# Design of a Dormitory Consumption Visualization & New Conceptual Directions

Will Odom, James Pierce, David Roedl
HCI / Design, School of Informatics, Indiana University
{wodom@indiana.edu, piercejj@indiana.edu, droedl@indiana.edu}

## Abstract

*In this paper, we build on previous research at the intersection of human-computer interaction (HCI) and information visualization to develop a visualization of Indiana University at Bloomington campus dormitory energy and water consumption. We describe the results of an ongoing study examining the potential role of consumption visualization in impacting dormitory resident behavior and frame this research within the nascent and growing literature at the intersection of HCI, information visualization, and environmental sustainability. We present initial findings and discuss how the implications and conceptual directions resulting from this study can inform potential future research and design practice within the HCI and information visualization communities respectively.*

## 1. Introduction

The fields of information visualization and human-computer interaction offer strong potential to provide humans with increased access to information and the tools to manipulate this information in meaningful ways. Across these fields, increasing concern has been growing with respect to how interactive systems can be used to (i) better inform the choices people make in their everyday lives, (ii) influence the factors guiding these decisions, and (iii) motivate positive behavioral or social change [2, 4, 5, 10]. In particular, a key emerging area of interest centers on the role that interactive technology can and should play in facilitating more environmentally sustainable behaviors [1, 7, 8].

This project focuses specifically on exploring the role that interactive visualizations of energy and water consumption in Indiana University Bloomington campus dormitories could play in motivating student dorm residents to reduce their resource consumption. The benefits of this study include both monetary savings for the university and, more importantly, a reduction in green house gas emissions, which have been shown to contribute to climate change [3]. We designed, developed, and implemented a dynamic visualization interface that was deployed in a campus-wide conservation competition. The immediate goal of this project was to transform student behaviors during the competition, in addition to facilitating changes in participants' long-term behaviors and attitudes toward resource consumption. Specifically, this study explores the following questions:

In what ways might consumption visualization affect the campus-wide student dormitory population's behaviors? How might this type of visualization transform this population's attitudes and orientations toward everyday resource consumption? And, how might this collective knowledge inform the design of future consumption visualizations?

In this paper, we offer a background to past research spanning the fields of HCI, information visualization, and environmental sustainability, which collectively motivate and inform this study. Following this, we will describe our process for developing, implementing, and evaluating our consumption visualization. We will then discuss the implications for design resulting from our study and conclude by suggesting new conceptual directions for the nascent, but growing, area of consumption visualization.

## 2. Background

With increasing concerns over global warming and financial costs of energy, energy management is becoming an important and growing area. Buildings consume considerable amounts of energy and water, and occupants generally have a high degree of control over their own consumption. For example, as originally quoted in [9], "Residential and commercial buildings account for two-thirds of the electricity used in the US, 36 percent of US greenhouse gasses, 9 percent of world greenhouse emissions, and 12 percent of US fresh water consumption [12]. Previous studies have estimated that occupant activities and choices control up to 50 percent of residential energy use, while the balance depends on physical characteristics of buildings and building equipment over which occupants have no control [11]."

Our work draws inspiration from a number of previous designs aimed at making visible the resources consumed within a building [6, 9]. These designs share an assumption that visualization can reveal resource consumption, motivating conservation goals and aiding occupants in achieving these goals by providing visual cues. The use-contexts of current consumption visualization fall into two primary areas, namely (i) private residential buildings and (ii) public commercial buildings. Currently, there are several commercially available home energy monitors available for residential homes that display—in real-time—the amount of energy consumed.[1] For commercial buildings, there are several companies which design public displays of resource consumption.[2] These interactive displays offer multiple views of consumption data in the form of simple graphs, charts and icons. In contrast to the traditional information visualization approach of these displays are artistic resource consumption visualizations, such as the 7000 oaks and counting project by Tiffany Holmes which uses moving images such as trees and SUVs to represent energy consumption [6].

The use-context we focus on in this study is college dormitories, which represent an occupying space between private residential homes and public commercial buildings. Similar to residential home occupants (and dissimilar to most public building occupants), dormitory occupants have a high degree of control over their consumption. Also, the owners of dormitories have a high degree of control over the building and can introduce technologies such as resource consumption visualizations even if the building occupants are uninterested or opposed to such interventions. However, college dormitory occupants do not pay directly for their utilities bills and hence may have less incentive to conserve than a residential occupant who directly pays for their own resource consumption. Thus, college dormitories present an interesting use-context to investigate non-financial motivations to conserve in a space where occupants have high control over their own consumption and owners have high control over the possible design interventions introduced within the building.

Our initial design borrows heavily from the work of Peterson and others [6] who designed and implemented a visualization of energy and water consumption in the dormitories at Oberlin College, which was situated in the context of a *dorm energy competition*. In that same report, the authors noted their competition and visualization resulted in a reported 32% reduction in consumption. Our research goals are to build on this emerging research direction to (i) evaluate the effects on occupants and consumption (especially where the aforementioned study's evaluation was lacking, e.g. the qualitative reporting of occupants' experience), and (ii) draw implications for design of future consumption visualizations.

