The Design and Evaluation of Intelligent Energy Dashboard for Sustainability in the Workplace

Ray Yun[1], Azizan Aziz[2], Bertrand Lasternas[2], Chenlu Zhang[2], Vivian Loftness[2], Peter Scupelli[3], Yunjeong Mo[2], Jie Zhao[2], and Nana Wilberforce[4]

[1] Computational Design, School of Architecture
[2] Building Performance and Diagnostics, School of Architecture
[3] School of Design,
Carnegie Mellon University, Pittsburgh, PA, United States
{ryun,azizan,blastern,chenluz,loftness,
scupelli,yleahmo,jayzhao}@cmu.edu
[4] Realty Services, PNC Bank, Pittsburgh, PA, United States
nana.wilberforce@pnc.com

Abstract. Office workers typically don't know how much energy they consume at work. Since the workers don't pay the energy bills, they tend to waste energy. To support energy conservation and motivate workers, the Intelligent Dashboard for Occupants (ID-O) was developed using multiple intervention strategies – eco-feedback (self-monitoring, advice, and comparison), remote controls, and automated controls. The baseline data was collected for fourteen weeks from eighty office workers and ID-Os with different features were deployed for seven weeks. The results show that the group with all the features (eco-feedback, remote controls, automated controls) made the biggest energy savings at 35.4%, the group that had eco-feedback and the remote controls showed 20.2% energy savings, the feedback only group achieved 9% energy savings, and the last group (the control group) produced 3.6% energy savings. The automated control feature produced the biggest energy savings, and was most effective in energy management for lights and phones, but not for computers and monitors.

Keywords: energy dashboard, sustainability, workplace, behavior change, eco-feedback, remote and automated control, plug load management, organization.

1 Introduction

Commercial buildings consume about 20% of the electricity in the United States [1] and 30-40% of this electricity can be saved as a result of changes in the behavior of the building occupants [7, 8]. To motivate people towards pro-environmental behavior, Human-Computer Interaction (HCI) researchers have developed various display technologies such as energy dashboards [e.g., 10,11,12,24], eco-art [e.g., 14], computer games [e.g., 13,15,16], and ambient displays [e.g., 17,18]. However, most of the HCI studies have the following limitations. First, as Froehlich et al. [9] pointed

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out, most of the HCI studies are not evaluated in depth in terms of the methods, number of participants, and the length of the study. Second, many of the studies targeted residential users [19, 20] and few focus on the domain of the office environment. Finally, the "control" strategy has not been thoroughly evaluated in the field of HCI research, in terms of moving the behavioral change towards increasing attainment of sustainability goals. The control strategy is an approach that allows people to easily manage their energy usage, using web or mobile based tools [4]. The research team is interested particularly in the workplace domain because office workers typically do not know how much energy they consume at work [4]. Also, since they do not pay the utility bill, they lack an incentive to save energy at work [19, 20]. To promote sustainability in the workplace, we designed and developed the Intelligent Dashboard for Occupants (ID-O), using multiple strategies, and conducted field studies to evaluate the impact of this system.

2 Background

Our previous study reviewed the nine intervention techniques to promote sustainability in the workplace [4]. Among these techniques, this study focuses on the most commonly used informational techniques – self-monitoring, advice, and comparison - and a relatively new approach, control intervention strategy. There are several related studies, which do focus on the workplace domain. For example, Granderson et al. (2010) evaluated the use of energy dashboard in commercial buildings for two to three years. The web-based dashboard displays real-time electricity consumption for the whole building. An 18-35% reduction of energy consumption was measured. Carrico et al. [2] provided employees with electricity consumption feedback (self-monitoring) and monthly advice via email for eight months. This approach led to an 8% reduction of energy consumption. Lucid's building dashboard [3] displays a building's real-time energy consumption (self-monitoring) and compares the consumption with other buildings' (comparison). This technique reduced energy consumption by an estimated 30%. These documented energy savings indicate the importance of energy data display about the whole building.

Another strategy, control, has not been thoroughly studied but has potential benefits [4]. Mercier et al. provided power strips and timers (control) to office workers for two months and measured up to 55% energy savings [5]. This study shows the importance of the use of distributed monitoring hardware and controls. In the ID-O system, more advanced features, such as real-time individual user's consumption (instead of the whole building's energy consumption), and online remote controls to actuate devices (instead of using offline plug controllers), were developed to further reduce energy consumption.

