision is made for me, but I get an idea what it is all about. I don't know if 100W are green, yellow, or red."

A general problem is that there is no obvious scale or maximum to which to relate the current value to. This also holds true for PEMs or the electromechanical electricity meter. The bar graph visualization provides such a visible maximum, but it requires additional logic as the maximum depends on other outlets connected to the same circuit. With inter-socket communication, the outlets of a same circuit could show the remaining capacity and help estimate if a specific appliance can still be powered.

During our study, we fixed the display at a usual height for a power outlet but it was still visible to the participants. This, however, is not always the case with real power outlets. If the outlet is placed behind some furniture, reading the LCD or the visualizations only relying on animation becomes difficult. The visualizations fading through colors can still be perceived, even if not directly visible, through a shining light.

Three of the participants mentioned that the pulse visualization feels like a prompt to unplug the appliance. This can be used in combination with other visualizations to suggest unplugging unused devices.

Future Work

The results of our study show that the ambient visualizations are perceived as aesthetically appealing, but the relation to the actual power consumption is not obvious enough. We will therefore revise the design of these ambient visualizations in a user-centered approach to tackle this problem. After that, we want to evaluate which two ambient visualizations work best, implement them in our hardware prototype, and again compare them to PEMs. The hardware prototype has the advantage that ambient effects, like the colored glowing light, are more visible behind some furniture.

Acknowledgements

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