## 3. The Study

The previously described background research and cases served as core impetus for our study. In this section we will describe our (i) development of client needs, (ii) user task analysis, (iii) dataset analysis, (iv) initial prototype design, and (v) our process for evaluation.

### 3.1 Client Needs

Formally, the client of our project was the Indiana University Residents Halls Association, which is running a competition in order to encourage conservation of electricity and water in dormitories. From discussions with members of the Residents Halls Association, we were able to articulate several project goals. Namely, (i) reduce overall energy and water consumption in all campus dorms participating in the competition, (ii) motivate conservation behavior amongst the student dormitory population, (iii) raise awareness about waste and environmental effects, (iv) encourage sustainable behaviors, and (v) develop a series of potential design alternatives or conceptual directions for next year's competition.

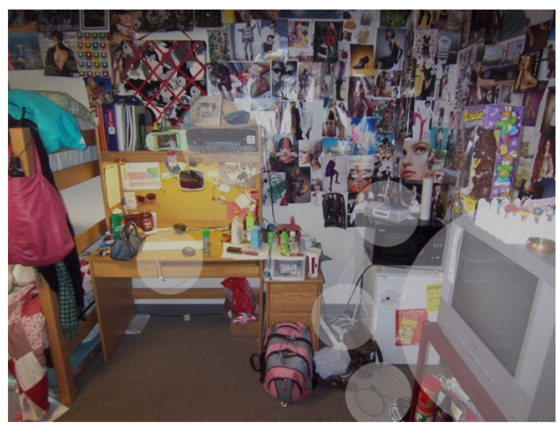

**Figure 1. Dorm room observations revealed several digital objects that students were unaware of their electricity consumption.**

## 3.2 User task analysis

In order to gain a better understanding of our user group's needs and requirements as well as to develop a sensibility for understanding their everyday lives, we conducted several contextual interviews and task analyses with undergraduate residents of dormitories across campus. Key insights arising from our interactions with students included (i) dormitory rooms are often cluttered with electronic devices, (ii) residents are largely unaware of how much energy particular devices and behaviors consume, and (iii) students did not know how

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[1] Reference for home energy monitors:
http://www.ecoeye.org/ecoeye/Home.html
http://www.diykyoto.com/
http://www.powercostmonitor.com/

[2] Reference for more commercial products:
http://www.luciddesigngroup.com/products.php
http://www.qualityattributes.com/greentouchscreen/

to reduce their energy consumption beyond the most common strategies. Oftentimes, residents believed they were already not using much energy and cited that they maintain simple practices engrained in them by their parents (e.g. not letting water run or turning off lights when exiting room). Nonetheless, it was widely unknown that unplugging devices that consume standby power could reduce consumption (figure 1) and most residents found it difficult to conceptualize how much energy (in kilowatt hours) and water (in gallons) they—as well as their building and the entire campus—use on a daily or monthly basis. This finding suggests that concrete feedback is important to link less visible energy consuming devices (e.g. plugged in phone chargers) with a reduction in overall consumption.

While some students voiced concern over environmental degradation, participants appeared to be largely unmotivated to change their behavior based on environmental consequences alone. Our observations indicated that students' consumption behaviors are strongly influenced by their peers,

*"When I came to college, people commented on my waste of water and leaving lights on, and so I started to become more conscious of it."*

Social motivation surfaced as a key component required to ensure our competition's success. Our visualization must include a social dimension to obtain a critical mass of participants and facilitate conservation,

*"…if all the girls on my floor really wanted to win, I'd try to save energy; otherwise, I probably wouldn't do anything differently."*

## 3.3 Analysis of Dataset

Our initial dataset was provided by the Residents Halls Association in the form of raw utility meter readings from all dormitories participating in the competition. These readings were taken twice per week for electricity and water meters associated with a residential building on campus. This data was then stored in an online SQL server database. In order to make the data more organized and relevant, we wrote PHP scripts that combined readings from multiple meters into aggregate numbers for each major residence hall. This was done primarily because the different meters do not necessarily correspond to distinct sections of a building, such as a wing or floor. Thus, in order to have a consistent organization for the data and for the competition, we decided to treat each residence hall as a single unit. This aggregate reading data is returned by the PHP scripts in XML format.

We then constructed some sample visualizations of the data using Adobe Flex. This application takes the readings as input and determines the amount of utilities used between each interval. Because each building has a different inherent efficiency, we needed a way to normalize the data for comparison in a competition situation. To do so, we calculated a baseline usage value for each dorm, determined from average usage of the previous three months of April. In this way, we are able to express the data in terms of total actual usage (kWh or gallons), per capita actual usage or in terms of a percentage of the per capita baseline. [3]

In order to make the data more understandable and relevant to our users, we collected some statistical factors for converting to different units. This allows us to express energy in terms of number of light bulbs burning, water in terms of number of toilet flushes, or environmental impact in lbs of Co2 and equivalent number of cars driving for 1 year. One of the more interesting—and challenging—aspects of our dataset is that it was being generated as we conducted our work on the project. While we have historical utility readings at a monthly interval, bi-weekly readings have just begun to be taken during this year's competition. Thus, we had to design portions of our visualization as the data began to be streamed to us.