3 Intelligent Dashboard for Occupants (ID-O)

As shown in Figure 1, the ID-O is equipped to provide self-monitoring, advice, comparison and control. The features are designed as follows:

Self-monitoring (Chart). The energy Chart is designed to display the energy consumption data item by item in real time with historical data. Many studies (e.g., [21, 22, 23]) suggest this mode of data presentation offers opportunities to save more energy. As shown in Figure 1, the system provides views of data usage in different time ranges (day, week, month) and chart types (area, bar, line) so that people can view their energy consumption from a variety of angles. By clicking specific items in the legend section, users can hide or display them in the chart, and by hovering over a data point they can view the numeric values and related statistics. The chart also projects past data, so that people can understand their previous consumption (e.g. a week ago) and predict their future performance.

Fig. 1. User interface of Intelligent Dashboard for Occupants home page

Advice (Eco-feedback Section). The ID-O offers 1) tips users can follow immediately, 2) suggestions to replace their inefficient devices with energy-efficient products for a long-term savings, and 3) user behavior effectiveness towards energy savings per device. When the system detects energy waste (e.g. the task light had been left on during the night last week), the advice text is displayed in red in the Recommendations column to alert the users. In addition to the information about the individual user, organization scaled monetary impact can be viewed as well. This shows the cost or savings if all employees in the organization acted as the user has done.

Comparison (Chart). The system provides a line chart that displays the energy consumption of the user, the office average, and the best person (least energy consumption) in the office (Figure 2). The blue line represents the user's personal energy usage at work. To highlight the user's personal energy usage, the area under the line is shaded with light blue. The red line represents the average value of the employees' energy usage in the office. The green line represents the user in the office with the lowest energy consumption for the selected period. Users whose offices are unoccupied, due to vacations or business travel are excluded. This occupancy was estimated based on their computer monitor's consumption.

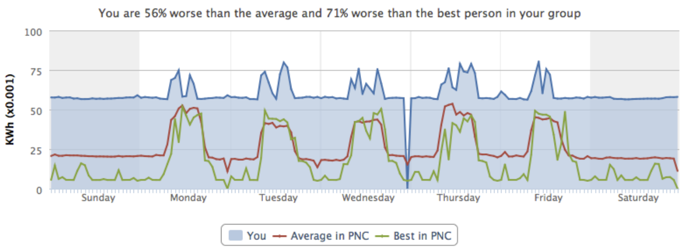

Fig. 2. Comparison chart example

Remote Controls. The dashboard also enables users to remotely control their connected devices individually or as a group. Users are able to switch off their devices by one-click action when they leave the office. Even if they forget to turn off the devices before leaving the office, users can still access the controls to the devices remotely by using this feature.

Automated Controls. Additionally, the automated control/scheduling feature is equipped to turn on and off devices automatically, based on the users' weekly schedule. Users set schedulers that can be dragged and dropped and place them on a timetable to set the day and time for this event to occur (see Figure 3).

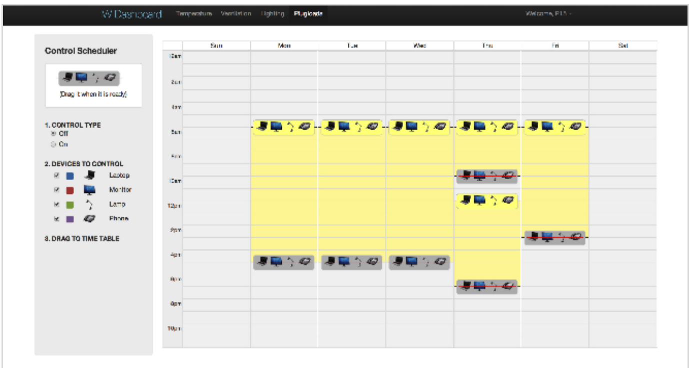

Fig. 3. Weekly calendar for automated controls

The Plugwise (http://plugwise.com) plug-load smart meter is used to measure a user's disaggregated electricity consumption and allows remote control of the individual devices. As shown in Figure 4, electrical devices plugged into individual Plugwise meters (Circles) transmit data wirelessly to the Plugwise server. The python program in the server uploads this data to a web server or conveys the control commands to the main server as a mediator. PHP is used to retrieve energy data from the database. For the chart representation, Highcharts (http://www.highcharts.com/), Javascript chart library is used. For styling the overall web components (e.g., buttons, forms, fonts, colors), Bootstrap (http://getbootstrap.com/) CSS library is used.