## 3.4 Initial Prototype Design

Based on our client needs and task analysis of our user group, we developed two major design components for our initial visualization concept: (i) competition standings and (ii) detailed consumption information.

**3.4.1 Competition standings.** This view (figure 2) communicates the competition standings, clearly showing who is winning (i.e. using the least amount of water and electricity) and by how much. The goal of this view is to motivate and facilitate conservation through competition.

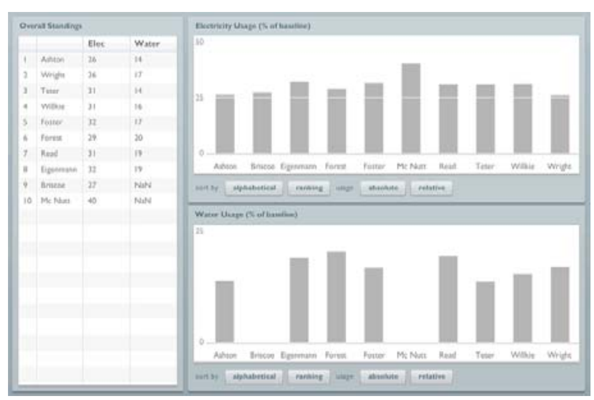

**Figure 2. An initial look at conveying consumption.**

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[3] an example of our dataset can be found here: http://chip.service.indiana.edu/UtilitiesMeter/index.php

We explored several different ways of communicating competition standings, ranging from a simple “Top 10” list, to a set of bar charts (as shown in figure 3) showing the percentiles of each competitors standings, which was measured as a percentage of a 1-month baseline.

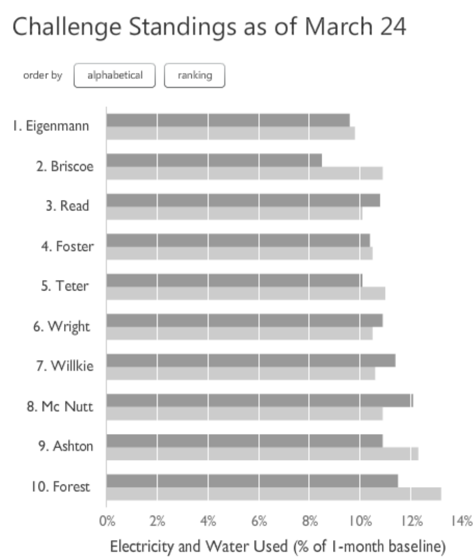


**Figure 3. The horizontal bar chart more clearly conveyed competition standings.**

**3.4.2 Detailed consumption information.** This view (figure 4) communicates the amount of energy and water being consumed, as well as the environmental impacts of this consumption. The goal of this view is to motivate conservation behavior by encouraging and facilitating reflection on consumption and its consequences.

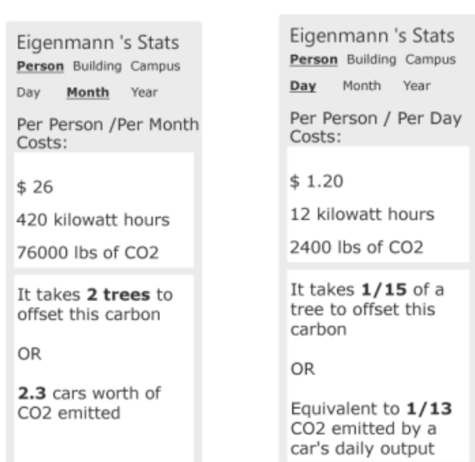


**Figure 4. An early attempt at conveying more detailed information about consumption effects.**

To communicate detailed consumption information, we listed several different figures to right of the competitions standings (figure 5). These figures include more abstract quanitites (dollars, killawatt hours, and pounds of CO2) and more concrete quanitites (number of trees to offset CO2 emitted, number of cars worth of CO2 emitted). These can be expressed in terms of per person, per building, or per campus and in terms of per day, per month, or per year. A range of metrics were chosen so that we could learn which were most meaningful to our users. We chose to communicate simple metrics in terms of a list of figures (as opposed to a line graph temporal display) because we wanted to investigate which metrics and metaphors are most effective in motivating conservation behavior. Figure 5 illustrates our intial visualization iteration combing aspects of *competition standings* and *detailed consumption information*.

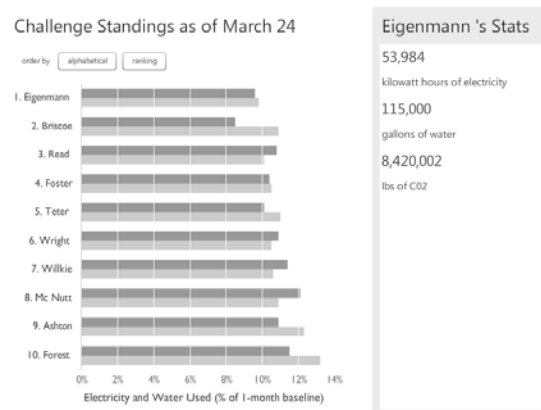


**Figure 5. Our final first iteration implemented both *competition standings* and *detailed consumption information*.**

## 3.5 Prototype Evaluation

As a part of our user-centered design process, we conducted preliminary evaluations of our visualization concepts (both independently and the final combined version). After sketching our concepts, we developed paper prototypes (figure 6) to test our sequence of interactions and, more importantly, how effective our visualizations were in engaging users in the competition and persuading them to change their behavior. At the beginning of each evaluation, we set the scene by introducing our participants into a common dormitory scenario and asking them to think aloud as they navigated the visualizations. We asked the participants to conduct a series of tasks and to discuss any difficulties they encountered and offer their thoughts on our visualizations’ effectiveness.

In specific regards to our core concept our evaluation revealed that additional color tagging was needed to help users avoid confusion and the competition standings needed to be more explicitly labeled (figure 7). Moreover, our users did not seem to be motivated by raw numbers of reduction alone (e.g. total tons of carbon dioxide reduced, etc.).

**Figure 6. We iterated on our concept through paper prototyping and user testing.**

Another common theme was that the study participants wanted control over seeing both their own impact and their dorm's total consumption. To address both of these requirements, we included various different forms of representing dormitory statistics (e.g. number of light bulbs burning, number of cars driven for one year, etc.). Finally, we included a toggle radial for users to switch between *per person* and *dorm total* statistical breakdowns (please see appendix II for larger image).

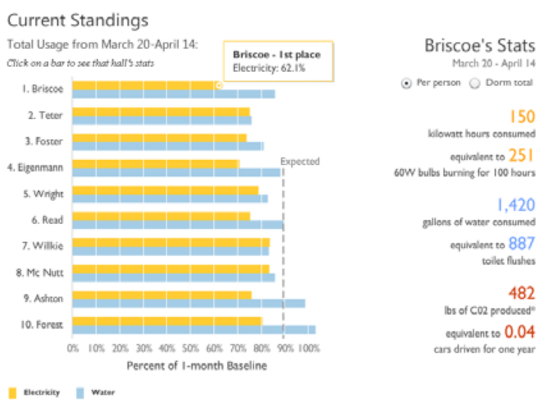


**Figure 7. The final iteration of our concept after user testing and feedback.**

Aside from specific input regarding our core concept, other key findings from our evaluation included:

- *Concrete consequences*—the calculations such as number of trees to offset and equivalent number of cars are more meaningful when they are large, aggregate figures (e.g. per building, campus). However, even if they are surprising or otherwise engaging, their potential to motivate action is still questionable, particularly without prescriptive suggestions for actions or social motivation.

- *Abstract quantities*—(e.g. kwh, pounds of CO2, $) are more meaningful when presented on a per person basis. They appeared to make people feel like their actions are having an impact. With large numbers, people felt hopeless to effect change.

- *Numbers and statistics are not motivating*—narratives or data-driven photographic visualizations may be more meaningful.

- *Even if people are surprised by their consumption impact*, they are unlikely to take actions if they do not know what to do—offering people the ability to calculate estimated savings from a variety of energy-saving behavior suggestions could provide more engaging alternatives.

- *The low resolution of the data is not ideal to make a meaningful impact*. Being able to communicate the amount of energy actually used for a particular dorm room or appliance ties to individual context of use and, consequently, is much more meaningful.

- *Baseline averages are confusing*—participants had a difficult time understanding the meaning of "baseline" numbers in the context of our site.

- *Difficult to make detailed comparisons between dorms*—the structure of our primary visualization made it difficult for participants to make in depth comparisons.

In terms of motivating conservation behavior, it appears that leveraging social motivation and competition should take first priority, along with provide concrete suggestions for conservation behaviors. Without a strong social incentive, it seems unlikely that students will even take the time to investigate our detailed consumption view, no matter how interesting and informative it may be.

## 4. Implications for Design & Emerging Conceptual Directions

Our review of the approaches to consumption visualization revealed two dominant approaches to providing persuasive feedback: consumption monitors and interactive art visualizations. Insights from contextual interviews and user feedback on our initial visualization suggest two additional design directions to pursue, namely, social incentive and prescriptive feedback.

### 4.1 Social Incentive

The power of social incentive to encourage conservation came up repeatedly in our research. Many students felt that they would only be willing to participate in the conservation competition if their peers were also motivated. Our initial visualization encourages social motivation to the extent that it facilitates competition to conserve by providing clear indicators of the competition standings and feedback on consumption. However, the power of social incentive can further be leveraged to raise awareness and encourage conservation behavior.

One concept in this direction is the *public pledge wall* (figure 8). The idea of this design is to complement our initial visualization with the ability for students to pledge conservation behaviors selected from a pre-defined list. The pledges will be shown on a public display in the lobby of the dormitory, and pledge data is used to calculate a projected savings and competition standings.

By allowing students to make pledges, the hope is they will feel more empowered to enact change and also become more engaged in the competition. By making pledges public, students both receive credit for their contributions and are motivated to fulfill their pledges.