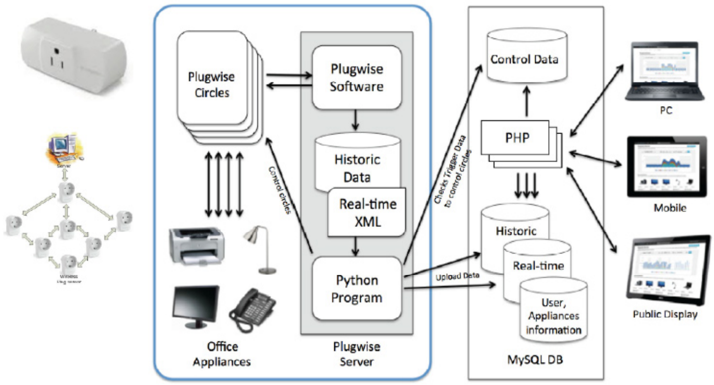

Fig. 4. The smart meter used for this study (*left*) and the ID-O's system structure (*right*)

4 Method

To investigate which strategies best contribute to energy savings, the research team is currently conducting a large-scale field study with eighty participants. The participants were recruited from one department (realty services) in a large company and all of them reported they are full-time workers and spend most of their time doing computer work. The participants were randomly assigned to four groups (twenty

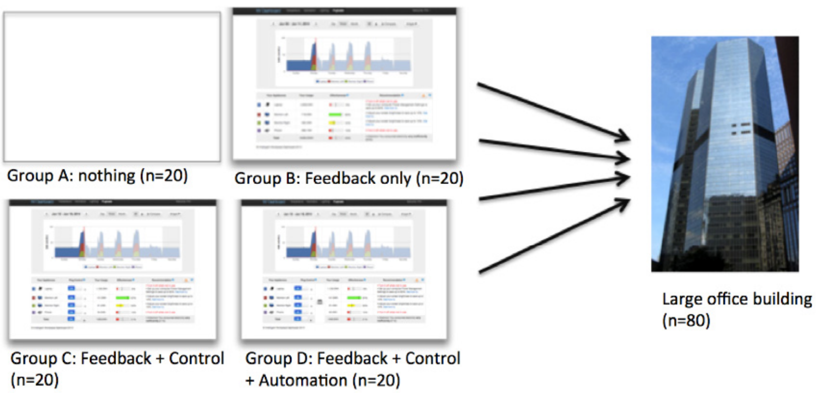

Fig. 5. Different energy dashboards were provided to four groups in a large office building

people per group) and their baseline data was collected for fourteen weeks. After the baseline data collection, the ID-O systems equipped with different features were introduced to the four groups as follows (Figure 5). The first group (Group A) was provided without any dashboard interface and served as a "control" group. The second group (Group B) was provided with feedback only (self-monitoring, advice, comparison), the third group (Group C) was provided with feedback and remote controls, and the last group (Group D) was provided with feedback, remote controls, and automated controls.

To introduce the systems to each group, group-training sessions were held at the company (Figure 6). The team demonstrated the system features, provided user names and passwords, and answered participants questions. After these training sessions, energy data was collected for seven weeks and each group's energy saving was measured.

Fig. 6. Group training session

Energy savings were calculated based on the difference between post-intervention energy usage compared to pre-intervention energy usage with similar occupancy patterns. Savings due to participants being away from the office, such as off-site work and being on vacation, are excluded from the energy savings calculation. Occupancy was estimated based on each participant's daily monitor usage. Our pilot study [24] revealed the need for a weekly reminder regarding use of the dashboard. To support engagement with the dashboard, participants received a reminder email every Monday morning. An example reminder email says "We encourage you to visit the energy dashboard site regularly and hope you're able to learn your energy performance and behave more pro-environmentally", with the dashboard URL and contact information included in case they have questions about the system. The reminder did not include any energy consumption information or other statistical data because the team wanted to measure the energy saving impact made by the dashboard intervention only.

5 Preliminary Results

The area charts (Figure 7) show each group's average energy consumption per person for a typical week before and after the systems were introduced. The groups equipped with the various ID-O interfaces (Group B, C, D) reduced more energy at night and during the weekends compared to Group A, where no intervention was provided.