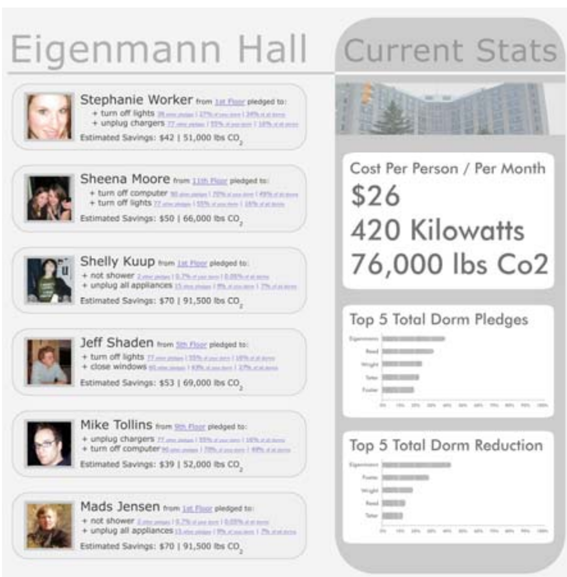


**Figure 8. The public pledge wall combines social networking and incentivizing with consumption feedback.**

## 4.2 Prescriptive Feedback

Another recurring theme in our research is that students are often unaware of how to best alter their behavior to conserve resources. Hence, raising awareness of the amount of resources consumed alone may be insufficient to encourage the most desirable conservation behaviors.

To address this lack of prescriptive feedback, we developed an interface (figure 9) which allows students to explore the effects of various conservation behaviors such as using the fan instead of the air conditioner or unplugging phone chargers when not in use. The savings associated with each conservation behavior selected is displayed both in terms of energy (kwh) and cost (dollars). In this way, the user can explore different combinations of behaviors and view the savings to help determine the most convenient and effective ways to conserve. The savings calculated are estimates based on energy consumption data from appliances.

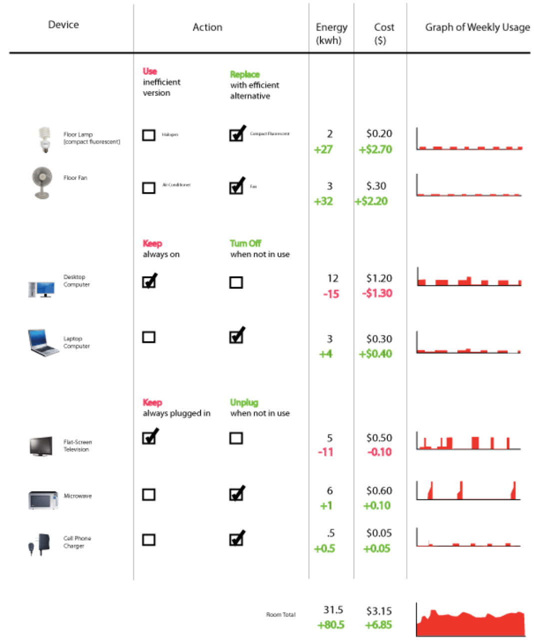


**Figure 9. The prescriptive feedback concept helps students explore the effects of their usage behavior.**

## 4.3 Preliminary Evaluation

In order to evaluate our concepts related to social incentives and prescriptive feedback, we tested them with eight students. Using paper prototypes, we described each concept to the participant and had them go through a brief set of scenarios and tasks using the interfaces. In a follow-up session, participants were asked to rate on a 5-point Likert scale how "motivating", "informative", "fun", "interesting", "enjoyable", "engaging", "appropriate" and "social" each concept was. Participants were also asked a series of open-ended questions to elicit feedback on how they anticipate they would use the visualizations and how it might affect their behavior. Our initial prototype was also evaluated in this manner, and participants were asked to compare the three concepts and provide feedback.

Overall, participants tended to express that either the social incentive and prescriptive feedback concepts would be more motivating than our initial concept. Three of the eight participants had strong preferences for the prescriptive feedback concept and felt that without concrete tips on how to save energy that they have difficulty become engaged in the competition. The other four participants preferred the social incentive pledge wall. These participants felt that the pledge wall offered a much more "fun", "enjoyable" and "engaging" experience than the other two concepts. Several participants described their interest in pledging creative and outrageous ways of conserving, such as not showering for a week. Six of the eight participants thought that they would be very likely to participate actively in the competition if our initial concept was complemented with the pledge wall or prescriptive feedback concepts. These six participants claimed they were considerably less likely to participate with only our initial concept. Our findings suggest that our concepts related social incentive and prescriptive feedback would encourage participation in the energy competition, likely leading to increased conservation.

## 5. Conclusion

At present, the dominant approach to designing consumption visualization to encourage conservation behavior is to create consumption monitors which clearly display consumption patterns. While past studies have indicated that this approach can lead to decreased consumption, we believe that other approaches may lead to more engaging experiences and further reductions in consumption. Here, we have suggested social incentive and prescriptive feedback as fruitful design directions to explore.