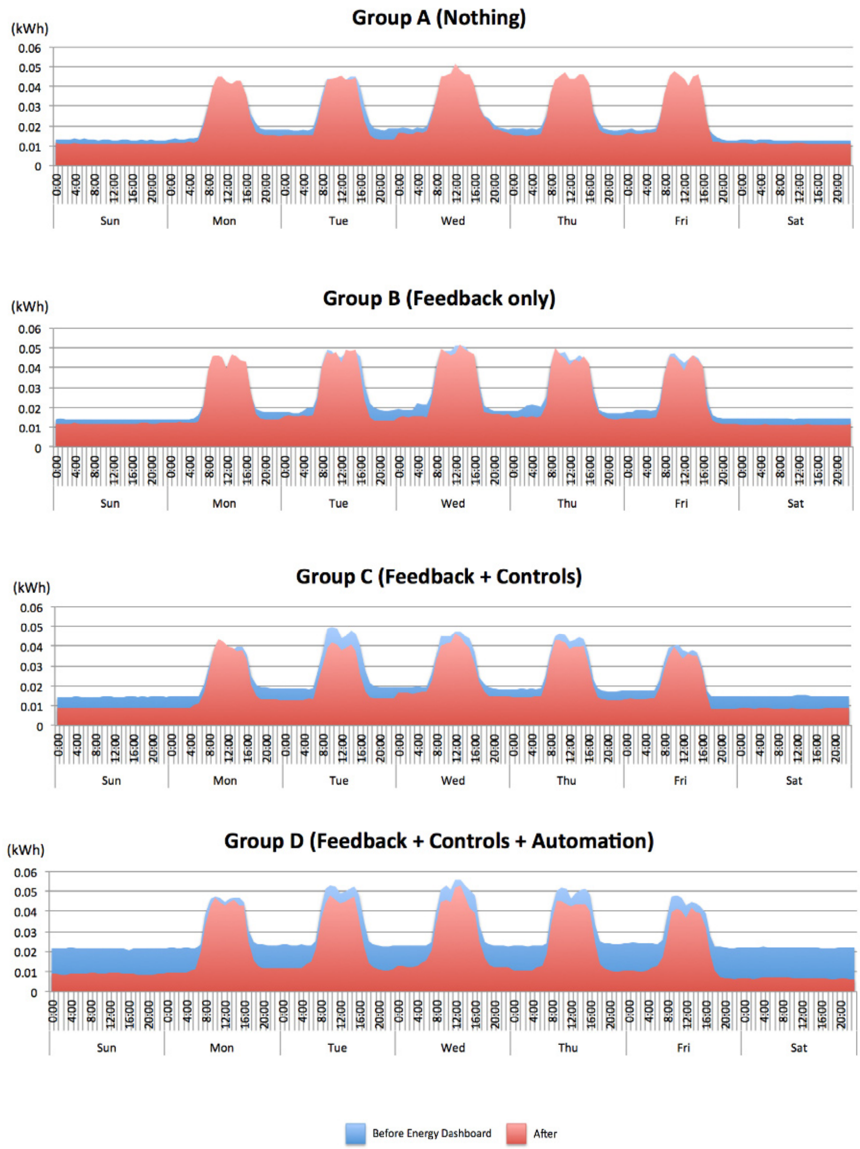

Fig. 7. Average energy usage before and after the dashboard intervention

The bar charts (Figure 8) show each group's typical week total energy savings, before and after the ID-O intervention. Group D, equipped with all the features including automated controls, achieved the biggest energy savings of 35.4%, followed by Group C with 20.2% energy savings. Group B reduced energy consumption by 9.0% and Group A, even without a dashboard, reduced consumption by 3.6%. Much of the savings were achieved during weekends (B: 18%, C: 39%, D: 64%) and at night (B: 19%, C: 23%, D: 47%).