While our study does suggest that increased social dimensions of consumption visualizations ought to be emphasized, our current prototype has produced worthwhile results. At the writing of this paper, 21 days after the competition began, residence halls have saved a combined 33,008 KWh of electricity and 724,322 gallons of water compared to baseline consumption of the previous three years. Effectively, this is equivalent to burning 563,344 60-watt light bulbs for 10 hours. Additionally, the combined residence halls avoided releasing 652,491 lbs of carbon dioxide emissions, a rough equivalent to taking 54 passenger cars off the road for 1 year.

In the future, we intend to continue to develop these concepts through prototypes and user-testing. A comprehensive evaluation of the initial concept we have implemented for the conservation competition will also be conducted which will include surveys, interviews, and analysis of visualization usage and consumption patterns. We also intend to explore the persuasive potential of more ambiguous representations of consumption such as interactive art visualizations. Our immediate goal is to implement a design for next year's conservation competition at Indiana University based on our research. More generally, we hope to draw design implications for resource consumption visualizations in other use-contexts, such private residential and public commercial settings.


## Acknowledgements

We would like to thank all of the participants that participated in our study. We also thank the Indiana University Residence Hall Association for their continued help.


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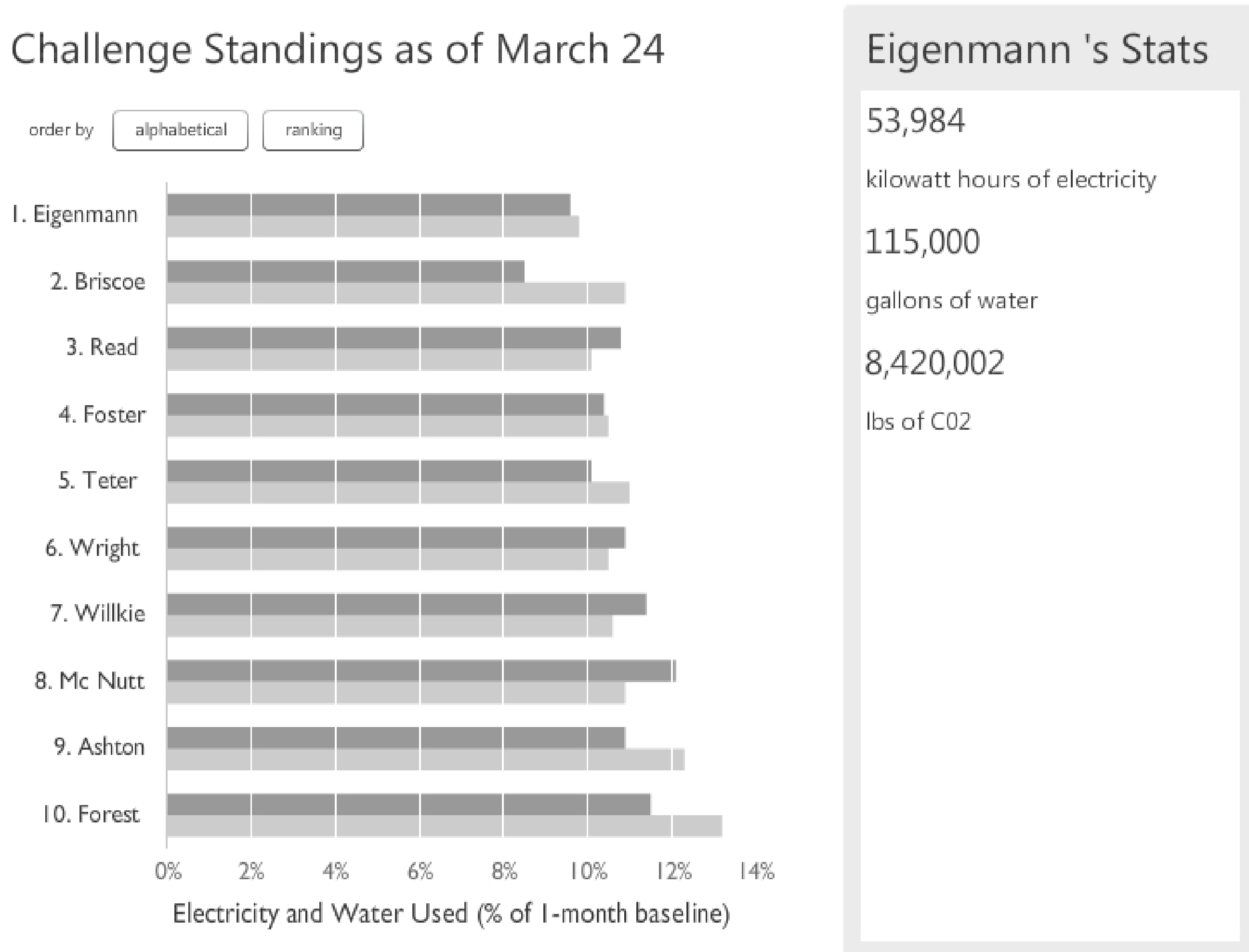
# Appendix

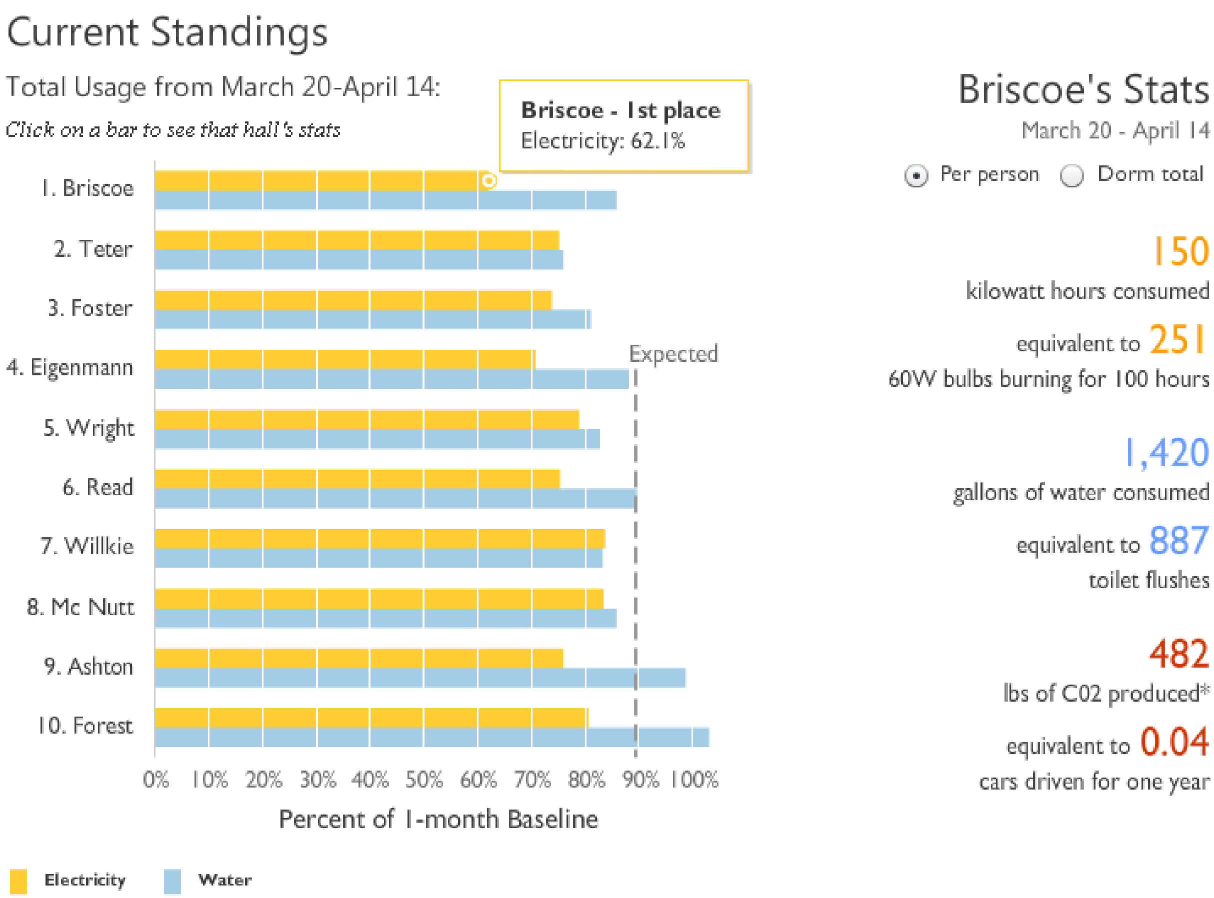
In this appendix you will find several larger versions of graphic mockups that we were not able to include directly in the paper.