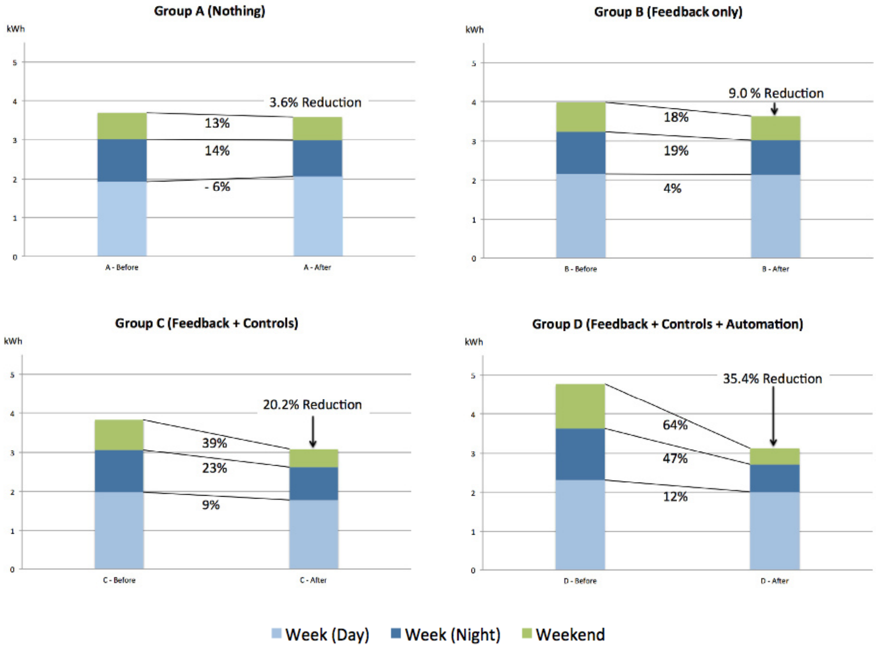

Fig. 8. Energy savings before and after the dashboard intervention

Figure 9 shows the average energy saving rates per device. Group C and Group D, equipped with the control features, showed relatively larger energy savings for lights (e.g., task lamps or under-bin light). Group D also showed relatively larger savings for phones. It was found that 70% and 65% of the participants in Group D set up the calendar for lights and phones respectively. However, only 12% of the participants set up the calendar for computers and monitors resulting in considerably lower savings. Only marginal savings were achieved from computer monitors throughout the groups since most of their monitors were already energy efficient and do not consume electricity when not in use.

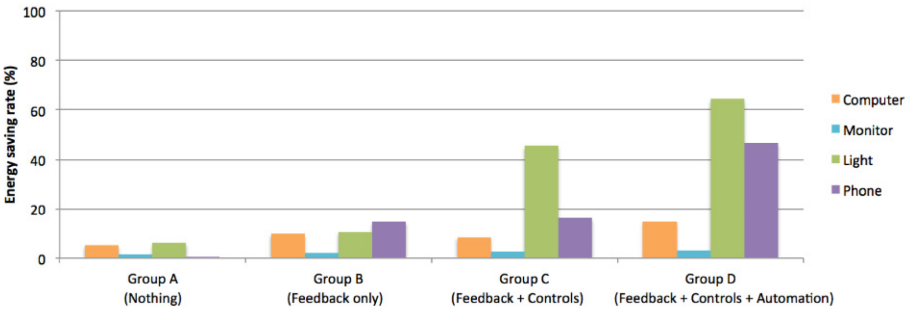

Fig. 9. Average energy saving rates achieved per device

6 Discussion

This section discusses the issues encountered during the implementation of the study.

6.1 Awareness and Discussion Frequency

This study measured not only the energy usage change but also the energy consumption awareness change before and after the interventions by conducting a survey [6]. Whereas Group D showed the biggest energy savings (35.4%), their awareness increase of 1.2% was relatively lower than Group B (6.5%) and Group C (10.4%). Each group's energy-related discussion frequency was also investigated. Group D's discussion frequency increase of 22.7% is also relatively lower than Group B's (77.5%) and C's (56.5%). The automation system may not support active learning of energy information from the system and energy-related discussions with coworkers.

6.2 Application Platforms

This study investigates the potential energy saving impact from the introduction of different user interface (UI) strategies aimed at changing user behavior regarding energy consumption in the workplace. To focus on the effectiveness of a "web-based" UI strategy, we did not include a mobile system in this study. However, mobile UI is expected to increase the energy saving potential significantly. The current dashboard system generates advice based on the last week's energy usage (if the week range is selected), but if the system can detect energy waste in real time and send advice messages with a control button to individual users, this will strengthen our current system resulting in increased energy conservation.

6.3 Control Group

The team assumes that Group A was not completely controlled because the participants were recruited from the same department and were located in close proximity to participants in other groups. As described earlier, Group A achieved an energy savings of 3.6% and their energy-related discussion frequency increased by 19.4% after the dashboard intervention [6], even though as the control group they did not receive a dashboard or any feedback directly. These numbers for Group A are relatively low compared to the other group's savings and discussion frequency, however, it indicates the control group might have been affected by the system users in other groups.

7 Summary

This study investigates the effectiveness of dashboard user interface strategies towards increasing energy conservation in the office environment. Three energy dashboards equipped with different strategies (eco-feedback, remote controls, and automations) were provided to the groups of participants. Over a seven-week period of dashboard system deployment, energy usage was measured and compared to the baseline data collected over a fourteen-week period. The group with the automation feature (Group D) showed the biggest energy savings (35.4%). The group equipped with the remote control feature but without the automation feature (Group C) produced the second biggest reduction (20.2%). The group that was given feedback only (Group B) showed the third biggest energy savings (9%). Finally the control group (Group A) showed a 3.6% energy savings. These are preliminary findings from an ongoing research study. The authors will continue this measurement for the additional seven weeks and then remove the systems from the users to study how persistently the savings will last with no intervention.

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