## Appendix I



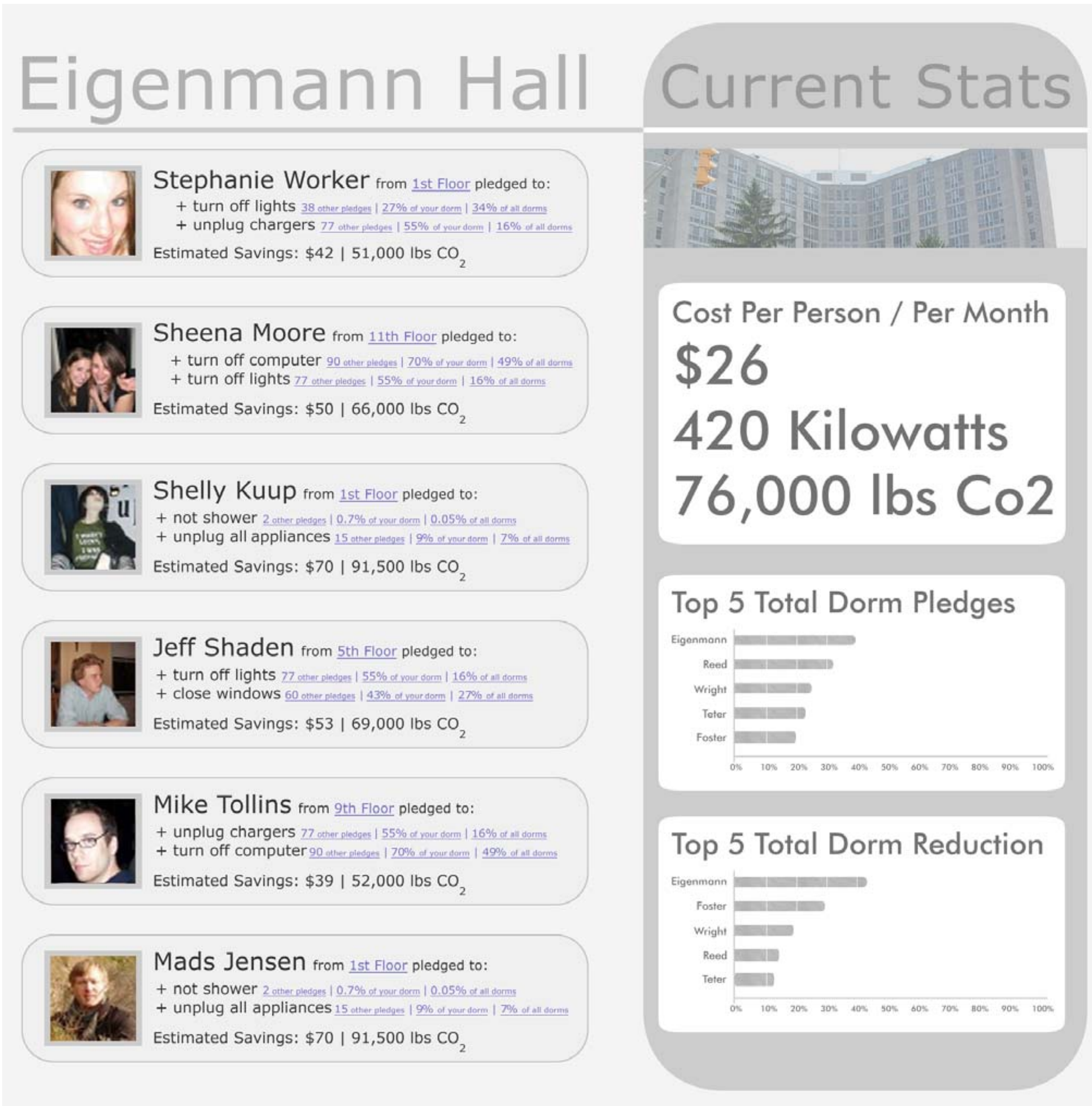

This mockup offers a look at the initial iteration of our core concept.

## Appendix II




A mockup of our final visualization (available at energychallenge.indiana.edu). This prototype displays substantial changes based on iterative user testing.

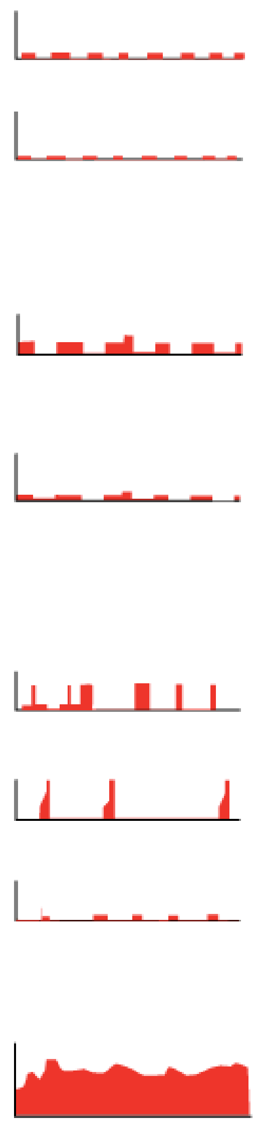
## Appendix III




Social Incentivizing Public Pledgewall emerging in our new conceptual directions.

# Appendix IV

| Device | Action | | Energy (kwh) | Cost ($) | Graph of Weekly Usage |
|---|---|---|---|---|---|
| | **Use** inefficient version | **Replace** with efficient alternative | | | |
| Floor Lamp (compact fluorescent) | ☐ Halogen | ☑ Compact Fluorescent | 2<br>+27 | $0.20<br>+$2.70 | |
| Floor Fan | ☐ Air Conditioner | ☑ Fan | 3<br>+32 | $.30<br>+$2.20 | |
| | **Keep** always on | **Turn Off** when not in use | | | |
| Desktop Computer | ☑ | ☐ | 12<br>-15 | $1.20<br>-$1.30 | |
| Laptop Computer | ☐ | ☑ | 3<br>+4 | $0.30<br>+$0.40 | |
| | **Keep** always plugged in | **Unplug** when not in use | | | |
| Flat-Screen Television | ☑ | ☐ | 5<br>-11 | $0.50<br>-0.10 | |
| Microwave | ☐ | ☑ | 6<br>+1 | $0.60<br>+0.10 | |
| Cell Phone Charger | ☐ | ☑ | .5<br>+0.5 | $0.05<br>+0.05 | |
| | | Room Total | 31.5<br>+80.5 | $3.15<br>+6.85 | |



Prescriptive Feedback concept